Technological and Market Interventions for Aflatoxin Control in Ghana: Final Report

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1 Executive Summary

Aflatoxins, a class of mycotoxins (toxins produced by fungi) are tasteless, odorless, invisible, and cause a number of serious health problems including liver cancer. Groundnuts and maize, both important staple foods in much of Africa, are the crops most vulnerable to aflatoxin contamination. Aflatoxin contamination may occur in the field, but tends to become most severe during storage; groundnuts that are not adequately dried or that are exposed to pests are particularly susceptible (Hell, Cardwell, and Poehling, 2003; Strosnider et al., 2006; Lamboni and Hell, 2009). There are many simple ways farmers can prevent contamination, yet adoption of these practices in Africa is low for several apparent reasons: 1) farmers and other actors along the value chain know little about aflatoxin and ways to reduce contamination (Florkowski and Kolavalli, 2013; Jolly et al., 2009; Wagacha and Muthomi, 2008), 2) tools to reduce aflatoxin contamination are not readily available or are prohibitively expensive, and 3) the market does not reward produce low in aflatoxins at a price that offsets the cost of prevention (Hoffmann et al., 2013; Hoffmann and Gatobu, 2014).

This report describes a randomized controlled trial among groundnut farmers in northern Ghana designed to test the impact of two approaches to encouraging adoption of post-harvest practices for the reduction of aflatoxin: free distribution of tarps for sun drying and a price premium for aflatoxin-safe nuts. Farmers assigned to each of these interventions, as well as those in a third ‘information only’ treatment group were trained on the risks that aflatoxin poses to human and animal health, and ways to prevent contamination through post-harvest management. Farmers in all three treatment arms had the opportunity to purchase tarps for sun-drying, and tarp purchases serve as an intermediate indicator of treatment impact.

Results indicate that simply training farmers and making tools for aflatoxin prevention available has a significant impact on post-harvest practices. An increase in tarp ownership was observed among farmers in the information only treatment, and improvements in drying, sorting, and storage practices were reported. Offering a market incentive for safe nuts appears to have led some farmers to invest in improved storage containers, and to treat their storage area with insecticide. Of the three experimental treatments, distribution of free tarps had the most dramatic effect on both observed and reported behaviors. In addition to the expected impact on drying practices, provision of tarps also led to an increase in reported use of insecticide during storage.

Overall, there was no statistically significant effect of the interventions on aflatoxin content of groundnuts, or on dietary exposure to aflatoxin through groundnuts. At least in the group provided with free tarps, the lack of impact may be largely attributed to the particularly low levels of aflatoxin encountered in the region due to favorable climatic conditions. For this reason, we modeled hypothetical intervention effects using the higher baseline groundnut aflatoxin levels and applying a previously determined reduction (-33%) in aflatoxin content of groundnuts to households that reported drying groundnuts on tarps. Nonetheless, for a variety of reasons including that tarp drying reduces but does not eliminate aflatoxin contamination, less than universal adoption of this technology by study participants, and the high variability in groundnut contamination and consumption levels observed, the modeled effect was not significant. The dietary results confirm that the risk of aflatoxin exposure from both maize and groundnut in the study region is high and, looking beyond advantages to households of being able to enter commercial groundnut markets, interventions are needed to reduce aflatoxin exposure from both sources from a public health perspective.

2 Background

2.1 Groundnuts in Ghana

Groundnuts are a cornerstone of Ghanaian agriculture. They provide income to farmers and constitute an important source of macro and micronutrients[1] throughout the country (Florkowski and Kolavalli, 2012). Over the past decade, Ghana has produced an average of 500,000 MT of groundnuts annually (FAOSTAT, 2016), making it the tenth largest producer worldwide. Eighty percent of the Ghanaian population report consuming groundnuts in some form at least once a week (Jolly et al. 2008). Susceptibility of this crop to aflatoxin poses both a domestic food safety challenge and a barrier to expanding groundnut exports. While awareness of aflatoxin and associated health risks is generally low in Ghana (James et al., 2007), the issue has received some media coverage in recent years (Ghana News Agency, 2013).

2.2 Aflatoxin

Aflatoxins are secondary metabolites of the fungi *Aspergillus flavus* and *A. parasiticus* that can contaminate many foods, most importantly maize, groundnuts, tree nuts, and cottonseed (Payne, 1998). These toxins have a number of negative health consequences for humans. They are known to increase the risk of liver cancer (IARC, 1993), especially for carriers of hepatitis B or C (Turner et al., 2003). Recent evidence also suggests that aflatoxins may impair physical development in children (Gong et al., 2003, 2004; Turner et al., 2007). Acute exposure to high doses of aflatoxin, known as aflatoxicosis, may cause liver damage or failure and inhibits blood clotting, among other problems. In extreme cases, aflatoxicosis can be deadly, as evidenced by the 150 deaths during consecutive outbreaks in 2004, 2005, and 2006 in Kenya (Wagacha and

[1] Groundnuts contain high levels of fats, proteins dietary fiber, potassium, magnesium and iron.

Muthomi, 2008). Consumption of aflatoxin-contaminated feed reduces livestock productivity and can pose health risks to humans who consume the products of affected animals, particularly milk (Keyl and Booth, 1971; Diekman and Green, 1992; Iqbal et al., 2014).

While aflatoxin exposure is relatively low in high-income countries due to routine testing and strict regulatory enforcement, exposure levels are much higher in developing countries. In tropical environments, high temperatures during cultivation can make crops vulnerable to fungal infection. Rains and high humidity levels around harvest time make drying down the crop for safe storage a challenge, leading to proliferation of fungi and aflatoxin production (Wagacha and Muthomi, 2008; Wu and Khlangwiset, 2010). Poor production, harvest, handling, and storage practices – largely due to a lack of knowledge (Wagacha and Muthomi, 2008; Florkowski and Kolavalli, 2013; Jolly et al., 2009; Wagacha and Muthomi, 2008) – also contribute to high aflatoxin levels. Globally, human exposure to aflatoxin is believed to be highest in Sub-Saharan due to the dietary importance throughout much of the continent of maize and groundnut.

2.3 Prevention, Mitigation, and Detection

Aflatoxin is heat stable and extremely difficult to remove or neutralize once present in food (Galvez et al., 2003). While the potential of fermentation and other processing techniques (Shetty et al., 2007), as well as the role of enterosorbents (Philips et al., 2008) are active areas of research for reducing aflatoxin exposure, consumer acceptability of these approaches is likely to be a challenge. Preventing contamination thus is the preferred approach to risk reduction.

The risk of aflatoxin contamination can be reduced at several stages. During planting, farmers can apply biological control agents to reduce toxigenic molds (Wu and Khlangwiset, 2010). The most common biocontrol approach is to apply atoxigenic strains of Aspergillus species, which outcompete toxigenic strains, to the soil. This approach, at between $10-20 per acre, is a promising solution, but must be adapted and approved for local conditions, and is not yet widely available in Africa (Institute of Tropical Agriculture, 2016).

Simple practices can prevent the spread of aflatoxins after harvest. Controlling humidity is essential; crops must be thoroughly dried before storage, and storage areas should be well ventilated and kept at a cool temperature (Strosnider et al., 2006; Turner et al., 2005; Udoh, Cardwell, and Ikotun, 2000). Using new storage containers or cleaning containers before each use reduces the risk of contact with mold spores or insect eggs. Damaged nuts are more susceptible to mold (Hell, Cardwell, and Poehling, 2003; Lamboni and Hell, 2009); sorting out damaged or moldy nuts throughout the drying and storage process is thus highly effective for preventing aflatoxin (Wu and Khlangwiset, 2010). Sorting reduces yield, but improves the average observable quality of the crop, while lowering aflatoxin risk. Farmers may also choose to apply insecticide to the storage area, in order to reduce damage by insects. The efficacy of training and provision of post-harvest technologies including pallets, jute storage bags, and insecticide has been shown through a previous field trial in the Gambia by Turner et al. (2005). However, farmers' willingness to pay for aflatoxin reducing technologies has not been shown. Characterizing adoption of an aflatoxin-reducing technology (tarps for sun drying) in the absence of subsidies is the first aim of the present study.

While health concerns may motivate investment in aflatoxin prevention for own-produced food, other incentives are likely needed when food is produced for sale. Voluntary compliance with aflatoxin standards could potentially be motivated by a price premium for safe food, or regulatory enforcement action could be imposed on those who fail to meet regulatory limits.[2]

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[2]In Ghana the maximum allowable level for aflatoxin in maize and groundnuts is 15 parts per billion (ppb) and in Kenya it is 10 ppb, compared to 4 ppb in the EU and 20 ppb in the U.S

Regulatory enforcement is generally understood to be infeasible at small scales of production and trade. Moreover, this approach could have the unintended consequence of leading value chain actors to avoid contact with government officials, making contamination even more difficult to address. Voluntary compliance, while unlikely to lead to major changes in mass markets in the short term, holds some promise as a strategy for catalyzing early adopters to take up prevention technologies in order to access premium markets. This could potentially have a ripple effect on other market segments, including production for home consumption.

A major barrier to implementation of compliance with aflatoxin standards – either voluntary or mandatory – is the high cost of testing (Wagacha and Muthomi, 2008; Wu and Khlangwiset, 2010; Masters, Daniels, and Sarpong, 2013; Zheng, Richard, and Binder, 2006). Rapid quantitative tests (Enzyme-linked Immunosorbent Assay - ELISA, fluorometric assay) give a numeric value for aflatoxin content, and require a reader costing upwards of $4,000. Test kits cost from $6 per sample. Rapid qualitative and semi-quantitative tests (lateral flow tests, flow-through immunoassay) do not require expensive equipment, and cost upwards of $4 per sample. However, less expensive and more portable detection methods are in the process of development. The International Center for Agricultural Research in the Semiarid Tropics (ICRISAT) is developing a competitive enzyme-linked immunosorbent assay (cELISA) test projected to cost $1-2 per sample (ICRISAT, 2009; Wu and Khlangwiset, 2010), and Helica has developed a similarly priced test (personal communication with Samuel Mutiga, March 17, 2016). "AflaGoggles", a system that will allow for rapid visual assessment of aflatoxin levels, are currently in the early stages of development (Yao and Burger, 2014).

As these technologies come down in cost, and growing awareness about the health risks of mycotoxins among consumers drives demand, premium markets for aflatoxin safe food are likely to grow. This is occurring in Kenya, where aflatoxin awareness is high due to frequent and widely reported aflatoxicosis outbreaks. The Cereal Millers Association of Kenya, representing 80% of the formal maize processing sector in the country, is working closely with a private party aflatoxin proficiency testing and control lab to improve the aflatoxin safety practices of its members, many of whom will not buy maize that fails to conform to the regulatory limit for aflatoxin contamination.[3] The potential for a premium market for safe groundnuts exists in Ghana. Potential buyers of safe nuts include a ready-to-use therapeutic food (RUTF) factory, and international food manufacturers such as Nestle and Hershey, whose commercial interests could be seriously threatened by a food safety incident. Currently, these buyers either source groundnuts internationally, or spend heavily to visually sort nuts, re-testing until the aflatoxin standard is achieved.[4] If technical and operational hurdles can be overcome, offering farmers premium prices could potentially be a worthwhile investment for such firms.

3 Interventions

This study compares the effect of providing farmers with free aflatoxin prevention technology to offering farmers a market incentive to produce groundnuts low in aflatoxin through a three-arm (plus control) randomized intervention. The first experimental arm, *Technology provision*, reduces the cost of aflatoxin prevention. The second arm, *Market incentive*, increases its benefits. Due to the low level of aflatoxin awareness in the study setting, participants assigned to both technology provision and market incentive arms also received comprehensive information about the causes, consequences, and prevention of aflatoxins through a training session held in the village. To isolate the effects of technology provision and a market incentive from the effects of

[3] See https://apteca.tamu.edu/
[4] The RUTF manufacturer, Project Peanut Butter, reports spending 13% of the value of nuts on sorting.

information, an *Information only* treatment group was also included. Finally, a pure control was included, against which to compare all three of these treatment groups. To maximize statistical power, treatment assignment was randomized at the household level after stratifying the sample by village and aflatoxin level at baseline (see Appendix 1 for details).

3.1 Information session

Two months before the 2015 groundnut harvest, enumerators visited participants' homes to invite one member to attend an information session on aflatoxin. The target individual was the person who had produced the most groundnuts the previous year, according to a baseline survey conducted six months earlier. If this individual was not expecting to harvest any groundnuts, another household member who was expecting to harvest was invited. During the invitation visit, enumerators asked farmers the quantity of groundnuts they expected to harvest. This determined the number of tarps the farmer would receive if he/she were to be selected for the free technology treatment group.

A trained agricultural extension agent conducted the information session from a script, and showed a short video on a tablet. The agent first explained the health impact of consuming contaminated groundnuts, and how aflatoxin contamination occurs. He made clear that contamination cannot be eliminated through cooking or processing groundnuts. The presentation continued with a discussion of different practices for aflatoxin reduction during harvest, plucking (removing pods from vines), drying, and storage. The training script and protocol are included as Appendix 2. At the conclusion of the information session, a public lottery was held in which participants drew numbers assigning them to one of three treatment groups: information only, information and free tarps, or information and market premium.

The group was then divided according to treatment assignment, and each farmer took a pictorial quiz on post-harvest practices based on the content of the training. To account for the low literacy rates in these populations, the test was designed using pictorials to depict 7 different practices covered in the information session, and farmers were asked to indicate which of a pair of pictorials depicted the recommended practice. This quiz was implemented as part of the process evaluation to determine the extent to which the information provided on post-harvest aflatoxin-prevention practices was understood and could be recalled. Knowledge is one important precursor to behavior change and hence could be an important determinant of farmers' use of the information in practice. Elicitation of farmers' comprehension through the quiz also allowed analysis of the extent to which variation in comprehension predicted adoption of recommended practices. After all participants had finished the quiz, correct answers were reviewed with the group by a member of the research team.[5]

At this point, participants in the *Technology provision* group were given tarps, while participants in the *Market premium* group were instructed on how and when they could have their nuts tested for aflatoxin and, conditional on a result below the regulatory level, receive a 15 percent price premium for any sales. The *Technology provision* and *Market incentive* interventions are described in greater detail below.

All participants were then given an opportunity to purchase plastic tarpaulin sheets measuring 10 × 10 feet for sun drying on the spot at a price of 10 Ghanaian cedis (GHc; approximately $2.50 US), and informed of the date between one and two weeks later (after the next local market day) on which the study team would return to the village to again offer these

[5] While the quiz was applied immediately after the information session among those selected for the treatment groups, among control farmers it was applied during the post-harvest period follow-up visits, after they had also received the training (the latter, hence, was not meant to be a pure control for knowledge).

sheets for sale. Plastic tarps were available in the regional market center for the same cost, but were not observed for sale in any of the study villages. A local opportunity to purchase therefore constitutes a reduction in transaction costs to obtain this technology. Participants were given non-transferable coupons allowing later tarp purchase up to the number of bags of nuts they expected to sell, and were told that the tarps were available for sale to study participants only.

3.2 Technology provision

Due to study budget constraints and the concern that spillover effects could invalidate results if those in the *Technology provision* group were given an unlimited number of tarps, participants in this group were given one 10 × 10 foot tarp for each jute bag of in-shell nuts they expected to produce, up to a maximum of six tarps. The restriction of six tarps was expected to bind for 27.1% of farmers, according to baseline data, and bound for 42.7% according to farmers' expectations of harvest elicited prior to distribution.

3.3 Market premium

Because no market for aflatoxin-safe nuts currently exists in Ghana, a price premium was designed to reflect likely market conditions should one arise in the near future. Based on the cost of sorting to achieve aflatoxin safety according to the Ghana Country Director of Project Peanut Butter, the premium for safe nuts was set to 15% above the prevailing market price. At the conclusion of the information session, a member of the research team explained to those assigned to the *Market premium* group that certain groundnut buyers are willing to pay more for nuts that contain allowable levels of aflatoxin, and that it would be possible to obtain a 15% premium above the prevailing market price for such groundnuts, starting two to three months after harvest. Sales were restricted to begin at this time to allow any impact on aflatoxin of differences in post-harvest practices to emerge, and to allow comparison of contamination levels across nuts tested for the premium payment versus sampled from household stores at the time of endline data collection. Participants were led through the premium prices corresponding to a series of potential market prices.

Participants in this group were reminded of the opportunity to sell at a premium price during a household visit immediately after harvest, and were called by phone ahead of the first opportunity to sell. Product testing occurred in the village at the point of sale, and farmers were shown test results.

4 Data sources

4.1 Study area and sample

Groundnut production and consumption are especially high in northern Ghana, the site of our study. Over 80 percent of national groundnut production occurs in the country's Northern Region (Tsigbey, Brandenburg, and Clottey, 2003), which accounts for the majority of land in northern Ghana[6]. Farmers were also recruited from the neighboring Upper East region, an area about one-eighth the size of the Northern Region. Northern Ghana is dry, with a single rainy season which takes place from April/May to September/October in the Northern Region, and from May/June to October in the Upper East region. Like most other crops, groundnuts are cultivated in the rainy season.

