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INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

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Information, Technology, and Market Rewards: Incentivizing Aflatoxin Control in Ghana

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Abstract

Food safety hazards threaten the health and market access of smallholder farming households. Smallholders face a number of barriers to improving food safety and quality, including low awareness, high input costs, and the failure of premium prices to pass through to producers. In this paper we examine how lifting these barriers affects Ghanaian groundnut farmers' adoption of low-tech, low-cost post-harvest practices that reduce aflatoxin contamination. We conduct a randomized controlled trial in northern Ghana over the course of two seasons to test three interventions: (1) training on aflatoxin and its prevention, (2) distribution of free drying sheets, and (3) a price premium for groundnuts that comply with local aflatoxin regulations. In the first year we test for effects on post-harvest practices and aflatoxin levels, and in the second we test for effects on aflatoxin levels only. We find that training farmers substantially improves post-harvest practices. Drying sheet distribution and to a lesser extent the premium price lead to further improvements. We find substantial corresponding decreases in aflatoxin levels from drying sheet provision in the study region where background aflatoxin levels were highest. Beyond regional differences, benefits are higher for households with higher aflatoxin at baseline, more members, and young children. The estimated impacts of the price premium intervention are of similar magnitude, but not statistically significant.

1 Introduction

Recent analysis indicates that the global health burden attributable to unsafe food compares to that of malaria and tuberculosis, and disproportionately affects developing countries (Havelaar et al., 2015). Furthermore, food safety hazards, many of which arise at the farm level, can lock producers out of valuable markets, and may tarnish the reputations of entire nations, limiting export opportunities. Many barriers prevent farmers in developing countries from adopting better food safety practices. First, long-neglected agricultural extension systems result in scarce information on food safety hazards and their prevention(Anderson and Feder, 2004). Second, fixed costs combined with small scale of production and low incomes of farm households can make adoption of technologies to improve the safety of produce unprofitable, or simply unaffordable. Finally, premiums for food safety and other difficult to observe qualities often do not pass through to the primary producer (Fafchamps, Hill, and Minten, 2008). In this paper, we examine the importance of each of these barriers to farmers' adoption of practices that reduce the risk of aflatoxin contamination.

Aflatoxins are a common food safety hazard in developing countries, particularly in Africa. These toxins are secondary metabolites of the fungi *Aspergillus flavus* and *Aspergillus parasiticus* that contaminate many foods including maize, groundnuts, cottonseed, and tree nuts (Payne, 1998). They are tasteless, odorless, invisible, and are known to increase the risk of liver cancer (IARC, 1993), especially for carriers of hepatitis B and C (Turner et al., 2003). More recently aflatoxins have been associated with impaired physical development in children (Gong et al., 2002, 2003, 2004; Hoffmann, Jones, and Leroy, 2018). Consumption of aflatoxin-contaminated feed reduces livestock productivity and may pose health risks to

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humans who consume food produced from affected animals, though contamination levels in animal products are far lower than those found in crops (Keyl and Booth, 1971; Diekman and Green, 1992; Iqbal et al., 2014). Acute exposure to high doses of aflatoxin can lead to aflatoxicosis, which is potentially deadly; an outbreak in western India resulted in 106 deaths in 1974 (Krishnamachari et al., 1975) and outbreaks from 2004-2006 in Kenya resulted in over 150 deaths (Wagacha and Muthomi, 2008).

Aflatoxins also have negative economic impacts through non-health channels. While the impact of aflatoxin contamination on African exports is difficult to separate from other challenges facing the region, Otsuki, Wilson, and Sewadeh (2001) estimate that strict aflatoxin standards and expensive testing protocols in Europe cost African producers hundreds of millions of dollars in exports per year.[1] In one recent episode, produce from Ghana had such a difficult time meeting European standards that several Ghanaian news sources (incorrectly) reported that the EU had banned cereal and groundnut imports from the country altogether (GhanaWeb, 2015; Citi Business News, 2015; Ghanaian Times, 2015). Even in domestic markets, aflatoxin risk has prevented groundnut farmers from selling to large-scale formal sector buyers and potentially receiving higher prices (Watt, 2015).

Aflatoxin exposure is rarely problematic in high-income countries due to routine testing and strict regulatory enforcement. The regulatory limit for aflatoxins in food is 20 parts per billion (ppb) in the US, and 4 ppb in the EU. These standards ensure that producers and intermediaries use best practices, some of which are described in greater detail below, to reduce risks. While standards do exist in some African countries—in Ghana the official regulatory limit for groundnuts is 15 ppb—they are practically never enforced in domestic markets (Wagacha and Muthomi, 2008; Wu and Khlangwiset, 2010; Masters, Daniels, and Sarpong, 2013). Even if enforced, such standards would not affect food produced for household consumption or local informal trade, which account for the majority of production. Subsistence and semi-subsistence farmers would have an incentive to reduce aflatoxin risk

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[1] Others contest the degree to which European standards versus domestic supply issues impede trade (Xiong and Beghin, 2011).

for health reasons if aware of the problem, but awareness among them is extremely low (Florkowski and Kolavalli, 2013; Jolly et al., 2009; Wagacha and Muthomi, 2008).

The pervasiveness of informal markets in developing countries presents numerous hurdles to the enforcement of food safety standards. Informal markets are characterized by a lack of branding and a large number of anonymous small-scale producers and intermediaries. Wholesalers, retailers, and ultimately consumers of agricultural goods rarely know the conditions under which these goods are produced, stored, or transported (Hoffmann and Gatobu, 2014; Fafchamps, Hill, and Minten, 2008). Furthermore, consumers are only able to learn about product quality through visual inspection or upon tasting, and producers thus focus on providing readily observable traits rewarded by the market (Fafchamps, Hill, and Minten, 2008). Because food products are generally consumed in combination, and resulting illnesses occur with some delay, food safety is in many cases a credence good—unknown to the consumer even after consumption. This is true of aflatoxin contamination, for which the health effects are primarily due to chronic exposure over time.