The sample consisted of 1005 farmers selected from 20 villages in the Northern Region and 20 villages in the Upper East Region. In each region, four villages each from the districts closest to the regional base of operations was selected (Tamale in Northern Region and Navrongo in Upper East). Within each district, villages were selected at random after restricting the selection

[6] and 30 percent of the country's total land area

pool to villages consisting of between 100 and 300 households, of which a large proportion grew groundnuts according to the Ministry of Agriculture. These restrictions ensured that at least 25 groundnut producing households could be found, and that a village census from which to sample households would be feasible to conduct.

4.2 Data collection and study timeline

Fieldwork took place between December 2014 and January 2016. In December 2014 (Northern Region) and January 2015 (Upper East) a baseline survey was conducted that included collection of groundnut samples from household stores for aflatoxin testing. The interventions were conducted approximately two months before the 2015 groundnut harvest (July in Northern Region and August in Upper East). In each village, 25 farming households were randomly selected from a village census conducted by the study team.

Upon arrival at a selected household, enumerators asked for the member who had harvested the most groundnuts in 2014 and still had some groundnuts in storage. If this person was not available, the enumerator asked to speak with another member who had harvested groundnuts in 2014 and still had some in storage. If no adult household members grew groundnuts and had some in storage, a replacement household was selected from a randomly ordered backup list drawn from the village census.

During September (Northern Region) and October (Upper East) 2015, two rounds of post-harvest observation visits were conducted as part of the study process evaluation. This allowed direct observation of drying and storage practices, both for validation of reported practices and for use as outcomes in the impact analysis. Given that post-harvest activities occur at different times, it was not possible to make complete observations of all practices in all households at the time of the household visits. Visits were timed to maximize the probability of observing drying, based on farmers' anticipated date of harvest as elicited prior to the training, and on data from a phone survey. In addition to observing the surface on which nuts were being dried, and the conditions under which they were stored, a survey was administered about various post-harvest activities, including the timing of harvest, length of time between uprooting and plucking, removal of visibly damaged or diseased nuts, and tarp purchase or possession. If the farmer had not yet begun drying, the enumerator returned for a second visit. Farmers assigned to any of the three treatment groups were reminded of best practices to prevent contamination during this visit, reinforcing messages from the aflatoxin training.

Finally, in December 2015 (Northern Region) and January 2016 (Upper East) an endline survey was conducted during which groundnut samples were again taken for aflatoxin testing. The end-line survey contained many of the same questions about groundnut production, post-harvest practices, marketing, and consumption as the baseline survey. In addition, a dietary module was administered to women of childbearing age and children aged two to four years. This module elicited consumption of any foods containing maize or groundnuts during the past 24 hours, as these are the local staples known to be most heavily contaminated with aflatoxin. The timing of the survey during the post-harvest period allowed observation of groundnuts and associated aflatoxin exposure at a time when these are most heavily consumed from household groundnut production. Note that because of the limited reference period of intake, dietary exposure results do not represent the overall impact of the intervention on daily aflatoxin ingestion at other times of the year.

To be eligible to participate in the dietary survey, women had to be between 18 and 49 years of age and had to have been present in the household the day before the interview and taken all meals with the household. If more than one woman matching these criteria resided in the household, the spouse of the head of household was interviewed preferentially. If this woman was unavailable or ineligible, the primary female caregiver in the household, or if necessary, the woman with the most children < 18 years of age resident in the households, as interviewed. Children aged 24 to 48 months were sampled using similar criteria, ensuring to the extent possible that the adult female respondent or another household resident available for interview was responsible for feeding the child or observed the child eating all meals consumed on the previous day.

In order to accurately capture consumption, female respondents were asked to sequentially recall and list all of her and her child's meals over the previous day, and to indicate which mixed dishes contained either maize or groundnuts, or both. For all groundnuts and maize consumed as individual food items, and for all composite dishes containing groundnuts or maize as ingredients, additional information was obtained on the portion sizes consumed, using one of two methods depending on the type of food. For whole groundnuts, the amount consumed was shown using real groundnuts and weighed directly on a dietary scale. For solid or liquid cooked items containing maize and/or groundnuts (e.g., porridges, soups, stews, sauces), she was asked to pour an equivalent volume of water into the dish used to consume the meal, and subtract any amount left over. If a food contained groundnuts, the respondent was asked to indicate the source of the nuts consumed (own production, market, other). In addition to the dietary recall, each respondent and child's weight were measured using digital anthropometric scales by trained enumerators, following training and a standardization exercise.

Mean daily intake of groundnuts and maize were calculated as grams of intake per day on a fresh, raw weight basis. If water weight was used to estimate portion sizes, weights were corrected for the difference in density (grams/milliliter). For composite dishes, the proportion of fresh raw groundnuts or maize flour per cooked weight of the dish consumed was determined based on standard recipe data collected from the region (either existing recent data or collected specifically for this project). We were able to estimate the groundnut content of 98% (Northern region) of all individual groundnut-containing food items reported (n=789 for women; n=562 for children); the remaining items were dropped as the recipes were unfamiliar and individual household recipe data could not feasibly be collected. In each case, groundnuts were a minor ingredient and the level of underestimation of total intakes was likely to be negligible.

After aggregating total grams of groundnut and maize consumed per day, we used total intake per person per day to calculate mean intakes per day for each study group from each source. We estimate the aflatoxin content for each source of groundnuts and maize by multiplying the gram weight intake by the aflatoxin content of each source. We used the results to calculate individual and group mean daily dietary exposure to aflatoxin (µg per day, and ng/kg body weight per day).

At the conclusion of the survey, farmers with nuts in store were asked if they wished to sell any of these. If a farmer was interested in selling, a groundnut buyer accompanying each survey team made the farmer an offer on the quantity he or she wished to sell, based on a visual assessment of quality and current market conditions. Those in the *Market premium* group were also reminded that they would receive a 15% premium above the buyer's offer price, conditional on their nuts testing below the regulatory limit of 15 parts per billion (ppb). In addition, samples of groundnuts were obtained from all participants with nuts in store (in exchange for a small fixed monetary payment) for aflatoxin testing. As at baseline, if nuts intended for household consumption and those intended for sale were stored separately, separate samples were taken. In order to capture the effect of the interventions on sorting practices, shells were removed from the consumption sample and participants were asked to remove any nuts that they would not consume.

In order to allow for immediate payment of the conditional price premium and comparison of aflatoxin contamination in nuts offered for sale and those retained for home consumption, a semi-quantitative mobile rapid testing platform (Mobile Assay's mReader with Neogen Reveal Q+ test strips)[7] was used for aflatoxin analysis at endline. This method has been independently validated in several laboratories (Rhoads et al., 2016) and was in addition validated by one of the authors prior to use in the present study (see Appendix 3).

Samples of maize and groundnuts were obtained from local markets immediately prior to initiation of the endline household survey for use in analysis of dietary exposure. Researchers visited 11 market towns across 3 of the 4 districts in Upper East region, and all four of the districts in Northern region represented in the study to collect maize and groundnut samples. Samples were purchased from several traders within each town and delivered to the Opoku lab at University of Development Studies - Navrongo within 24 hours for cold storage. Groundnut samples were analyzed immediately using the Mobile Assay mReader. Maize samples were stored for one year before analysis using the same method. A total of 50 groundnut samples from all 11 towns were analyzed, and 23 maize samples were analyzed from 7 of the towns representing 3 districts, all in Northern region.

Median aflatoxin content of these samples collected from markets were applied to all maize reported to be consumed, and to all groundnuts consumed that were reported to obtained from market or other sources outside the household. For groundnuts consumed that were reported to be sourced from the household, data from the aflatoxin content of household samples

[7] Neogen Q+ Reveal test strips (Neogen Corp., Lansing, MI), with Mobile Assay's mReader (Mobile Assay Inc., Longmont, CO)

determined during the endline survey were used. For those households that did not have groundnuts specifically reserved for household consumption, the aflatoxin content was imputed as the median from households in the same village, or district if no consumption samples were taken in a particular village.

5 Baseline sample characteristics, marketing, and aflatoxin

5.1 Sample characteristics at baseline

Table ***1*** presents summary statistics for the data collected at baseline by randomly assigned study group. P-values for tests of means between each treatment group and the control group are presented as a validation that the randomization resulted in groups that were comparable at baseline.[8]

Households consisted of five members on average, and 84.5% were headed by a male. Respondents were female in 32% of cases, reflecting the large role played by women in groundnut production. Literacy in this population is low, and only 14% of respondents reported that they could both read and write. Living conditions among the study sample were basic: only 39% of households had electricity in their homes at baseline. Fifty-six percent of households obtained water from a bore hole, and 59% lived in homes with unimproved dirt floors.

Ninety-three percent of the sample reported deriving income from farming, and average landholdings were 1.88 acres. In addition, 47% of households owned a storage facility. Livestock ownership was high: the average household owned 26 small livestock or poultry, 9 medium sized

[8] P-values are taken from a regression of each variable on treatment indicators, as well as village dummies and baseline aflatoxin level (on which the sample was stratified prior to random treatment assignment), and are adjusted for within-village correlation.

livestock (goats, pigs, or sheep), and almost 4 large animals (cattle or horses).

Table 1: Sample Summary Statistics for Socio-Demographic Characteristics

	Information only mean	P-val info vs. control	Tech provision. mean	P-val tech vs. control	Market incentive	P-val market vs. control	Control mean
Northern, n	121		135		118		123
Upper East, n	116		142		120		130
Demographics							
Household size, n	5.4	0.44	5.1	0.785	5.2	0.935	5.2
Male head of household, %	0.835	0.866	0.852	0.51	0.853	0.682	0.838
Female respondent, %	0.333	0.48	0.296	0.757	0.34	0.352	0.304
Respondent can read and write, %	0.148	0.022	0.159	0.009	0.109	0.347	0.083
Housing Quality, %							
HH Has electricity	0.422	0.154	0.39	0.581	0.387	0.562	0.364
Basic Floor	0.544	0.257	0.603	0.737	0.613	0.694	0.597
Rudimentary Floor	0.43	0.323	0.372	0.557	0.366	0.613	0.387
Water Source, %							
Private tap	0.013	0.511	0.007	0.189	0.017	0.8	0.02
Private Well	0.008	0.805	0.007	0.869	0.004	0.725	0.008
Bore Hole	0.523	0.173	0.574	0.676	0.555	0.559	0.581
Public tap or Well	0.16	0.516	0.166	0.319	0.147	0.783	0.138
Surface Water	0.291	0.181	0.242	0.961	0.277	0.354	0.249
Finished Floor	0.025	0.616	0.025	0.401	0.021	0.711	0.016
Farming							
Experience groundnut farming, years	18.9	0.461	19. 4	0.293	18.4	0.814	18.3
Land Cultivated, acres	1.9	0.438	2.0	0.067	1.8	0.807	1.8
Owns Storage, %	0.477	0.437	0.513	0.793	0.464	0.308	0.506
Poultry, n	24.4	0.579	25.5	0.97	29.3	0.177	25.8
Goats, Sheep, Pigs, n	9.0	0.651	8.8	0.489	10.8	0.188	9.5
Cattle & Horses, n	3.3	0.622	2.9	0.382	5.3	0.108	3.7

In general, sample characteristics are well-balanced across groups. We see some differences in literacy levels, with the literacy rate in the control group several percentage points lower than that in the either the *Information only* ($p<0.05$) or *Technology provision* group (0.01). No other differences are statistically significant at the 5% level.

5.2 Groundnut marketing practices

Farmers in the sample sold dried groundnuts both in-shell and as kernels. Most reported obtaining groundnut price information from either the market (63%) or family and friends in the village (21%). The primary buyers of these nuts were small-scale traders locally known as "market ladies" who typically function both as aggregators and retailers of nuts (57%). Local traders (of larger scale than the market ladies) constituted 25% of buyers, followed by village retailers (13%). Seventy-seven percent of respondents reported selling to different individuals each year, indicating the feasibility of attracting sellers to the market premium intervention. Farmers reported arranging groundnut sales since the most recent harvest in various ways. One third had brought their groundnuts to the market to look for a buyer, 16% had been visited by a known buyer for immediate purchase, and 16% said an unknown buyer had visited them for immediate purchase. Finally, 14% had arranged to sell their crop in advance. Fifty-five % of sales occurred at home or on the farm, while 40% took place at the local market, and 5% percent were conducted at the regional market. The distance between a respondent's home and the point of sale was less than 5 miles for 90% of the sample, and 97% reported a cost of 10 GHc (around US$ 3) or less to get to the point of sale. We find evidence of a market penalty for poor quality groundnuts: 86 percent of farmers reported that buyers inspect groundnuts prior to purchase, and 76 percent reported receiving a lower price for moldy nuts.

5. 3 Baseline Aflatoxin Levels

At the conclusion of the baseline survey, enumerators asked to purchase a small sample of groundnuts for aflatoxin testing. When nuts intended for future sale and household consumption were stored separately, separate samples were taken by intended use. If a household had more than one container (generally bags) of nuts for a particular purpose in store, one container (bag) was randomly selected. Groundnuts were then sampled from multiple locations within each selected container. Samples were transported immediately to Dr. Opoku's laboratory at the University of Development Studies, Nyankpala campus. Samples were ground and homogenized, and then a sub-sample was tested for aflatoxin using a fluorometric assay (FluoroQuant reader from Romer Labs, Union, Missouri).[9]

Enumerators were able to observe stored groundnuts for 979 out of 1005 farmers interviewed. 72 percent of farmers planned to sell at least some of the stored groundnuts. 920 samples were collected from the stored nuts, 195 of which were taken from groundnuts exclusively intended for sale, 648 from groundnuts intended exclusively for home consumption, and 207 from mixed samples. Overall, the mean aflatoxin concentration level at baseline was 63.1 ppb. The long right tail on the histogram of log aflatoxin contamination in our baseline sample presented in Figure 1 highlights the fact that while the majority of farmers in the sample produced groundnuts below Ghana's regulatory cutoff of 15 ppb, extremely high levels of contamination in a small number of samples drive up the average.

Given the skewed nature of aflatoxin content distributions, we used log-transformed data in all related analyses and present non-transformed descriptive data alongside log-transformed results.

[9] A report on laboratory quality control procedures is included as Appendix 3.

Figure 1: Histogram of log ppb (parts per billion) aflatoxin contamination at baseline

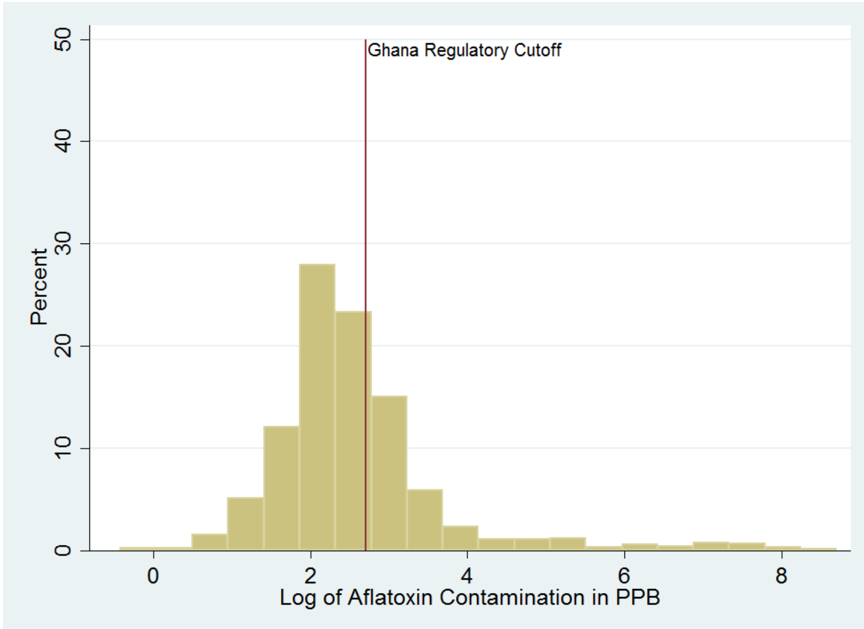


Table 2 presents summary statistics describing the distribution of contamination in the sample, and shows that the median aflatoxin concentration at baseline was 10.82 ppb, but the 99th percentile (1,576.3 ppb) and maximum (6,062 ppb) are orders of magnitude larger than the median.

Table 2: Baseline aflatoxin contamination (parts per billion)

Minimum	**0.66**
1st percentile	1.87
First quartile	7.41
Median	10.82
Mean	63.12
Third quartile	17.56
99th percentile	1576.3
Maximum	6061

Table 3 describes the level of aflatoxin contamination by use for the entire sample. For the majority of the distribution, the nuts saved for home consumption appear to be somewhat less contaminated. However, groundnuts saved for home consumption in this sample contain a larger proportion of extremely high values than those saved for sale.

Table 3: Baseline Aflatoxin Levels by Intended Use

	PPB, HH Use	Log PPB, HH use	PPB, Mixed Use	Log PPB, Mixed Use	PPB, Sale	Log PPB, Sale
First quartile	7.18	1.97	7.28	1.99	7.92	2.07
Median	10.0	2.31	12.7	2.54	12.0	2.48
Third quartile	16.1	2.78	20.7	3.03	21.5	3.07
95th percentile	59.5	4.09	141	4.95	139	4.94
99th percentile	3001	8.01	962	6.87	1033	6.94
Maximum	6977	8.85	1510	7.32	1474	7.30
Mean	90.3	2.50	50.5	2.67	44.4	2.69
Observations	644	644	207	207	195	195

Notes: PPB, parts per billion (equivalent to nanograms per gram); HH, household

T tests reveal that the mean log aflatoxin level is indeed significantly lower among nuts saved for household consumption (p=0.0392) than those reserved for sale when considering the entire sample. This result also holds when using non-transformed aflatoxin levels rather than the log of aflatoxin and restricting the sample to the lowest 95% of observations in terms of this outcome (p=0.000). However, when we compare levels in either the top 99% of the distribution, or the entire sample, the means are not statistically different by intended use (p=0.7548 and p= 0.2664 respectively), and contamination in groundnuts allocated for consumption is higher.

Because households who save groundnuts for consumption may be systematically different in terms of production and post-harvest practices than those who save their harvest to sell, it is not clear from the comparisons above whether differences in how particular households cultivate or store nuts for different purposes drives the observed differences in contamination levels. To understand whether differential treatment of nuts is a factor, we compare nuts saved for sale versus home consumption among the sample that had stored groundnuts for both purposes separately at baseline. Table 4 shows descriptive statistics for this sub-sample of 108 households.

Table 4: Baseline groundnut aflatoxin content by intended use among households with groundnuts store separately for sale and own consumption (n=108)

	Own consumption	Sale
	Parts per billion	
First quartile	7.97	7.64
Median	12.2	11.4
Third quartile	20.7	19.4
95th percentile	2580	105
99th percentile	6597	276
Maximum	6977	645
Mean	285	28.0
Observations	108	108

In the smaller sample of households with nuts saved for both household consumption and sale, we observe that throughout most of the distribution, nuts retained for consumption are no more contaminated than those saved for sale. However, among the nuts in the upper end of the distribution, the aflatoxin content was much higher for nuts saved for household consumption than for those saved for sale. Comparing means within this sample, nuts saved for home use are statistically significantly more contaminated in levels using the entire sample (p=0.0181), but not when excluding the top 1% (p=0.1954) or 5% (p=0.6398) of observations by intended use. Comparing the log of contamination, nuts saved for home consumption are more contaminated, with marginal statistical significance (p=0.0540).

Overall, our analysis of nuts by intended purpose at baseline thus indicates that, among the minority of farmers who differentiate between nuts for consumption versus sale, some appear to reserve their highest quality for sale. Overall, nuts saved for consumption are generally less contaminated than those sold onto the market, though a small number of highly contaminated nuts destined for home use renders the difference in levels between nuts for consumption and sale a statistical zero.

6 Process Evaluation

6.1 Post-training quiz

Post-training quiz scores were high (85%, on average), and did not differ significantly among the three treatment groups (Table 5). The control group did not receive information or training from the project until after the intervention and endline survey were completed. The control group scored slightly, but significantly higher than the treatment groups (89%; $P<0.001$). It is speculated that the control farmers may have learned from their peers in the treatment groups, and hence were able to perform better when tested on knowledge after the information session.

Table 5: Post-training quiz scores by group

	Treatment			Treatment comparison	Control
	Info only	***Technology provision.***	***Market premium***		
Post-training quiz score (out of 8)	6.78	6.79	6.77	ns	7.09[1]
Observations	229	267	229		220

Notes: ns, non-significant.
[1]For the control group, the training session and post-training quiz were conducted after the intervention program ended for the treatment groups (i.e., post-endline survey).

As indicated in

Table ***6***, post-training quiz scores are not correlated with adoption of recommended practices or with endline aflatoxin contamination (P-values are shown for the information only group but test results were similar for the other treatment groups). Correlations may not be apparent because the test scores were high among the majority of respondents. In addition, since one of the trainers went over the correct answers with the group after all participants had completed the quiz, it's possible that the quiz scores underestimate knowledge retained by farmers and potentially acted upon at the time of post-harvest activities. Nonetheless, this result does suggest that farmers' ability to learn new techniques is not a major limiting factor in the adoption of the simple post-harvest practices promoted.

Table 6: Correlation between quiz scores and endline practices, treatment groups only

	Correlation with quiz score (SE)	P-value, info only group
Endline Survey Complete	-0.00384	0.884
	(0.00708)	
Observed Drying Crop on Tarp	-0.00938	0.061
	(0.0224)	
Observed Drying Crop on Dirt	0.0138	0.131
	(0.00922)	
Observed Storing Crop on Pallets	0.0183	0.182
	(0.022)	
Observed Drying Crop on Roof	0.00797	0.318
	(0.0117)	
Reports Drying Crop on Tarp	0.0177	0.629
	(0.0181)	
Reports Drying Crop on Dirt	-0.00332	0.813
	(0.0129)	
Reports Storing Crop on Pallets	-0.00388	0.258
	(0.00982)	
Reports Drying Crop on Roof	0.00908	0.0657
	(0.00604)	
Reports Sorting Crop Before Storage	0.00209	0.455
	(0.015)	
Reports Storing Crop for Seed	0.0373	1.386
	(0.0446)	
Reports Using New Storage Container	0.00504	0.586
	(0.0154)	
Reports Treating Storage Area w/ Insecticide	0.0026	0.268
	(0.0161)	
Reports Sorting Crop by Hand Before Consumption	0.00334	0.596
	(0.0139)	
Reports Disposing of Worst Groundnuts	-0.00734	0.207
	(0.0137)	
Aflatoxin Contamination in PPB	-0.583	3.005
	(0.357)	

Notes: Correlations computed from multivariate regression of each variable on quiz score, controlling for treatment group and baseline aflatoxin level for the household. None of the correlations are significant at p<0.1.

6.2 Tarp distribution and sales

Farmers in all treatment groups (excluding control) were able to purchase tarps through the study, both immediately following training and at a later date. Tarp sales as well as the total tarps distributed through the project are summarized in Table 7. Across the three treatment groups, 14-17% of farmers purchased tarps, and this percentage did not differ significantly by group (Table 7). Among those who did purchase tarps from the project source, the average number purchased was slightly lower ($p<0.1$) among those in the *Technology provision* group compared to those assigned to the *Information only* treatment, which is not surprising since the *Technology Provision* group already had received free tarps from the study. The total number of tarps obtained, either by purchase from the project or received from the study (*Technology provision* group), was significantly higher in the *Technology provision* group than in the other two groups ($P<0.001$).

Table 7: Tarp purchases and distribution

	Treatment			Treatment comparison
	Info only	***Technology provision***	***Market premium***	
Any tarps purchased	0.15	0.14	0.17	ns
Number purchased, if any	2.17	1.79	1.71	*
Number tarps obtained[1]	0.34	4.90	0.28	***
Observations	229	267	229	

Notes: ns, non-significant.
***P<0.001, free tarps versus both market premium and information only; * p<0.1, information only vs. free tarps
[1]The number of tarps obtained by the '*Technology provision*' group free of charge from the study was determined based on the amount of groundnuts they intended to harvest, as indicated at the time of the training session; some farmers in this group purchased tarps in addition to those obtained for free

Those in the control group were not offered an opportunity to purchase tarps through the project. For this reason, and also because farmers may have purchased tarps from other sources, farmers' responses on tarp purchases in the endline survey are used in the impact analysis presented below.

6.3 Direct observation of post-harvest practices

To make at least some direct observations of the use of post-harvest practices, the farmers and research field staff needed to remain in communication during the harvest period and arrange a time for the observational survey. This posed some logistical challenges, and observations were made across a range of different stages of the post-harvest activities. Of the observations made, a large percentage of farmers had already stored their harvested groundnuts, and just over 30% were observed during the drying period (Table 8). In an effort to reach as many farmers as possible during the drying stage, some farmers were visited twice, resulting in a greater number of observations than farmers enrolled in the study.

Table 8: Stage of post-harvest activity at time of observation

Post-harvest practice observed	Number of observations	Proportion of sample[1]
Plants still in ground	205	0.204
Plants harvested but not plucked	130	0.129
Drying	306	0.304
Storage	452	0.450
Sold	56	0.056
Total	1149	

1 Because some households were observed at multiple stages, the total of the proportions is greater than 100%.

We then compared the prevalence of observed post-harvest practices with the prevalence of post-harvest practices reported in the endline survey. Comparison of observed and reported drying and storage behaviors are illustrated in Figure 2 and

Figure 3. Some degree of difference across measures is expected, for three reasons. First, the composition of sample represented in each measure varies, as some participants could not be found during observational visits, and others were not available during the endline survey. Second, there was a difference in the format of allowable survey responses in the observational

and endline survey instruments (the survey allowed only one response for the primary drying surface or storage container, while the post-harvest observation allowed multiple responses). Finally, individuals assigned to any of the three treatment groups were reminded of recommended practices during the observational visit, which could have led to an increase in those practices by endline. In addition to these differences, courtesy bias in the treatment groups may also have led to over-reporting of recommended practices at endline.

Despite these differences, reported practices and those observed directly among the subset visited during each stage of production follow a similar pattern across treatment groups, providing confidence in the accuracy of practices as reported in the endline survey. Both observational and reported outcomes are included in the regression analysis of impact presented below.

Figure 2: Observed versus reported drying surface

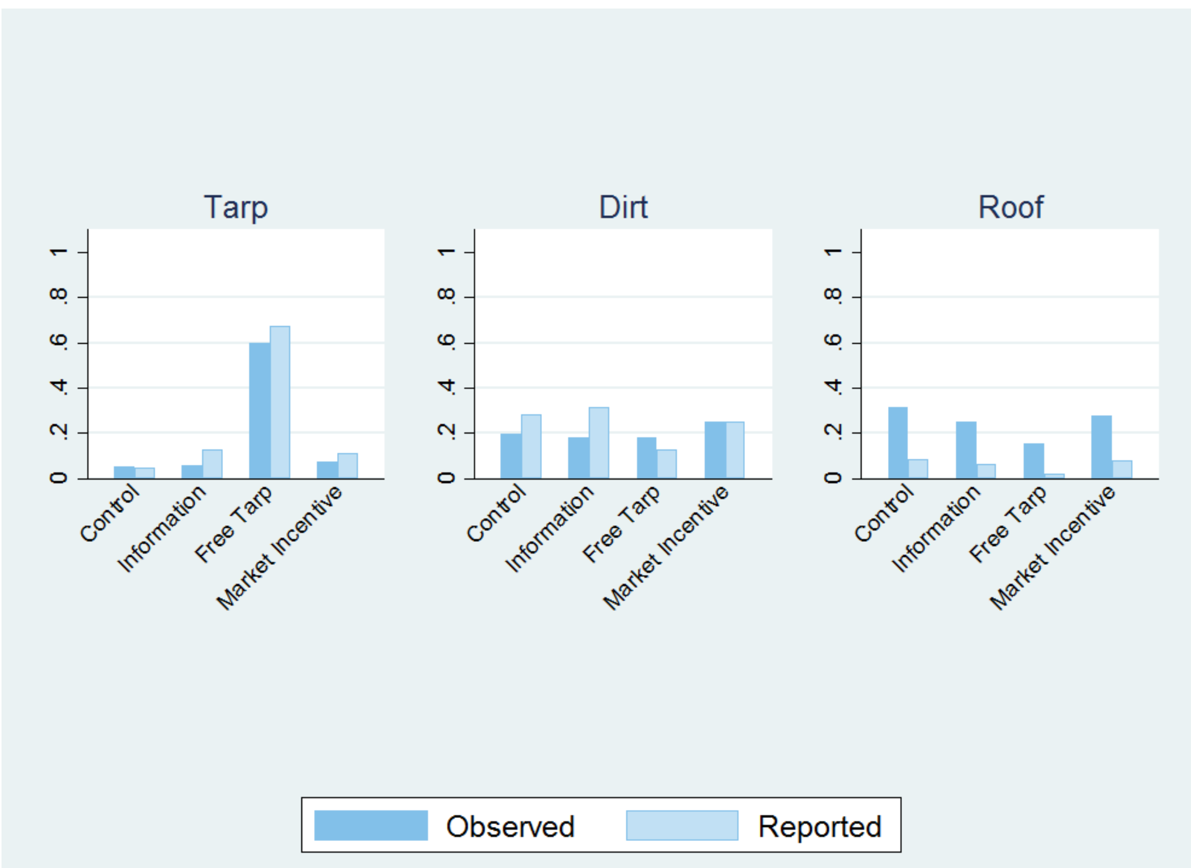
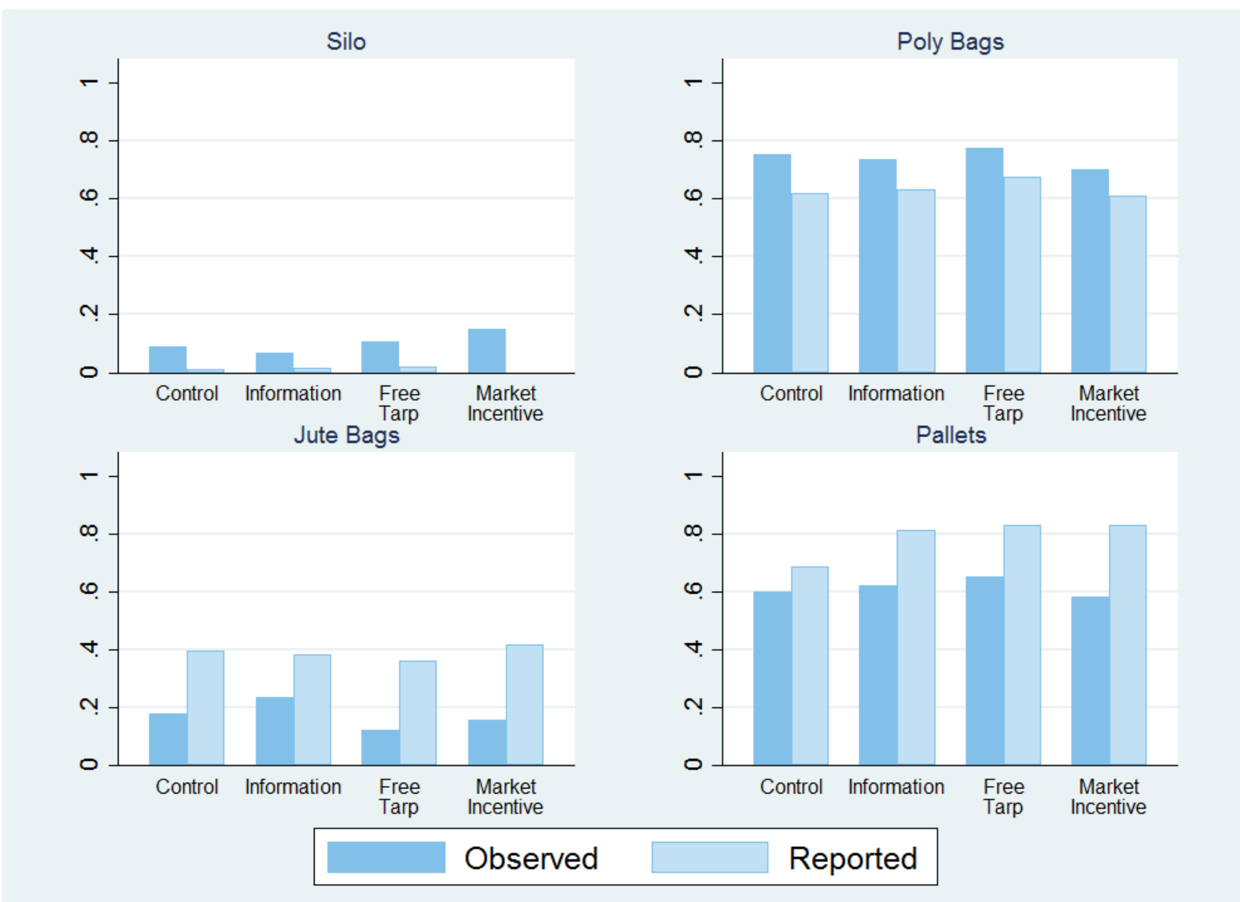


Figure **3** illustrates the proportion of households that dry their crop on each type of surface according to enumerator observation and participant reports. Reported tarp use appears to be slightly higher across all three treatment groups, likely due to a combination of the reminder effect of the post-harvest observation visit and courtesy bias (note that the two measures are almost identical in the control group). The figure also shows that many more households were observed drying their crop on compound roofs than reported doing so in the survey, suggesting that roof drying was generally combined with drying on other surfaces and that the roof was not generally considered by households as the primary drying surface.

Figure 3: Observed versus reported storage conditions



As shown in

Figure **3**, observation of storage in any type of hard plastic or metal container (to which we refer as silos) was systematically higher in the observational data. As with roof drying, this is likely due to differences in question format. Storage in polypropylene bags was systematically under-reported relative to observational data, and storage in jute bags was disproportionately over-reported. We hypothesize that this is due to a language issue, as “jute bag” in the study area is commonly used to refer to a particular size of bag used for crop storage, regardless of the material of which it is made. Finally, storage on pallets is more common according to reported data than the direct observation. Like the discrepancy in tarp use, we hypothesize this is due to a combination of the reminder effect and courtesy bias.

7 Impact of interventions

This section presents the impact results of the randomized interventions on reported and observed post-harvest practices, as well as on aflatoxin contamination of groundnuts sampled during endline data collection, and finally on dietary aflatoxin exposure. First, summary statistics on reported post-harvest practices at baseline and endline are presented by study group. Then, to ascertain the extent to which any changes in practices among participants assigned to treatment groups can be attributed to the intervention, multivariate regression analysis is used to test for causal impacts on the outcomes of interest.

7.1 Reported practices by treatment group at baseline and endline

Table 9 summarizes the post-harvest activities that groundnut farmers undertook at baseline and endline by treatment status. While certain practices known to reduce aflatoxin contamination increased dramatically between baseline and endline, others did not change significantly. In particular, we see very different drying and sorting practices between baseline and endline. At baseline, 59% of all households dried their plucked groundnuts on the bare ground, while only one percent dried their harvest on tarpaulins. In contrast, at endline, only 23% of respondents reported drying their crop on the bare earth, while approximately the same proportion reported drying their groundnuts primarily on tarps. This effect was driven by those assigned to the *Technology provision* group, among which over two thirds reported using tarps for drying. Similarly, after groundnuts had been dried, at baseline only 15.9% of the entire sample indicated that they had sorted their groundnuts, compared to 44% at endline.

Table 9: Post harvest practices, baseline and endline

Post-harvest practices for groundnuts	***Information only***	***Technology provision***	***Market premium***	***Control***
Drying on tarpaulins, %				
Baseline	0.013	0.014	0.008	0.008
Endline	0.129	0.672	0.110	0.044
Drying on dirt, %				
Baseline	0.586	0.585	0.592	0.597
Endline	0.314	0.125	0.252	0.280
Hand sorting after drying, %				
Baseline	0.165	0.144	0.185	0.146
Endline	0.462	0.484	0.481	0.342
Disposing of worst groundnuts, %				
Baseline	0.198	0.144	0.193	0.150
Endline	0.224	0.281	0.190	0.147
Insecticide treated storage unit, %				
Baseline	0.257	0.307	0.248	0.253
Endline	0.267	0.430	0.357	0.280
Storing in new containers, %				
Baseline	0.354	0.491	0.500	0.411
Endline	0.500	0.578	0.519	0.449
Storing on wooden pallets, %				
Baseline	0.806	0.793	0.830	0.811
Endline	0.689	0.814	0.832	0.829

We see limited changes in storage practices between baseline and endline. At baseline, 26% of respondents reported disinfecting their storage containers or storage area, while 33% reported this practice at endline. Reported storage of groundnuts on wooden pallets was already quite prevalent at baseline (81%) across all groups, and remained so at endline. At baseline, 44% of the sample used new storage containers for groundnuts; this number changed only slightly by endline, when 51 percent of respondents reported using new containers. A similar shift in sorting practices is reported, with 17% reporting that they disposed of their worst groundnuts at baseline versus 22% at endline. For some of these practices, difference in adoption are evident across treatment groups at endline, though baseline levels are similar (and none are statistically significantly different). Below, regression analysis is used ascertain the extent to which these changes can be attributed to the randomized intervention.

In the next three sub-sections, we use multivariate regression analysis to assess the impact of the three randomized interventions on post-harvest practices and aflatoxin levels. This approach allows us to control for any differences across villages that may affect technology adoption, as well as differences in aflatoxin levels across households at baseline, which is likely to be correlated with the quality of baseline post-harvest practices. In addition to these controls, outcomes are regressed on indicator variables for each experimental treatment—*Information only*, *Technology provision*, and *Market incentive*. Standard errors are clustered at the village level to account for correlations in treatment effects among households within a given village. Analysis of the completeness of follow-up data and how this may affect causal inference is presented and described in Appendix 4.

The tables below present regression coefficients which indicate the difference in mean value, controlling for possible confounders, of the outcome variable between each treatment group and the control group. Descriptive statistics for the control group are shown for reference at the bottom of each table. Finally, p-statistics indicating the significance of the difference in mean outcomes between those in the *Information only* and *Technology provision* groups, and between those in the *Information only* and *Market premium* groups, are shown.

For the post-harvest practice outcomes, results are shown for farmer-reported practices as determined in the endline survey, and for the subset of direct observations made by enumerators during post-harvest household visits, for the purpose of providing some validation of the self-reported practices.

7.2 Tarp ownership and drying practices

Participants in all three treatment arms had the opportunity to purchase tarps through the project, and as such, we expect to see increases in tarp ownership among all of these groups relative to those in the control group.

Table **10** presents the impact of the interventions on reported and observed tarp ownership, as well as tarp purchases over the past year. Compared to the control group, households in all three treatment groups were both observed to own, and reported purchasing over the past year, a significantly higher number of tarps. As expected, the effect on the number of tarps observed in the compound (taken as the number of tarps owned) is most pronounced for the *Technology provision* group.

Table 10: Estimated impact on tarp purchases and ownership

	Observed: Number of Tarps in Compound – post-harvest	Reported: Purchased Tarp - endline	Reported: Number of Tarps Purchased - endline
	(1)	(2)	(3)
Information only	0.286***	0.097**	0.291***
	(0.098)	(0.036)	(0.098)
Technology provision	3.484***	0.063**	0.170***
	(0.272)	(0.028)	(0.054)
Market premium	0.208**	0.134***	0.275***
	(0.089)	(0.036)	(0.083)
Observations	616	901	901
R-squared	0.538	0.019	0.018
Number of Village Clusters	37	40	40
Control Group Mean	0.156	0.0844	0.120
P-Value: Info vs Tech	0.000***	0.374	0.215
P-Value: Info vs Market	0.409	0.273	0.891

Farmers in the *Market premium* group were 13.4 percentage points more likely to report having purchased any tarps than those in the control group, while those in the *Information only* treatment were 9.7 percentage points more likely to have done so. The quantity of tarps reported purchased is similar between the *Market premium* and *Information only* groups (0.275 tarps and 0.291 tarps respectively). As those in the control group were not presented with an opportunity to purchase tarps through the study, increases in the other groups relative to the control are not surprising.

The first two columns of Table 11 show the impact of each treatment on the prevalence of drying groundnuts directly on the bare ground. Column 1 reports the impact from the smaller sample of households whose practices were directly observed, while column 2 shows the impact using self-reported data at endline. At endline, 28% of households in the control group reported drying their groundnuts primarily on the bare earth. In contrast, households given free tarps were 15.7 percentage points less likely to report this practice ($p<0.01$).

Columns 3 and 4 show the impacts on observed and reported tarp use respectively. We find similar results; 4.4% of the control group reported drying groundnuts primarily on tarps at endline, compared to 66.8% of households who received free tarps, an increase of 62.3 percentage points. The effect of tarp distribution on observed tarp use is somewhat lower (54.4 percentage points), but still significant. The *Information only* treatment generated an 8.4 percentage point increase in the probability of reported drying on tarps, while the market incentive (which was always accompanied by information) led to a 6.4 percentage point increase, suggesting that the incentive had essentially no impact beyond providing information alone.

The only impact we observe on the probability that households dry their groundnuts on their compound roof is a 6.3 percentage point decrease among households who received free tarps. This is in line with the substitutability of these two methods, both of which prevent contact of nuts with

Table 11: Estimated impact on drying practices

	Drying on dirt		Drying on tarps		Drying on roof	
	Observed	Reported	Observed	Reported	Observed	Reported
	(1)	(2)	(3)	(4)	(5)	(6)
Information only	-0.039	0.037	0.017	0.084***	-0.082	-0.020
	(0.063)	(0.047)	(0.037)	(0.022)	(0.063)	(0.022)
Technology provision	-0.113**	-0.157***	0.544***	0.623***	-0.079	-0.063**
	(0.044)	(0.042)	(0.067)	(0.034)	(0.057)	(0.028)
Market premium	0.012	-0.034	0.046	0.064**	-0.051	-0.005
	(0.039)	(0.034)	(0.031)	(0.024)	(0.043)	(0.027)
Observations	306	901	306	901	306	901
R-squared	0.051	0.035	0.405	0.370	0.019	0.014
Number of Village Clusters	38	40	38	40	38	40
Control Group Mean	0.197	0.280	0.0526	0.0444	0.316	0.0844
P-Value: Info vs Technology	0.219	0.000***	0.000***	0.000***	0.964	0.0194**
P-Value: Info vs Market Incentive	0.394	0.113	0.585	0.454	0.581	0.427

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

the ground and were recommended during the training session. With regard to drying on roof tops, we see no other changes due to market incentives or a pure information treatment, nor do we see changes in observed behavior.

7.3 Sorting Practices

As shown in the first column of tarp distribution led to an improvement in the perceived quality of nuts produced by farmers, which led them to save more of these for use as seed. The proportion of respondents who reported discarding bad groundnuts only increased among households who received free tarps. The last column shows that while 14.7% of those in the control group reported disposing of the worst groundnuts, 27.9% of respondents in the *Technology provision* group reported doing so, an increase of nearly 100%.

Table 12, all of the interventions increased the proportion of farmers who reported sorting their groundnuts by hand prior to storage. While 34% of control group households reported sorting groundnuts after drying, households in the *Information only* group were 12.7 percentage points more likely to report doing so. Those who received tarps or market incentives in addition to information were 13.8 and 14.4 percentage points more likely to report sorting their nuts prior to storage relative to control. We find no impact of any of the treatments on the proportion of respondents who sorted their groundnuts by hand immediately prior to consumption (column 2).

We also find that all treatments increased the volume of nuts stored for use as seed the following year. Column 3 of tarp distribution led to an improvement in the perceived quality of nuts produced by farmers, which led them to save more of these for use as seed. The proportion of respondents who reported discarding bad groundnuts only increased among households who received free tarps. The last column shows that while 14.7% of those in the control group reported disposing of the worst groundnuts, 27.9% of respondents in the *Technology provision* group reported doing so, an increase of nearly 100%.

Table 12 shows that the *Information only* treatment increased the amount of nuts stored for use as seed by 19.4 kg, while the tarp treatment led to a 30.1 kg increase, and the market treatment led to an 18.7 kg increase. The effects of the *Information only* and *Market premium* treatments on this outcome are significant only at p<0.1, and *Technology provision* had the strongest impact. We theorize that tarp distribution led to an improvement in the perceived quality of nuts produced by farmers, which led them to save more of these for use as seed. The proportion of respondents who reported discarding bad groundnuts only increased among households who received free tarps. The last column shows that while 14.7% of those in the control group reported disposing of the worst groundnuts, 27.9% of respondents in the *Technology provision* group reported doing so, an increase of nearly 100%.

Table 12: Estimated impact on sorting practices

	Sorted nuts before storage	Sorted nuts before consumption	Number of 100 kg bags stored for seed	Disposed of Moldy Seeds
	(1)	(2)	(3)	(4)
Information only	0.127***	0.032	0.194*	0.067
	(0.045)	(0.044)	(0.115)	(0.044)
Technology provision	0.138***	-0.017	0.301***	0.129***
	(0.051)	(0.045)	(0.079)	(0.039)
Market premium	0.144***	0.014	0.187*	0.039
	(0.050)	(0.045)	(0.111)	(0.041)
Observations	901	901	1,005	901
R-squared	0.017	0.003	0.008	0.017
Number of Village Clusters	40	40	40	40
Control Group Mean	0.342	0.578	1.188	0.147
P-Value: Info vs Technology	0.817	0.260	0.434	0.175
P-Value: Info vs Market Incentive	0.727	0.686	0.955	0.562

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

7.4 Storage practices

In column 1 of Table 13, we see evidence that both the *Technology provision* and the *Market incentive* treatments increased the chance that farmers treated their groundnut storage area with insecticide. In particular, provision of free tarps resulted in a 15.1 percentage point increase (p<0.01) in the probability that farmers treated the storage unit with insecticide before storing freshly harvested groundnuts relative to a base usage rate of 28% in the control group. The *Market premium* treatment increased this practice by 8.5 percentage points (p<0.05). Both of these impacts were statistically significantly different from the impact of information alone.

In column 2, we see that only the *Technology provision* treatment increased households' reported use of new bags for storage (by 11.8 percentage points); no other treatment yielded a change in this behavior. However, as shown in column 4, all three treatments increased the likelihood that households reported storing groundnuts on a raised platform or wooden pallets by 12.3 to 14.5 percentage points, a 25% improvement over the control group mean. We cannot rule out that one treatment was more effective than any another in terms of this outcome.

Table 13: Estimated impact on storage practices

	Reported Applying Insecticide to Container	Reported Using New Container	Observed Storing on Pallets	Reported Storing on Pallets	Observed Storing in Silo	Reported Storing in Silo
Information only	0.001	0.042	0.017	0.124***	-0.024	0.003
	(0.049)	(0.054)	(0.072)	(0.043)	(0.042)	(0.012)
Technology provision	0.151***	0.118***	0.051	0.143***	0.043	0.010
	(0.040)	(0.043)	(0.064)	(0.041)	(0.043)	(0.009)
Market premium	0.085**	0.075	-0.014	0.145***	0.072	-0.010*
	(0.040)	(0.051)	(0.078)	(0.038)	(0.046)	(0.006)
Observations	901	901	451	901	451	901
R-squared	0.022	0.009	0.003	0.024	0.020	0.005
Number of Village Clusters	40	40	37	40	37	40
Control Group Mean	0.280	0.542	0.602	0.689	0.0885	0.00889
P-Value: Information vs Technology	0.001***	0.124	0.576	0.617	0.170	0.637
P-Value: Information vs Market Incentive	0.0610*	0.524	0.631	0.589	0.0470**	0.222

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

7.5 Aflatoxin Levels

Overall, aflatoxin contamination levels in the study area were very low in 2015, apparently due to climatic conditions. The mean contamination of groundnuts collected from households in the study sample was just 3.3 ppb, well below the regulatory limit of 15 ppb; only 4.6 percent of samples tested above 15 ppb. Other research groups have reported similar findings for the 2015 harvest in the study region.[10] Within this context, between-group differences in aflatoxin levels are difficult to detect, as are any changes attributable to the randomized intervention and we see no significant impact of the intervention on this outcome overall.

[10] Personal communication, Dr. Mumuni Abdulai, CSIR-Savanna Agricultural Research Institute, Tamale.

Table 14: Estimated impact on aflatoxin contamination of groundnuts

	Aflatoxin (parts per billion)		
	All	Farmers who saved > 1 bag for seed	Farmers who saved ≤ 1 bag for seed
Information only	0.334	1.320	1.320
	(0.683)	(1.003)	(1.177)
Technology provision	1.092*	2.754**	-0.680
	(0.579)	(1.129)	(0.951)
Market premium	0.951	2.038*	-0.242
	(0.792)	(1.167)	(1.281)
Observations	737	368	369
R-squared	0.003	0.017	0.002
Number of village clusters	40	38	40
Control Group Mean	2.745	2.106	3.514
P-Value: Information vs Technology	0.306	0.107	0.954
P-Value: Information vs Market Incentive	0.455	0.445	0.816

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

The first column of Table 14 presents estimates of treatment effects on aflatoxin content of stored groundnuts for the overall sample. The dependent variable is the aflatoxin level in nuts sampled from households during the endline survey. If two groundnut samples were taken from a particular household at endline (because nuts were stored separately for household consumption and sale), the mean of aflatoxin values of these is used. Note that the smaller sample size relative to the results on reported practices is due to the fact that not all households that participated in the endline survey had nuts in store. We see that assignment to the *Technology provision* treatment is associated with a 1.092 ppb increase in aflatoxin (p<0.1). Although this effect is not significant at conventional levels (i.e. p<0.05), its direction is surprising.

We hypothesize that the estimated impact on aflatoxin may be confounded by changes in sorting behavior resulting from the intervention. All treatments increased the volume of groundnuts retained by households for use as seed, and the *Technology provision* treatment had the largest effect on this outcome. Nuts saved for seed were not sampled (farmers would not allow this, as these are the best of their seeds and critical for future production). As the quality of nuts reserved for seed is generally higher than that of nuts allocated for consumption or sale, differential sorting of the best nuts by treatment could lead to upward bias in aflatoxin estimates. In the second and third columns of Table 14, we therefore separately estimate the impact of each treatment by the volume of nuts saved as seed (> or ≤ 1 bag). Splitting the sample this way, we indeed find significantly higher aflatoxin levels among treated households who saved more than 1 bag of groundnuts for seed, an effect that is pronounced in the *Technology provision* group (2.754 ppb increase; $p<0.05$), and the *Market incentive* group (2.038 ppb; $p<0.1$). We find no impact among households that save less than one sack of their groundnuts for use a seed, and a negative coefficient value, suggesting that the results in our combined sample are indeed confounded by households reserving their best groundnuts to use as seed.

During endline data collection, participants were asked to remove any nuts that they would normally not eat from the sample of nuts taken to reflect household consumption. This allows us to observe the impact of the intervention on the aflatoxin exposure of study households, including through its impact on sorting behavior. Because nuts are mostly sold in-shell, such sorting could not be done for samples of nuts to be sold. This prohibits comparison of contamination level by use. We are, however, able to estimate treatment effects separately for each intended use. These results, presented in Table 15, show no significant treatment effects on log aflatoxin levels of nuts either stored specifically for home consumption or for later sale.

Table 15: Estimated impact on aflatoxin contamination of groundnuts by intended use

	Household Use	Sale
Information only	-0.129	-0.107
	(0.113)	(0.197)
Technology provision	-0.0188	0.205
	(0.117)	(0.194)
Market premium	-0.02	0.162
	(0.125)	(0.217)
Observations	650	239
Number of village clusters	39	37

7.6 Impacts on dietary exposure to aflatoxin

This section describes the impact of the interventions on dietary exposure to aflatoxin among women of childbearing age and children aged two to four years. Dietary intake data were available for 394 women and 256 children from the Northern region and 378 women and 184 children in the Upper East region. Because aflatoxin levels were so low at endline, we also model hypothetical impacts for a higher aflatoxin year, using aflatoxin data from baseline and efficacy data on the impact of tarp use on groundnut aflatoxin from a technology pilot conducted during the first year of the study.

Contamination levels of market-sourced groundnuts and maize, and households' groundnuts stored for consumption are summarized in **Error! Not a valid bookmark self-reference.**. In calculations of dietary exposure, household level data on aflatoxin content of groundnuts reserved for household use were used. For households that did not store nuts specifically for own consumption, the median value at the village, or if not available the district, was used. For purchased groundnuts, the median contamination of market-sourced nuts by region was used. The overall (Northern) median level of contamination in market-sourced maize was used for all maize consumption, regardless of source.

Table 16: Aflatoxin contamination in groundnuts and maize

		Northern Region	Upper East Region
Groundnuts – Market[1]	Aflatoxin, ppb	7.45 (3.03, 40.38)	6.35 (5.25, 6.95)
	n	30	20
Groundnuts – Household (all)[2]	Aflatoxin, ppb	1.0 (0.5, 1.6)	1.8 (1.1, 2.8)
	n	307	422
Maize – Market[1]	Aflatoxin, ppb	9.4 (3.6, 164)	-
	n	23	0

Notes: ppb, parts per billion; values shown represent sample median, (first quartile, third quartile).

Error! Not a valid bookmark self-reference. and 18 show consumption amounts (grams/day) of groundnuts and maize, as well estimated aflatoxin exposure through these foods, among children and women, respectively, represented in the endline nutritional module for all treatment groups combined. Maize consumption, in terms of weight, is considerably higher than groundnut consumption for both demographic groups. This, combined with the lower observed average aflatoxin levels in groundnuts relative to maize implies that a relatively small proportion of total estimated dietary exposure to aflatoxin in this sample is through groundnuts.

The amounts of groundnuts and maize estimated to be consumed in this study were relatively high for both women and children (Tables 17 and 18). Given that the survey was conducted in the early post-harvest season, it is likely that groundnut intakes were higher than they would be in the off-season. Groundnut and maize intakes were higher than those reported in the WHO Global Environment Monitoring System (GEMS)/Food Consumption Cluster Diets from 2006 for the West African region (i.e., 57.4 grams of maize per day and 30.5 grams of groundnuts per day), a dataset that has been used to model dietary aflatoxin exposure risk (Wu et al., 2013). Given the importance of groundnut production in the Northern Region of Ghana, and the predominance of maize as a staple food, this population may well be at elevated risk of dietary aflatoxin exposure compared to other parts of West Africa.

Table 17: Estimated aflatoxin exposure from groundnuts and maize among children aged two to four years at endline

	Amount consumed (grams/day)		Dietary aflatoxin intake (ng/day)			Dietary aflatoxin exposure (ng/kg bodyweight / day)		
	Groundnut	Maize	Groundnut	Maize	Total	Groundnut	Maize	Total
Mean	51	191	107	1799	1906	13.0	138.1	151.1
First quartile	18	0	19	0	377	1.3	0.0	16.9
Median	40	151	54	1414	1518	4.3	115.0	121.8
Third quartile	66	298	126	2804	2891	10.5	216.9	232.5
Observations	440	440	440	440	440	440	440	440

Table 18: Estimated aflatoxin exposure from groundnuts and maize among women at endline

	Grams consumed		Aflatoxin exposure (ng/day)			Aflatoxin exposure (ng/kg bodyweight / day)		
	Groundnut	Maize	Groundnut	Maize	Total	Groundnut	Maize	Total
Mean	90	218	251	2049	2300	4.7	37.1	41.7
Mean	34	0	24	0	87	0.4	0.0	1.5
First quartile	67	176	74	1653	1842	1.3	26.6	29.9
Median	113	388	198	3644	3970	3.5	65.6	71.3
Observations	634	634	634	634	634	634	634	634

Analysis of the impact of the intervention (Tables 19 and 20) on aflatoxin exposure does not reveal any significant impact on exposure through groundnuts. We see that log aflatoxin exposure through maize consumption among children is 22% higher at endline in the *Information only* treatment. This effect arises purely through higher maize consumption in this subgroup, as the estimated level of aflatoxin contamination in maize was used for the entire sample. Baseline maize consumption was not measured, so it is not possible to determine whether this variable was also imbalanced at baseline, but it seems more likely that maize consumption levels were higher in this subgroup due to chance than as a result of the study intervention. The last three columns of Table 19 and 20 scale aflatoxin exposure by bodyweight. Again, we see that the *Information only* treatment is associated with a significant increase in exposure through maize among children, but no other treatment has an effect. The lack of significant impacts on aflatoxin exposure through groundnuts are unsurprising given the low levels of aflatoxin measured in the region at endline, as well as the lack of any impact observed in the contamination of stored groundnuts reported above.

Table 19: Estimated impact on aflatoxin exposure among children aged two to four years

	Grams consumed		Aflatoxin exposure (log ng/day)			Aflatoxin exposure (log ng/kg bodyweight / day)		
	Groundnut	Maize	Groundnut	Maize	Total	Groundnut	Maize	Total
Information only	-0.136	22.020	0.001	0.221**	0.045	0.005	0.200***	0.040
	(5.035)	(16.742)	(0.161)	(0.082)	(0.172)	(0.169)	(0.072)	(0.170)
Technology provision	-2.162	-18.827	0.193	-0.093	0.007	0.201	-0.077	0.010
	(6.371)	(19.476)	(0.163)	(0.116)	(0.191)	(0.168)	(0.111)	(0.191)
Market premium	0.527	-13.377	-0.073	0.010	-0.317	-0.073	0.038	-0.315
	(7.506)	(18.296)	(0.206)	(0.106)	(0.197)	(0.212)	(0.103)	(0.203)
Observations	440	440	379	254	419	379	254	419
Number of village clusters	40	40	40	37	40	40	37	40
R-squared	0.002	0.024	0.009	0.032	0.018	0.009	0.027	0.017

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 20: Estimated impact on aflatoxin exposure among women

	Grams consumed		Aflatoxin exposure (log ng/day)			Aflatoxin exposure (log ng/kg bodyweight / day)		
	Groundnut	Maize	Groundnut	Maize	Total	Groundnut	Maize	Total
Information only	-11.972	14.271	-0.215	0.050	-0.021	-0.226	0.043	-0.026
	(11.731)	(17.091)	(0.161)	(0.097)	(0.124)	(0.166)	(0.098)	(0.127)
Technology provision	-2.682	3.999	0.193	-0.066	0.200	0.185	-0.061	0.194
	(7.646)	(15.596)	(0.159)	(0.095)	(0.151)	(0.158)	(0.093)	(0.154)
Market premium	-6.151	15.452	-0.123	0.056	-0.013	-0.130	0.061	-0.013
	(11.172)	(17.539)	(0.169)	(0.093)	(0.113)	(0.173)	(0.092)	(0.114)
Observations	634	634	535	395	582	535	395	582
Number of village clusters	40	40	40	39	40	40	39	40
R-squared	0.002	0.011	0.016	0.007	0.007	0.016	0.006	0.006

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Finally, we modeled the impact of the intervention on dietary aflatoxin exposure through groundnuts and overall to simulate a year when climatic conditions lead to higher levels of aflatoxin contamination. For this exercise, we used baseline aflatoxin levels of groundnuts in stored nuts collected from the study sample. For respondents who reported using a tarp on which to dry groundnuts, we reduce the level of aflatoxin in stored nuts by 33%, based on findings from a pilot study conducted by our team in the study region the year prior to the main intervention (Kanyam, 2016).[11]Maize samples were not taken at baseline. Based on the assumption that aflatoxin levels in a given year are correlated across crops, we increased the modeled level of contamination in maize by a factor equivalent to the difference in median contamination in stored groundnuts between endline and baseline, which is 9.01.

Summary exposure statistics for children and women from these modeled data are presented in Tables 21 and 22, respectively, and modeled impacts of the randomized interventions for both groups are shown in Table 23. Even under these hypothetical conditions, the model shows no significant reduction in aflatoxin exposure through groundnuts either for children (-13.7%, p=0.190) or women (-13.7%, p=0.126). Given the high proportion of dietary exposure through maize consumption in this sample, the proportional reduction in exposure from the two sources combined is further from being statistically significant (p=0.231 for children; p=0.807 for women).

[11] That study was conducted among a separate sample of 40 farmers, each of whose groundnut harvest consisted of at least nine bags. Farmers were assisted with dividing their harvest into nine separate batches and with drying and storing each of these nine different ways, including the use of tarps for drying.

Table 21: Children's Modeled Aflatoxin Exposure[1]

	Modeled Aflatoxin exposure (ng/day)			Modeled Aflatoxin exposure (ng/kg bodyweight/day)		
	Groundnut	Maize	Total	Groundnut	Maize	Total
Mean	3066	15343	18409	247	1245	1492
First quartile	172	0.00	1759	13.6	0.00	137
Median	441	12773	13718	36.4	1036	1086
Third quartile	1201	24707	26620	97.8	1955	2127
Observations	440	440	440	440	440	440

[1] The modeled results presented here substitute endline aflatoxin content data for groundnuts with the measured content at baseline, and increased the maize content measured from market samples at endline by the same factor.

Table 22: Women's Modeled Aflatoxin Exposure[1]

	Modeled Aflatoxin exposure (ng/day)			Modeled Aflatoxin exposure (ng/kg bodyweight/day)		
	Groundnut	Maize	Total	Groundnut	Maize	Total
Mean	3209	18465	21674	60.6	334	395
First quartile	270	0.00	884	4.74	0	15.6
Median	725	14894	16435	13.3	240	255
Third quartile	1789	32838	35950	33.0	591	646
Observations	3209	18465	21674	60.6	334	395

[1] The modeled results presented here substitute endline aflatoxin content data for groundnuts with the measured content at baseline, and increased the maize content measured from market samples at endline by the same factor. For those farmers who reported at endline to have used tarps for drying.

Table 23: Hypothetical Impact Results for Modeled Aflatoxin Exposure[1]

	Children's Modeled Aflatoxin Exposure			Women's Modeled Aflatoxin Exposure		
	Groundnut ng/kg body weight/day (log)	Maize ng/kg body weight/day (log)	Total ng/kg body weight/day (log)	Groundnut ng/kg body weight/day (log)	Maize ng/kg body weight/day (log)	Total ng/kg body weight/day (log)
Information only	0.077	0.199***	-0.077	-0.106	0.052	-0.033
	(0.116)	(0.070)	(0.180)	(0.128)	(0.099)	(0.151)
Technology provision	-0.147	-0.084	-0.212	-0.148	-0.058	0.031
	(0.110)	(0.107)	(0.174)	(0.095)	(0.092)	(0.125)
Market premium	-0.033	0.030	-0.341*	-0.000	0.056	0.059
	(0.149)	(0.105)	(0.189)	(0.123)	(0.093)	(0.111)
Observations	383	316	421	540	391	585
R-squared	0.435	0.033	0.042	0.347	0.005	0.023
Number of Village Clusters	40	37	40	40	39	40

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

[1]For those farmers who reported at endline to have used tarps for drying, the modeled aflatoxin content of groundnuts at endline was assumed to be reduced by 33%, based on earlier efficacy study results conducted in this population for use of tarps.

8. Discussion

8.1 Summary of intervention impact results for post-harvest practices

The results from this study, based on a randomized intervention that provided information, post-harvest technology and market incentives for aflatoxin reduction in groundnuts by farmers show that free provision of effective technologies to reduce aflatoxin exposure can have dramatic effects on the adoption of recommended practices. Providing tarps free of charge increased the practice of drying groundnuts on these by 54% (observe) to 62% (reported), preventing contact with the soil, a major source of fungal contamination. Farmers who had received free tarps were also more likely to report using insecticide to treat groundnut storage areas compared to those who were trained on best practices for avoiding aflatoxin, but not provided with free tarps.

Information provision combined with an opportunity to purchase tarps increased reported tarp purchases in the year the study was conducted by 9.7 percentage points on a base of 8.4 among those in a control group, and increased the average number of tarps observed in study compounds. The proportion of farmers who reported drying their nuts on tarps was 8.4 percentage points higher in the information only arm, compared to just 4.4% among the control group. Information also had a significant impact on sorting prior to storage: farmers in this group were 12.7 percentage points more likely to sort than those in the control group, of whom 34.2% reported doing so. Storage on pallets to keep bags of stored groundnuts off the ground was higher in the information group by 12.4 percentage points relative to the control group (68.9).

While premium prices for safe food may have the potential to incentivize farmers to invest in aflatoxin prevention, the 15% premium offered through this study had no additional impact on most of the post-harvest practices measured in this study relative to the provision of information alone. Two exceptions are the observed use of storage silos, which was higher by 9.6 percentage points among farmers offered the incentive relative to those in the *Information only* group, and an increase in use of insecticide during storage, which showed an 8.4% increase on a base of 28%. In the end, only five percent of farmers across treatment groups were interested in selling groundnuts through the study, and this was not significantly different across treatment groups. The low overall interest in selling could have been related to the timing of purchases, which only began at the time of the endline survey, two to three months after harvest. While farmers were offered the opportunity to sell at a later time as well, very few actually contacted the study team to do so. The lack of an effect of the market treatment could also be due to the existing market premium paid for visibly high-quality nuts as reported by farmers. Since aflatoxin is strongly negatively correlated with visible groundnut quality (Donner, 2008), and Ghanaian buyers who need to meet aflatoxin standards achieve these through sorting, the introduction of an explicit aflatoxin safety premium may not have changed market conditions sufficiently to have any impact on farmer behavior.

The process evaluation indicated that post-information session quiz scores on post-harvest practices were high for the majority of farmers and quiz scores were not correlated to reported post-harvest practices used. These results suggest that farmers' ability to comprehend the recommended best-practices was not a primary limiting factor in changing behavior and other factors need to be considered, including additional barriers or motivating factors.

8.2 Summary of results for aflatoxin content of groundnuts and dietary aflatoxin exposure

By including an examination of the consumption of groundnuts from home production and any practices around segregating better quality groundnuts for sale (or use as seed) from lesser quality groundnuts to be retained for home consumption, this study also considered the public health impact of these interventions. Given the relatively low aflatoxin contamination in the post-intervention harvest season and the low level of participation in the market incentive intervention and farmers segregating groundnuts specifically for sale, the potential effect of the interventions on concentrating aflatoxin in groundnuts for home consumption was likely muted. Considering the whole sample, regardless of intervention group, groundnuts reserved for home consumption actually had a lower aflatoxin content than those reserved for sale. However, when considering samples only from those households that had segregated groundnuts for both sale and for home consumption from the same harvest, a direct comparison of aflatoxin content suggested there were fewer cases of highly contaminated groundnuts in those reserved for sale, suggesting a potential negative consequence for home consumption in some households. An additional hypothesis emerged from this study whereby the practice of reserving the best groundnuts for seed for next season's planting (a practice that may have increased due to the use of tarps and an associated increase in groundnut quality) may also serve to concentrate more contaminated groundnuts for other purposes, including home consumption, but this would require further study. These results are somewhat inconclusive but this potential negative consequence for farming families should continue to be monitored in the context of similar interventions and be emphasized during training.

Despite the relatively low aflatoxin content measured in samples collected at households as part of the endline survey (Table 16), the estimated mean intake of aflatoxin from groundnuts alone was 13.0 and 4.7 ng/kg body weight/day for children (Table 17) and women (Table 18), respectively – well above levels observed in Europe or the US. However, when we applied the aflatoxin content for groundnuts measured at baseline, which is thought to be more typical for this region, the estimated mean aflatoxin ingestion by women (60.6 ng/kg body weight) was toward the upper end of the previously reported range, and that for children (247 ng/kg body weight/day) was well above the maximum previously reported previously reported (i.e., 9.9 to 99.2 ng/kg body weight/day from groundnuts alone, and expected to be much higher if aflatoxin from maize was also considered; Leong et al., 2012). While some studies have previously reported on the aflatoxin content of maize and/or groundnut products in Ghana (Sugri et al., 2015; Florkowski and Kolavalli, 2013), we have not identified previous estimates of the combined contribution of maize and groundnuts to dietary aflatoxin exposure in Ghana.

Considering the total ingestion of aflatoxin from both maize and groundnuts, as estimated at endline in this study for a low aflatoxin year, dietary exposure was elevated (mean of 151.1 and 41.7 ng/kg body weight/day among children and women, respectively), and within the range of that previously estimated for the African region; the Food and Agriculture Organization of the United Nations/World Health Organization Joint Expert Committee on Food Additives (JECFA) estimates that dietary aflatoxin exposure from all food sources is 3.5 to 184 ng/kg body weight/day in Africa, compared to 0.9 to 2.5 ng/kg body weight/day in Europe and 2.7 ng/kg body weight/day in the United States (JECFA, 2008). However, when modeling the aflatoxin intakes using the elevated aflatoxin content results for groundnuts measured at baseline, and the proportionately increased content in maize, the total aflatoxin ingestion from these two sources was found to be very high, reaching a mean of 1492 and 395 ng/kg body weight/day in children and women, respectively. These data provide strong evidence for the importance of aflatoxin prevention measures for this population in Northern Ghana, from a public health perspective.

Results of the interventions on aflatoxin contamination are muted, reflecting overall extremely low levels of contamination in the region during end-line data collection. Modeling the impact of these treatments using results form a pilot study on the efficacy of sun drying on tarps and aflatoxin data from the baseline survey indicates that free provision of tarps would significantly reduce dietary aflatoxin exposure through groundnuts during higher aflatoxin years. However, considering the relative contribution of groundnuts and maize to aflatoxin ingestion in the study sample, groundnuts provided a considerably smaller fraction of total ingested aflatoxin from these two sources. This is partly attributed to the much larger intake of maize compared to groundnuts, as well as the somewhat higher aflatoxin content used for maize in the analysis, which was based on samples acquired from local markets. In the modeled data using baseline groundnut aflatoxin content, the aflatoxin content of maize was scaled up by a factor proportionate to the difference between baseline and endline groundnut aflatoxin. Assuming that aflatoxin content of these two staples varies in a proportionate manner from year to year, the results of this hypothetical impact modeling exercise suggest that interventions to reduce exposure risk in this population can only be partially addressed by focusing on groundnuts alone.

While the intervention approaches tested here may facilitate access of small-holder farmers to commercial groundnut markets in the future (although not demonstrated here) and possibly improve their incomes, they could only have a limited impact on total aflatoxin exposure risk to the farmer families. There appears to be no consensus on an acceptable maximum exposure level for aflatoxin, and the current goal is to keep it to a reasonable minimum. However, toxicological assessments estimate that every 1 ng/kg body weight/day increase in aflatoxin ingestion results in an increased risk of 0.01 to 0.03 cases of liver cancer per 10,000 individuals, (depending on the prevalence of hepatitis B infection) (Wu et al., 2013). From that perspective, any decrease in aflatoxin intake will decrease the risk of death due to liver cancer. Insufficient causal evidence is as yet available to estimate the effect of aflatoxin exposure level on other outcomes, including those that disproportionately affect children, such as impaired growth and immune function

(Williams et al., 2004). To address a greater public health good, the post-harvest reduction practices promoted in this study should nonetheless be extended to maize.

8.3 Limitations of the study

Several limitations of this study have already been noted in the discussion of results above. Worth emphasizing are two main points. First, it is difficult to anticipate farmers' response to different incentives and hence to intervention strategies. Farmers' decision-making processes are complex, involve many competing interests, and include assessment of risk-benefit of changing behavior. Additional in-depth understanding of farmer's responses to the intervention may be helpful in assessing modified approaches to encourage adoption of these post-harvest practices and how commercial markets and associated regulatory enforcement might play a role. Second, as aflatoxin is affected by environmental conditions that cannot be controlled, and its occurrence within and between different batches of harvested crops is uneven, it is challenging to characterize its occurrence in a food supply and even more challenging to quantify risk for specific groups of individuals. This posed a particular challenge in this study for demonstrating intervention effects. One strength of this study compared to others that quantify dietary aflatoxin exposure is that a very large number of groundnut samples were collected at household level, rather than from markets alone, providing a more direct estimate of exposure in this particular population.

8.4 Conclusions

In conclusion, the provision of information and technology in the form of tarps for drying groundnuts successfully encouraged the use of this practice that had previously been shown to be effective at reducing aflatoxin contamination, and, to a lesser extent, encouraged the use of other risk-reducing post-harvest practices around sorting and storage. Providing information only or information plus a market incentive for aflatoxin-safe groundnuts led to the adoption of some best-practices, but generally by less than 15% of the farmers in those groups. Very few farmers responded to the market premium incentive, and it was speculated that such premiums may already be attainable when presenting visibly good quality groundnuts for sale. Further understanding of the barriers to adoption would be useful to improve uptake of these practices.

From a public health perspective, further efforts to reduce aflatoxin contamination of groundnuts should continue to consider potential negative consequences to farmer families as a result of sorting visibly good quality groundnuts for other uses, including sale to markets and potentially for seed. While any reduction in aflatoxin would likely be beneficial for reducing health risks, it is clear that in this population, best practices for reducing contamination would need to be extended beyond groundnuts to maize to have a more meaningful impact, given that maize contributes a much larger amount of aflatoxin due to higher daily consumption amounts.

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Appendix 1: Randomization procedure

To obtain better balance between treatment and control, the sample was stratified prior to randomization as follows. First, strata of four households within each village were defined based on aflatoxin levels recorded at baseline. Next, three out of four of these households were assigned one of the three treatment groups and the fourth to control. For villages that did not have 20 or 24 farmers, either 20 households (for those with between 21-23 households) or 24 households (for those with more than 24 households) were stratified based on aflatoxin levels. The 1, 2, or 3 remaining households were assigned treatment at random so that no two of these remaining households received the same treatment. This procedure was repeated 1000 times to ensure balance in both aflatoxin levels and a number of post-harvest practices, which are also outcomes of interest for this study. Among the 1000 randomized allocations generated, those for which the p-value for aflatoxin level was below 0.8 were eliminated. Of the remaining allocations, the one with the maximum minimum p-value for all outcomes was selected following (Bruhn and McKenzie, 2009).

For the sake of transparency and to demonstrate the randomness of treatment assignment to participants, those assigned to any of the three treatment groups were invited to a meeting at which a public lottery assigning final treatment status was conducted. Results in this lottery overrode prior treatment assignment for those who participated (the originally assigned treatment assignment is used in the analysis for those who did not participate). Because most participants took part in the lottery, randomization across the individual treatment groups cannot be considered stratified.

Appendix 2: Intervention protocol and training script

Recruitment Day

Recruitment occurs at least one day before the planned training meeting. The recruitment team should arrive in the village by the time farmers are returning from their fields, and stay as late as needed to talk directly with all of the original participants who are currently in the village (have not traveled away overnight).

<u>*To bring to the field:*</u>

Each member of the recruitment team will carry with them a copy of the pre-filled *Farmer Invitation Roster* for the entire village, and complete it as they go.

This form includes the following prefilled information:

- HHID, original participant's full name
- Full names and personal IDs of three back-up household members.
- Phone number from the baseline survey, if available.

The recruiter should indicate which of the people listed on the form (original respondent, household member 1, or household member 2) is expected to attend the meeting with a check-mark next to that person's name. If the original participant is listed twice, indicate their participation with a checkmark in the "original respondent" column.

It also includes the following blank fields, to be filled in during recruitment:

- updated phone number of the person expected to come to the meeting if the number has changed
- the amount of groundnuts that person expects to harvest this year, in jute bags
- the approximate harvest date
- whether (re)consent was obtained from the person expected to come to the meeting
- if no one was recruited from the HH, whether the household has migrated, ceased groundnut farming or is potentially still available – in which case the team should try to find someone from the household on the day of the meeting.

<u>Village entry</u>

Greet village leaders and **explain the need to limit the intervention to invited farmers only.** You can say that keeping the training group to a manageable size is important to the quality of the training, and that we are only able to do one training at this time due to limited resources. Explain that there will be another training for others in a few months, which will be open to everyone in the village.

<u>Recruitment process</u>

Every effort should be made to talk to the original participant. If the original participant is not home and cannot be reached by phone, ask other household members or neighbors when s/he will return. Call the number from the baseline survey that is pre-loaded on the recruitment form. If that number does not work, ask others for the participant's phone number and try to contact the person by phone. Return as many times as needed to find the original participant by the end of that day in the village. Count the participant as "unavailable" only if they are traveling outside of the village and will not return by the end of the day. Consult with the team leader before deciding an original participant is not available and moving to section B.

A. If the baseline respondent is available:

1. Greet the farmer. Ask whether s/he planted groundnuts this season, how the season is going, any problems, and how many jute bag or size 4 plastic bag (in-shell) bags s/he expects to harvest this year, and the expected date of harvest. Do this in a casual way as though you are simply making conversation. Record the expected number of bags and expected date of harvest. If the participant does not expect to harvest groundnuts this season, ask to speak to the first back-up household member (*go to part B*). Note that the expected amount and time of harvest should be recorded in pencil so that it can be changed in such cases.

2. Invite the respondent to the meeting. Inform him or her that if s/he comes to the meeting s/he could win valuable materials for groundnut production, or an opportunity to sell his/her nuts for a higher price. Emphasize that the respondent must personally attend the meeting in order to receive these materials or the market premium.

3. Indicate on the roster whether the baseline respondent plans to attend the meeting. If the baseline respondent is not available to attend, note the reason on the roster (planning travel, work with fixed hours, etc.), and then ask to speak to the first back-up household member (*go to part B*).

4. Confirm the phone number of the baseline respondent, or a number at which s/he can be reached on the meeting day. Give him or her a paper with the invitation details as a reminder.

5. Obtain re-consent using the revised informed consent form.

B. If you are unable to find the baseline respondent, if the baseline respondent does not expect to harvest nuts this season, or if the baseline respondent is not available to attend the meeting, speak to one of the back-up household members. Start with Household member 1. If Household member 1 is not available, move to Household member 2.

1. Greet the household member. Ask whether s/he planted groundnuts this season, how the season is going, any problems, and how many jute bag or size 4 plastic bag (in-shell) bags s/he expects to harvest this year. Do this in a casual way as though you are simply making conversation. Record the expected number of bags. If the household member did not plant nuts this season, or does not expect to harvest any, ask to speak to the household member on the roster and start at the beginning of this step (B1).

2. Invite the household member to the meeting. Inform him or her that if s/he comes to the meeting s/he could win valuable materials for groundnut production, or an opportunity to sell his/her nuts for a higher price. Emphasize that he or she must personally attend the meeting in order to receive these materials or the market premium.

3. Indicate on the roster whether the household member plans to attend the meeting. If the farmer is not available to attend, ask to speak to the next household member on the roster (*go back to B1*).

4. Once you identify a household member who is available and agrees to come to the meeting, this person becomes the "expected attendee" for the meeting, and the "replacement respondent" for the rest of the study, including follow-up data collection.

5. Record the phone number of the replacement respondent or a number at which s/he can be reached on the meeting day. Give him or her a paper with the invitation details as a reminder.

6. Obtain consent from the replacement respondent to participate in the study.

<u>*Phone number updates*</u>

At the conclusion of the recruitment day, update all farmers' phone numbers who have changed from the baseline survey on the *Farmer Training Roster*.

Training Day

The team should arrive in the village one hour before the scheduled meeting time.

<u>*To bring to the field:*</u>

1. Each trainer should carry a copy of the *Farmer Training Roster*, which includes the following prefilled information:

- HHID, expected attendee's full name
- Expected attendee's phone number (to trace attendees in advance of the meeting)
- The name of two other household members (to aid in tracing attendees)
- The number of bags of plastic size 4 / jute bags of unshelled nuts that the expected attendee expects to harvest this year
- Whether (re-)consent has been obtained

It also includes the following blank fields, to be filled in during the meeting:

- Randomly drawn group number
- Comprehension quiz score.

2. The team should also carry a copy of all sheets of the filled *Farmer Training Roster* for the village, which contains the name of original participants, in case this information is required during the meeting.
3. Laminated images to show during training
4. One camera (phone or tablet camera is fine)
5. Demonstration materials: tarps (blue, black, and stitched from old bags), one bag of groundnuts, a rake made from local materials, thatch for covering nuts
6. Tarps for distribution to the free tarps group
7. Coupons for distribution to all groups

Mobilization:

In the hour between arrival in the village and the scheduled meeting time, the team gathers the expected attendees (as recorded on the *Farmer Training Roster*) to the meeting.

Find out when the next market day will be that is at least one week from the day of the meeting. This is the day on which tarps will be offered for sale in the village.

If there is a dispute about who in the household should attend the meeting (if more than one person is trying to attend), and/or someone from a participating household comes, who is not the expected attendee:

- Allow more than one member of the household to attend, but be clear that any benefits that might be obtained through the training (materials for groundnut production or higher prices) will go to just one person, the "primary attendee" for the household.
- The primary attendee is the baseline respondent if s/he is available, even if this person was replaced with another household member during the invitation process (consult *Farmer Invitation Roster*)
- If the baseline respondent is not available, the person who was noted with a checkmark as the "expected attendee" during the invitation process is the "primary attendee" (consult *Farmer Invitation Roster*)
- If someone from the household comes, who is neither the baseline respondent nor the expected participant, they become the "primary attendee" only if neither the baseline respondent nor the expected participant can attend. If this person grew groundnuts, they become the replacement respondent for the rest of the study. If this person did not grow groundnuts this year, ask them to pass on the information and any materials provided to the baseline respondent.

For any of the above situations: If the "primary attendee" is not the expected attendee on the "Farmer Training Roster", cross out the name of the expected attendee and write on the bottom of the sheet the name of the person who attended for the household. This person is the "replacement participant" for future data collection.

No one from outside the invited households should be allowed to stay for the training. Explain that another training will be held 2-3 months after harvest.

Consent:

Prior to the start of the meeting, obtain consent using the revised informed consent form for any attendees whose consent (for back-up members) or re-consent (for original participants) was not obtained during recruitment. Indicate on the roster that consent has been obtained.

Training Script

Introduction:

Thank you for welcoming us into your village today. We truly appreciate your time and your hospitality. We are a team of researchers from University of Development Studies in Nyankpala [in Northern]/Navrongo [in Upper East] and from research organizations in the United States.

We are here to share with you some important information about groundnuts. Specifically, we want to teach you some very simple things you can do to increase the quantity and especially the quality of groundnuts you produce. The quality of your groundnuts not only affects your ability to sell your groundnuts at market and can have important implications on your family's health.

0) Motivation

   Have you ever eaten groundnuts and found that they tasted bitter? Those nuts were probably affected by **molds**.

   Have you ever had your groundnuts rejected by a buyer because they did not look good? **Mold** was likely part of the problem.

When crops, including groundnuts, are not dried well, molds grow on them. A serious problem with some molds that grow on groundnuts is that they produce a **poison called aflatoxin** that can lead to sicknesses including **cancer and liver disease**. Aflatoxin may also cause your **children** not to grow well. These sicknesses may not affect you and your family right away. However, over a long period of eating even a small quantity of bad groundnuts, you and your family's chance of getting sick will increase.

Sometimes, if you eat a lot of bad nuts at once, aflatoxin may cause you to experience diarrhea or to vomit.

Once aflatoxin is present in groundnuts, it does not leave. Even if mold is no longer visible, aflatoxin remains. You cannot get rid of aflatoxin by cooking groundnuts. You cannot get rid of it by making groundnut chips, groundnut stew, or dawa dawa. Your only defense from aflatoxin is to prevent from developing in your groundnuts to begin with.

Fortunately, there are many easy things during and after your harvest that you can do to prevent this from happening and produce good-tasting, healthy groundnuts to sell or for your family.

Let's watch a short video first that describes the problem of aflatoxin and how to prevent it. Then we will discuss the recommendations for producing safe groundnuts in detail.

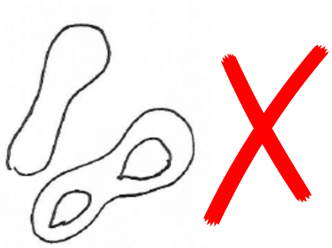
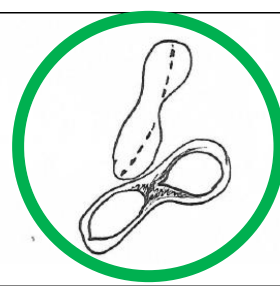
Hand out tablet computers to small groups and instruct them on how to play the video. Have all the groups start the video at the same time by doing a countdown: "3, 2, 1, play!"

1) Harvesting

The first step is to **harvest at the right time**. Do not harvest too early or too late. The groundnuts are ready to be harvested when the leaves are wilting and yellow. But do not mistake leaf spot diseases with mature groundnuts. Leaf spots will also turn leaves yellow, but with round brown spots.

	
Groundnuts ready to harvest	Leaf spot disease making leaves yellow

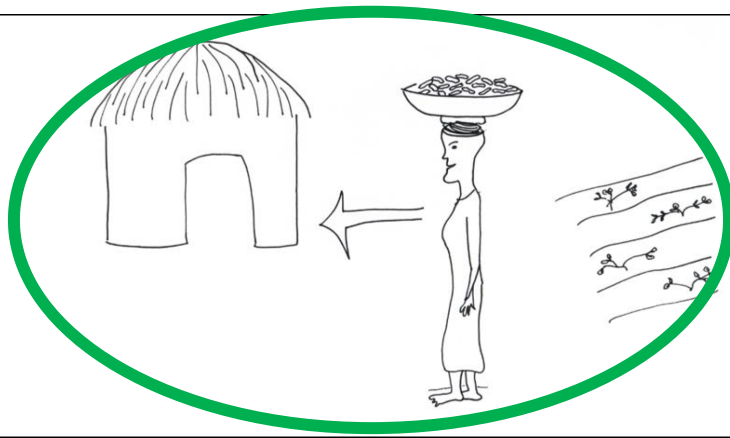
To check that the groundnuts are ready, pull some and break them open. You should see black lines inside pod. Take 10 pods and break them open. If you see black lines inside the pod for at least 7 of the 10 groundnuts they are ready to be pulled.

	
Not yet ready	Ready to harvest

If possible, pull when the ground is moist; if the ground is dry, dig out around the plants with a hoe, and avoid breaking the pods. Broken pods are very susceptible to mold.

2) Plucking

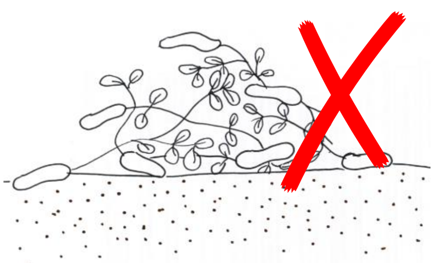
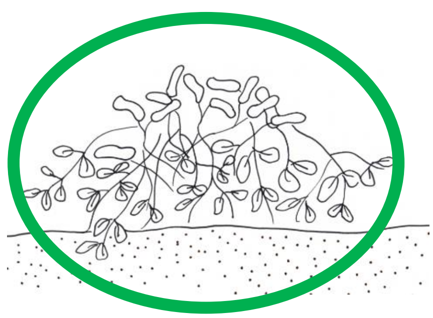
Second, after harvesting, you should **pluck immediately if possible, and then move pods to compound for drying**. Leaving groundnuts in the field exposes them to rain, insects, and soil. When the nuts are wet, it is easier for mold to grow. Insects weaken the shells and allow the mold to come in. And the mold comes from the soil, so it is important to get the nuts away from soil as quickly as possible.



As quickly as possible, pluck your nuts and take them to where you will dry them.

We know that sometimes it is not possible to pluck your groundnuts right away, as labor is not available. If you must leave the plants in the field after they are harvested, turn the plant upside down so that the roots are facing up and the pods do not come in contact with the ground. This will prevent moisture from accumulating on the pods and also prevent insects from attacking the pods.

Do not heap the nuts in the field while you are waiting to pluck, heaping concentrates moisture and allows mold to grow.

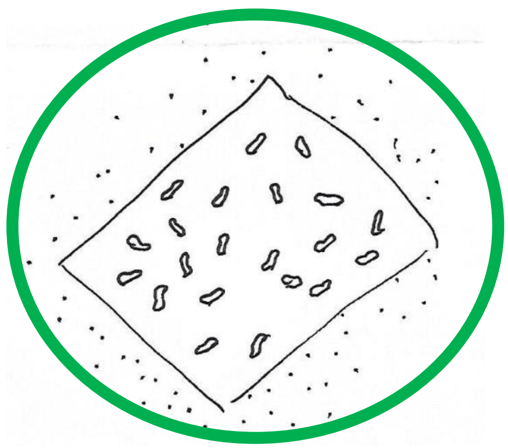
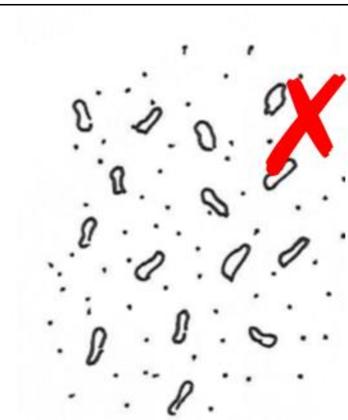
	
Pods exposed to dirt and insects, hidden from sun	Pods protected from dirt and insects, facing sun

As early as possible after harvest, you should remove any nuts that are shriveled, or which have visible mold, holes, breakage, or discoloration and separate them from your good nuts. These nuts are more likely to be affected by mold, and could spread the mold to your other nuts if you do not remove them right away. Sort out any bad nuts during plucking if possible.

3) Drying

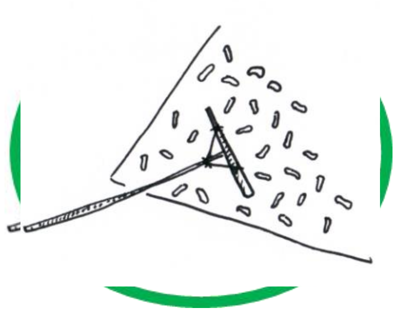
Third, when the groundnuts are plucked and taken to the compound, they should not be dried on the bare dirt. Drying on the bare dirt allows moisture to reach the pods, and also exposes them to insects. You should dry on a tarp, concrete slab, or concrete roof if possible. Tarps are very effective for drying your groundnuts and preventing mold. We will discuss where you can obtain a tarp later.

Whatever drying surface you use, be sure that water will not pool up in the event of rain. A smooth surface is therefore best.

	
Drying on a tarp protects nuts from the dirt	Drying on bare ground exposes nuts to danger

[Show farmers tarps (blue, black, stitched)]

When you spread the pods to dry, be careful not to break them. Do not walk on the pods as this could cause them to break. Do not let animals walk on them either. Using a rake to spread them gently is a good idea.

	
Gently spreading with a rake prevents breaking	Spreading with your feet can break pods

[Demonstrate spreading nuts using rake]

When you spread out your nuts, you should sort again to remove any cracked or molded pods or pods with holes. Mold and disease can spread from bad groundnuts to good ones during the drying process and reduce both the quantity and quality of your groundnuts.

4) In case of rain

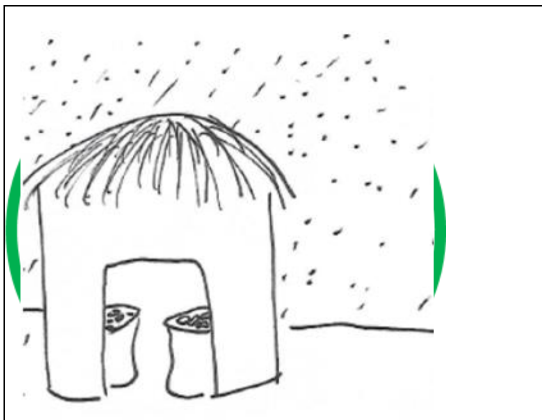
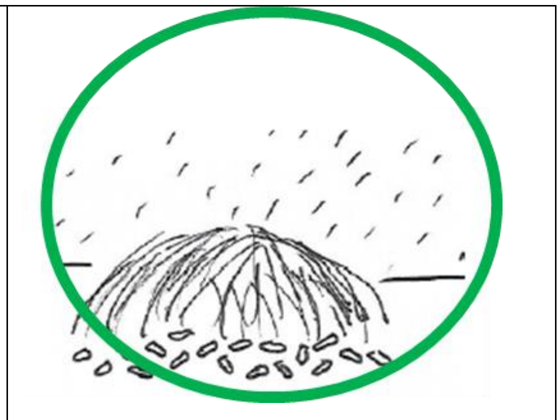
When it rains you need to keep your groundnuts dry. You can do this in two ways.

i. One way is to bring the groundnuts into your compound under a roof, and bag them. This takes a lot of effort, especially if you have a lot of groundnuts. However, it will keep them very dry and in a cool environment.

   In the bags, the groundnuts are concentrated which concentrates moisture in bag. This causes mold to grow. Therefore as soon as possible, you should bring your groundnuts back outside and spread them on the tarp to continue drying.

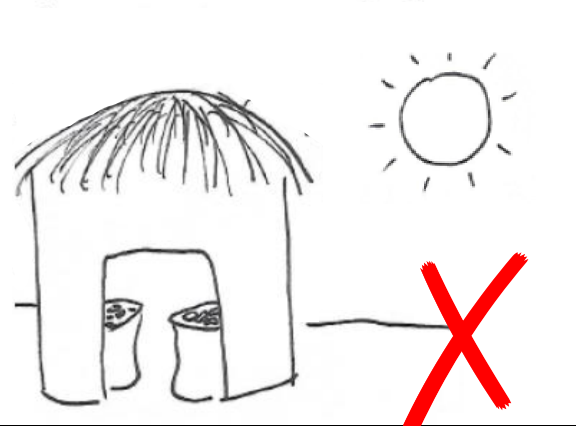
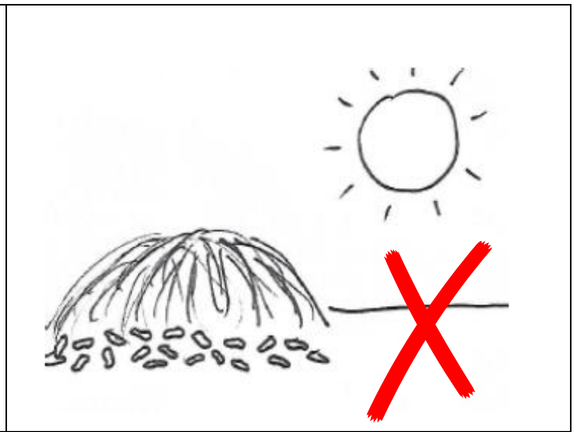
   The bags you use to store the nuts overnight or during rain should be very clean, and new if possible. If there is any dirt on these bags it could introduce mold to your nuts. Your nuts will be very susceptible to mold while they are still drying.

ii. If you cannot bring your groundnuts inside you can cover them where they are drying. Many farmers heap their nuts in a pile, and cover them with thatch. Thatch diverts water away from the groundnuts and keeps them somewhat dry. The thatch you use should be very clean. Use new thatch each season if possible; if you use old thatch, brush any dirt off the thatch before you use it as this dirt could contain mold. Finally, leave the thatch out in the sun for at least a day on each side at the beginning of the season; the sun will kill any insect eggs that may be on the thatch.

	
Nuts inside during rain	Nuts covered with thatch during rain

[Demonstrate covering nuts with thatch]

While tarps are great for keeping your groundnuts protected from dirt while drying, they are not so good for covering the nuts, since a tarp placed on top of the nuts can trap moisture inside and cause mold to grow. For this reason, we recommend you never cover your nuts with a tarp, only use tarps under the nuts.

	
Nuts inside during sun	Nuts covered with thatch during sun

No **matter how you protect your groundnuts from the rain, you should keep them covered or inside for a short of time as possible**. Immediately after the rain stops, and first thing in the morning before the sun comes up, take off any cover you have placed over the pods and remove them from bags if you have brought them inside. Get them into the open air and under the sun as quickly as possible. This will allow them to dry faster, and prevents moisture from staying on the nuts for too long. **Covering the nuts or keeping wet nuts in bags for too long prevents airflow and concentrates moisture, which causes mold to grow.**

If the sun is shining, the nuts should be spread out and uncovered. Leaving nuts covered when the sun is shining not only slows down the drying process, but allows the mold to grow.

[Remove thatch from nuts and spread them out]

After you dry your nuts and before you store them, you should again sort out nuts with visible mold, holes, or breakage, or discoloration. Also sort out shriveled nuts. Nuts with any of these features are particularly likely to contain mold and high levels of aflatoxin. **You should not consume bad nuts, even as peanut stew or dawa dawa. Cooking the groundnuts does not eliminate aflatoxin!**

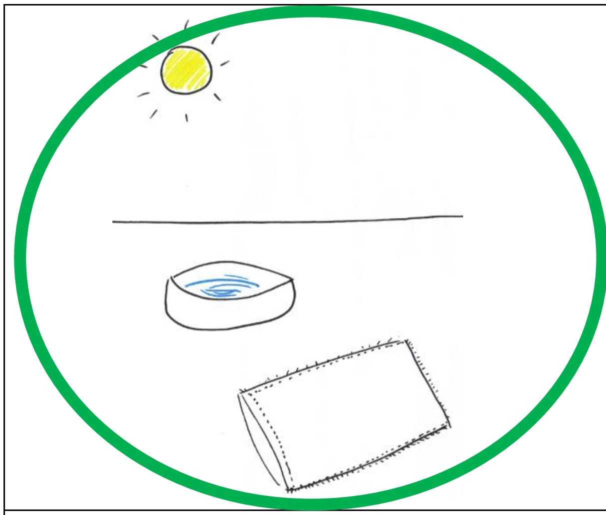
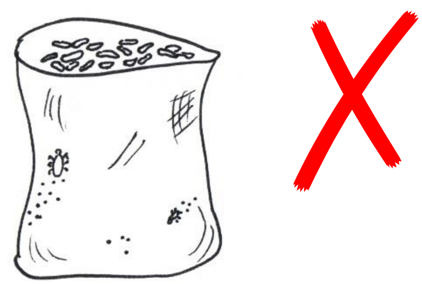
[Show examples or images (photos) of bad nuts with these traits]

Also do not feed your livestock the bad nuts, as the toxin can cause livestock to grow more slowly, and if milk cattle consume contaminated feed, the milk they produce will also be contaminated. With the bad nuts, you should either make oil or otherwise bury them in the ground so no people or animals will eat them. If you make oil you need to discard the remaining solid portion of the nut as this could contain high levels of aflatoxin.

5) Storage

After you are done drying and sorting your groundnuts, there are more things you can do to protect them from mold and aflatoxin. Now I will talk with you about proper storage techniques.

It is important to have clean bags in which to store your groundnuts. This will prevent insects and mold from attacking your groundnuts. One possibility is to use new bags. If you do not use new bags, you should clean your old bags. Before putting pods in bags, turn the bags inside out, brush off any visible dirt off, wash if possible, and then allow the bags to sit in the sun for at least a day on each side. This will reduce the number of viable insect eggs and mold spores that may be inside the bags.

	
Leaving bags in sun before storage kills insect eggs	Insects can hatch from eggs hidden in dirty bags

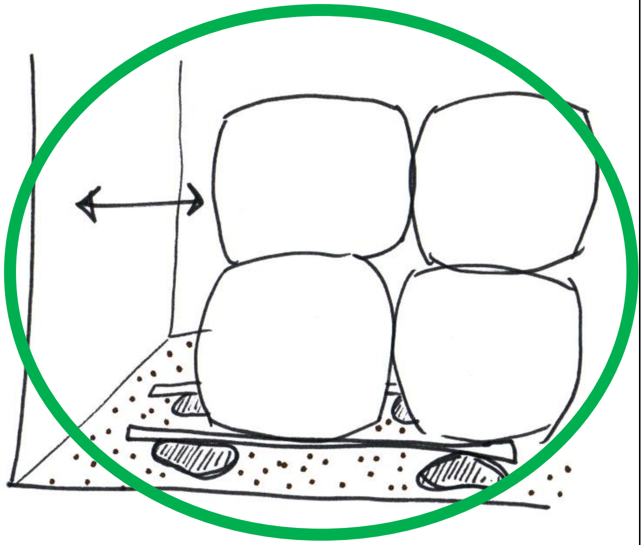
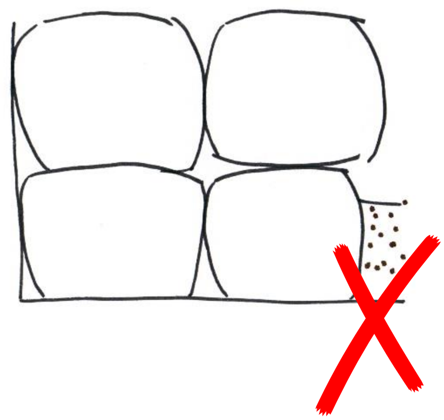
[Demonstrate turning bags inside out, shaking, and putting in sun]

You can also treat bags with insecticide. While this is costly, it is extremely effective at protecting your valuable groundnuts from insects. One insecticide you can use on your bags is cypermethrin, but it depends on the types of insects that usually affect your stored nuts. You can ask your local extension agent or agricultural input supplier for advice on what insecticide to use. The herbicides that you use in your field to prevent weeds will not prevent insects or mold so do not use this for storage.

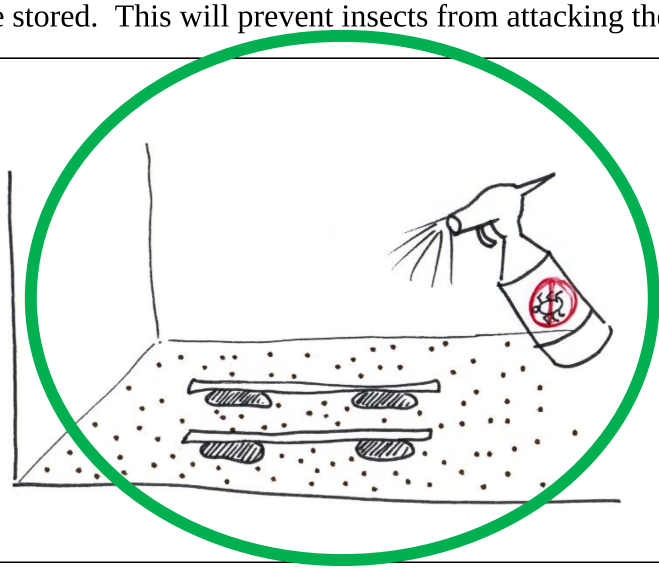
Once your groundnuts are in bags, there is more you can do to protect them from mold, insects, and rodents. You should keep the stored bags off the ground. You can do this by creating a simple platform with rocks and sticks on which to place the bags. It is important that air can come in through the bottom of the platform.

[image of platform without bags]

Also, be sure to leave a space between the bags and the wall of your storage area. Keeping the stored bags off the floor and away from the walls will keep air circulating around the nuts and prevent moisture from the air from affecting your nuts and allowing mold to grow on them. Furthermore, just like mold can live in the ground and attack your nuts, it can also live in the walls. It is important to keep some distance between your stored nuts and the floor and walls of the storage building.

	
Air circulates around and below the nuts	Air does not circulate well allowing mold to grow

If possible, you should put insecticide on the floor of the storage area, under where the nuts are stored. This will prevent insects from attacking the stored nuts.



If possible, apply insecticide to storage area.

6) Summary and tarp purchase

If you do some of these simple practices, you can prevent a great deal of mold from growing on your groundnuts and reduce aflatoxin. This will result in groundnuts that are easier to sell and safer for your family to eat. You do not need to do all of these things to reduce mold and aflatoxin. **Every measure you can take helps.** For instance, if do not have and cannot afford insecticide, you should still take the other measures we talked about to protect your groundnuts.

One piece of material that is very helpful is tarps. Last year, we tested tarps with farmers like you and found that if you use tarps instead of drying groundnuts on bare ground you will reduce the amount of mold and risk of aflatoxin in your groundnuts.

Today we will be giving tarps to some lucky farmers in your village determined by a lottery.

[Show blue tarp]

Others of you will be given an opportunity to purchase inexpensive tarps through this project.

[Show black tarps]

Simple tarps like these [show black tarps] can be purchased for 10 cedis in Tamale. Because you participated in this study with us we are giving you a special opportunity to buy these tarps right here in the village.

I want to make it very clear that we are researchers, not businesspeople. We have studied these tarps and found them to be effective, and we want to introduce the practice of using tarps to dry groundnuts into this area to help farmers like you produce safer groundnuts. We will return at the end of the growing season to discuss your production, including your experience using a tarp if you decide to do so. We will make **no money** from you if you purchase these tarps because we pay 10 cedis for each one sold, and sell them to you at the same price.

Now we would like to divide you into three groups. I will bring a bag around, from which you will draw a piece of paper with a number on it.

[Distribute lottery tickets]

Now that you have your tickets, we will split into three groups.

[Separate groups as much as possible. They should not be able to hear what is going on in the other groups.]

Information retention quiz (for all groups)

To make sure that everyone has retained the key messages from today's training, I would now like everyone to do a simple exercise. I will distribute these papers with images of good and bad practices for harvesting, drying, sorting, and storing groundnuts. I would like you to circle the good practices and put an X through the bad practices.

[Hand out quizzes and pens. Ensure that all participants understand what they are supposed to do. Give them ample time so that the all finish their quiz.]

[As they complete their quizzes, collect and score them. Enter the scores in the *Farmer Training Roster***.** Return the completed quizzes to the farmers. When everybody has theirs, go through the images one by one and discuss the correct answers.]

Thank you for completing these exercises. I now will distribute a new set of images where the good practices are circled and the bad practices are X'd out. Please take them home with you so you can remember what you learned today when it is time to harvest your groundnuts. You may keep the pens, if you like.

[Go to the part of the script that corresponds to the number of the group you are working with.]

Group 1: Training only

Unfortunately, you are not the lucky group to win tarps today. We are sorry we cannot provide tarps to everyone. But we want you to be able to purchase a tarp should you want one. As I said before, we will return to the village soon to sell tarps to **participants of our study only**. On [DAY next week or the week after next (the next market day at least one week from today)], someone from our team will wait at this same location [venue of training] between the hours of [XX] and [XX] with the tarps, and sell them at a price of 10 cedis each.

I will now distribute coupons that you can use to buy tarps. Each coupon allows you to purchase a single tarp at a price of 10 cedis. Because these coupons are for you and you alone, we will put your name on the back of the coupons.

You are receiving a number of coupons based on your expected groundnut production. You will not be able to buy a tarp without a coupon, even if you bring money.

[Give each farmer a coupon for as many tarps as bags of expected production (**from the tracking sheet**). When you give someone a coupon, take the farmer's lottery ticket and write his or her name on back. Write their name and lottery number (1, 2, or 3) on the back of the coupon. **These steps are very important!]**

Using a tarp and adopting the other practices we taught today can prevent aflatoxin-producing molds from growing on your peanuts. This will produce a greater quantity and quality of groundnuts. These groundnuts will be easier to sell in the market and healthier for you and your family.

[Thank farmers individually and dismiss them from the meeting].

Group 2: Free tarps

Congratulations, you are the lucky winners of tarps today. You are receiving a number of tarps based on your expected groundnut production.

[Consulting your list, present a farmer one tarp for each bag of groundnuts they expect to produce up to 6 tarps].

We are sorry we can only provide a limited number of tarps. But we want you to be able to purchase additional tarps should you want them. As I said before, we will return to the village soon to sell tarps to **participants of our study only**. On [DAY next week or the week after next (the next market day at least one week from today)], someone from our team will wait at this same location [venue of training] between the hours of [XX] and [XX] with the tarps, and sell them at a price of 10 cedis each.

I will now distribute coupons that you can use to buy tarps. Each coupon allows you to purchase a single tarp at a price of 10 cedis. Because these coupons are for you and you alone, we will put your name on the back of the coupons. You are receiving a number of coupons based on your expected groundnut production. You will not be able to buy a tarp without a coupon, even if you bring money.

[Give each farmer a coupon for as many tarps as bags of expected production (**from the tracking sheet**), *minus the number of tarps already given to the farmers*. When you give someone a coupon, take the farmer's lottery ticket and write his or her name on back. Write their name and lottery number (1, 2, or 3) on the back of the coupon. **These steps are very important!]**

Using a tarp and adopting the other practices we taught today can prevent aflatoxin-producing molds from growing on your peanuts. This will produce a greater quantity and quality of groundnuts. These groundnuts will be easier to sell in the market and healthier for you and your family.

[Thank farmers individually and dismiss them from the meeting].

Group 3: Price premium

As people become more aware of the dangers of aflatoxin in groundnuts, there is increasing demand for groundnuts and groundnut products with very low levels of aflatoxin. Therefore certain groundnut buyers are willing to pay more for nuts that do not contain aflatoxin, because they can then sell their products to new markets for more money.

Our project is working with buyers demanding aflatoxin-safe nuts.

[*show price premium video*]

We are willing to pay 15% more than the current market price for nuts that meet the Ghanaian standard for aflatoxin safety. We are confident that if you take the measures we have taught you about today, you can achieve these low levels of aflatoxin. We tested many groundnuts produced last season and found that many farmers like you produced groundnuts that meet the Ghanaian food safety requirement.

Between 2 and 3 months after harvest, we will come to your homes. If, at that time, you have groundnuts that you are willing to sell, we will take a sample of these nuts, and perform a test for aflatoxin. This test will be performed immediately, at your home, and you will be shown the result.

If the test shows that these groundnuts are aflatoxin-safe, we will pay you the market price on that day plus an additional 15%. For example, if the price is 100 cedis for one bag of in-shell nuts, we will pay you 115 cedis. If the price is 150 cedis for one bag of in-shell nuts, we will pay you 172.5 cedis, and if the price is 200 cedis we will pay you 230 cedis.

This table here shows for every market price, how much the price will be with the 15% aflatoxin-safe bonus.

[*Go through table*]

eSoko is an agricultural information system that anyone can access from their phone. You simply call 1900 on your phone and you will reach someone who can tell you the current price of groundnuts in Tamale [Navrongo]. We will add 15% to the Tamale [Navrongo] price quoted by eSoko on the day we come to buy from you.

In case you do not wish to sell on the day we come, but you may want to sell later in the season when you need money, we will provide you with the phone number of our buying agent. When you call, he will arrange to come to this village within one week to test your groundnuts. If they test to be aflatoxin-safe he will purchase them at 15% above the market price. You should keep in mind, however, that aflatoxin levels can increase over time. They do not decrease. Your best chance to get the 15% price premium is therefore to sell groundnuts to us the first time we come. Plus, you will save the effort of bringing them to a central location in the village in case the buyer is not able to come to your home.

While your group was lucky to receive the opportunity to sell your groundnuts to us at a higher price, you are not the lucky group to win tarps today. We are sorry we cannot provide tarps to everyone. But we want you to be able to purchase a tarp should you want one. As I said before, we will return to the village soon to sell tarps to **participants of our study only**. On [DAY next week or the week after next (the next market day at least one week from today)], someone from our team will wait at this same location [venue of training] between the hours of [XX] and [XX] with the tarps, and sell them at a price of 10 cedis each.

I will now distribute coupons that you can use to buy tarps. Each coupon allows you to purchase a single tarp at a price of 10 cedis. Because these coupons are for you and you alone, we will put your name on the back of the coupons. You are receiving a number of coupons based on your expected groundnut production. You will not be able to buy a tarp without a coupon, even if you bring money.

[Distribute coupons. When you give someone a coupon, take the farmer's lottery ticket and write his or her name on back. Write their name and lottery number on the back of the coupon. **These steps are very important!]**

[Give each farmer a coupon for as many tarps as bags of expected production (**from the tracking sheet**). When you give someone a coupon, take the farmer's lottery ticket and write his or her name on back. Write their name and lottery number (1, 2, or 3) on the back of the coupon. **These steps are very important!]**

Using a tarp and adopting the other practices we taught today can prevent aflatoxin-producing molds from growing on your peanuts. This will produce a greater quantity and quality of groundnuts. These groundnuts will be easier to sell in the market and healthier for you and your family.

[Thank farmers individually and dismiss them from the meeting].

Appendix 3: Laboratory quality control procedures and validation against controls

Aflatoxin tests for this study were carried out at the Food Technology Laboratory, Nyankpala Campus of the University for Development studies, Tamale Ghana using the Romer Labs Fluoroquant Afla (FQ AFLA) for Aflatoxin and Neogen / Mobile Assay mReader testing systems, as well as on location in study villages using the Neogen / Mobile Assay system.

This Annex describes laboratory quality control procedures, and validation of the two analysis platforms used for baseline and endline data analysis, respectively.

Quality control procedures

For both platforms, manufacturer's instructions were strictly followed. To ensure accuracy and repeatability of results the following quality control procedures were followed at least daily, before running each set of tests. If in the course of testing a set of samples, the process is interrupted, for example due to an interruption of power supply, calibration of the testing equipment is repeated before recommencing testing.

1. *General sanitization*: working benches were always cleaned with 70% alcohol before and after work
2. *Cleaning of blending and extraction materials*: blending glass jars, extraction jars and glass funnels were first cleaned with water shaken and wiped dry and cleaned dry again with 70% ethanol. Stainless steel blending jars were cleaned with ethanol and lab tissue.
3. *Calibration of testing equipment*: for the FQ reader two calibrations were performed: calibration with the internal calibrators and calibration with peanut standards of known aflatoxin concentration. For the internal calibration, tests were only run if values were within the manufacture's acceptable range. The second calibration was performed with peanut standards of known aflatoxin concentration. Depending on the reference material available, at least one, and generally two, tests were performed: one for a low value standard and then for a high value standard. This second calibration was also performed for the mReader. Romer recommends that the FQ Afla reader standard values should read ±40% of the true standard value (±5 ppb for the high value

standard used and ± 3 ppb for the low valued standard). Mobile Assay recommends that the mReader readings should be ± 3 ppb for either high or low value standards. Accordingly, analysis of samples was performed only when testing of standards produced readings within these ranges.

4. For the mReader, all samples for which readings ≥50 ppb were obtained were diluted, retested and value multiplied by the dilution factor.

Validation of Neogen / Mobile Assay Test against Romer Fluoroquant Platform

Three Neogen/Mobile assay tablets were validated using peanut paste standards (spiked peanut paste with known aflatoxin concentration 11.1 ppb). Tests were carried out at four (4) different time points. Validation results are shown in Table A1.

Table A1: Mean Aflatoxin concentration (ppb) recorded for three Neogen/Mobile assay tablets and FQ Afla reader for peanut standard of 11.1 ppb

Time Point	Tablet 1	Tablet 2	Tablet 3	FQ Afla
1	16.6	18.7	17.3	26.9
2	19.2	21.7	21.2	22.8
3	15.9	18.7	18.6	21.3
4	13.2	14.7	13.6	18.7

A number of groundnut (peanut) samples from farmers were randomly selected and tested using both methods prior to analysis of samples collected at study endline. Prior to actual testing, a spiked peanut standard (11.1 ppb) was tested using both systems. A mean of 12.9 ppb and 19.2 ppb were recorded for the Neogen/mobile assay and the FQ Afla reader respectively. Data obtained from the field samples are shown in Table A2.

Table A2: Aflatoxin concentration of 20 randomly selected groundnuts samples generated from Neogen/Mobile assay tablets and FQ Afla reader

HHID	TABLET (ppb)	ROMER (ppb)
1	0.8	6.8
2	0.1	13.6
3	0.2	7
4	0.3	10.4
5	0.9	10.5
6	11.4	10.4
7	1.6	12
8	2.2	13.7
9	0.1	421.3
10	1.9	15.1
11	1.8	10.3
12	0.4	26.7
13	0.6	11.7
14	9.3	9.4
15	1.1	6.6
16	1.2	7
17	0.3	12.4
18	0.6	7.5
19	1.7	9.7
20	0.8	6.8

Final validation was performed using spiked peanut samples provided by Professor Kumar Mallikarjunan of Virginia Polytechnic Institute and State University (Blacksburg, VA). This analysis, shown in Table A3, was conducted with no prior knowledge as to the levels of aflatoxin in the samples. After testing, results were sent to Prof. Kumar of Virginia Tech after which he later sent the expected concentrations of aflatoxin in the various samples.

Table A3: Aflatoxin concentration of various spiked peanut samples from Virginia Tech.

Sample name	Actual value (ppb)	mReader (ppb)	FQ-Reader (ppb)
RUTF #1	2.5	2.9	313.3
RUTF #2	22.5	27.2	509.1
RUTF #3	225	53.8	727.3
Sp. PP#1	2	1.2	46.5
Sp. PP#2	20	9.2	62.4
Sp. PP#3	200	51.8	117.1
Peanut Flour #1	247.6	50.7	161.3
Peanut Flour #2	999.9	55.7	1247.4

For samples with values greater than 50 ppb dilutions were not performed and for that reason mReader values are near the upper limit of the detection range (50 ppb). When dilutions were done at a later stage the values measured were quite accurate (values are not presented here since this analysis was performed after knowledge of the actual aflatoxin concentrations).

Appendix 4: Data completeness

Values reported in table A4 represent coefficients of a regression in which the outcome is equal to one if the data source is available for a particular household, and zero otherwise. Differences in data availability across treatment groups are minor, and never statistically significant at the 5% level. 89% of participants in the control group were successfully interviewed at endline, while the practices of 30% were directly observed while groundnuts were being dried, and 44.7% were observed while their nuts were already stored. Participants in the *Free tarps* groups were slightly (3.8 percentage points) more likely to be interviewed at endline, though this effect is only significant at the 10% level. Higher rates of follow-up data availability among study participants who have benefited most from a particular intervention is common in randomized interventions, and the discrepancy observed here is not large enough to substantively affect the results presented below.

Table A4. Differences in data completeness by treatment group

	Endline Complete	Drying directly observed	Storage directly observed
Information Treatment	-0.005	0.009	0.003
	(0.024)	(0.033)	(0.039)
Technology Treatment	0.038*	0.028	0.007
	(0.022)	(0.036)	(0.044)
Market Incentive Treatment	-0.006	-0.009	0.003
	(0.028)	(0.036)	(0.043)
Observations	1,005	1,005	1,005
Control Group Mean	0.889	0.300	0.447
P-Value: Information vs Technology	0.104	0.618	0.899
P-Value: Information vs Market Incentive	0.971	0.588	0.982