Under these conditions, quality (and specifically food safety) is not rewarded with a higher price and will be under-provided in the market (Antle, 2001; Pouliot and Sumner, 2008). This can happen in both the case of asymmetric information, as first described by Akerlof (1970), or symmetric imperfect information, where neither producers nor consumers know the quality of the good (Antle, 2001). Empirical evidence supports a disconnect between quality and price in unbranded produce. In Kenya, Hoffmann et al. (2013) find no relationship between aflatoxin content and the price of unbranded maize, whereas in branded maize flour Hoffmann and Moser (2017) find a negative relationship.[2]

It is generally accepted that farmers will adopt a practice if the expected benefits of doing so exceed the cost, absent constraints (Feder, Just, and Zilberman, 1985). In the

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[2] The relationship between price and aflatoxin content in branded maize is not due to farmers receiving a higher price for low aflatoxin maize; it is because mills offering premium flour brands are more likely to test and reject lots of maize with high levels of aflatoxin. While intermediaries do receive higher prices from premium millers, farmers generally do not benefit due to the lack of traceability in this market (Hoffmann and Moser, 2017).

case of practices to improve food safety among semi-subsistence farmers, benefits include improved health and potentially higher revenue. Ghanaian groundnut farmers are largely unaware of the health risks posed by aflatoxin, and the markets they serve do not reward aflatoxin safety. However, a small number of buyers in Ghana do test for aflatoxin and pay a premium price; this market will likely grow as awareness of the problem increases.[3]

On the cost side, many aflatoxin prevention measures are simple and inexpensive (Strosnider et al., 2006; Turner et al., 2005; Udoh, Cardwell, and Ikotun, 2000). These measures do, however, generally involve some costs (both time and cash out of pocket), mostly incurred around harvest time, when farmers are busy and cash-constrained. Thus even if farmers are aware of aflatoxin and how to prevent it, and believe the market would reward aflatoxin safety, they may not be able to make the appropriate investments.

In this study we test three interventions designed to encourage smallholder farmers in northern Ghana to adopt good post-harvest practices to decrease aflatoxin levels in groundnuts. We do this using a randomized controlled trial conducted over the course of two years. The first intervention is training on aflatoxin, its origins, the health consequences of exposure, and how to prevent contamination. The second intervention, intended to address the cost problem, is the provision of free drying sheets to a subset of treatment group farmers. The third intervention, intended to address the lack of market incentives for provision of safe produce, is the offer of a premium price from a "special buyer" for groundnuts that test below the regulatory limit. In year 1 of the study there were three treatment groups and one control group. The first treatment group received information only, the second received information and free drying sheets, and the third received information and a premium price offer. The control group received nothing. In year 2, all farmers received information (there was no longer a pure control), an additional subset of farmers received free drying sheets, and another group received a market premium offer that was higher and more flexible than

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[3] Corporations with a global brand to protect, and producers of nutritional supplements for malnourished children are among those currently willing to pay a premium (Roberts, 2017). Media coverage of aflatoxin in Ghana is growing; a Google News search for "aflatoxin Ghana" reveals a steady annual increase from only one result per year between 2010 and 2012, to 35 results in 2018.

in year 1.

Despite information spillovers, we find that directly training farmers leads to improvements in reported and observed practices relative to a control group that was not directly trained. Demand for equipment to improve the safety of nuts is low, even when a premium price is offered for groundnuts low in aflatoxin. The provision of drying sheets results in high rates of observed use, and appears to modestly crowd in other recommended practices. In the region where aflatoxin was non-negligible overall, provision of drying sheets reduces contamination by 25-50 percent in year 2 of the study (levels were too low to detect an impact anywhere during year 1). We use machine learning techniques to investigate treatment effect heterogeneity and find that beyond regional differences, benefits are higher for households with higher aflatoxin at baseline, more members, and young children. In year 1 of the study few farmers sold for the premium price despite eligibility to do so. The timing of sale at the premium price was made more flexible in year 2 and farmer sales through this channel were higher, though the relative importance of each mechanism at play — namely, timing, increased credibility of the offer, and size of the premium — is impossible to disentangle. Offering farmers the opportunity to sell their produce at a premium price conditional on a safety test has no discernible impact on drying sheet purchases relative to information alone, but does improve reported post-harvest practices. Treatment effects on aflatoxin levels are similar in magnitude to those of drying sheet distribution, but are not statistically significant.

The literature on technology adoption in developing countries is vast (see Feder, Just, and Zilberman (1985), Foster and Rosenzweig (2010), and Jack (2013) for reviews of different vintages). However, to our knowledge, the only other paper that focuses on the adoption of practices to improve food safety is Hoffmann and Jones (2018). That paper utilizes a similar design as ours but stops at the intermediate outcome of technology adoption; treatment impacts on aflatoxin contamination are not analyzed. The authors find that Kenyan maize farmers who produce for sale have significantly poorer post-harvest practices at baseline and are less likely to adopt a drying technology that reduces aflatoxin contamination, but are more responsive to both subsidies and market incentives for food safety than pure subsistence farmers. Other studies that examine barriers to production of higher quality or higher value crops address similar questions: do farmers fail to adopt because they are unaware of the benefits of doing so (either monetary or non-monetary)? Do they lack the capital to make the required investments? Or do they lack the knowledge on how to produce safer food?

Perhaps the closest analog to adoption of practices to increase food safety is adoption of biofortified crops. Like food safety, the nutrition content of foods is in most cases a credence good. Biofortified crops will therefore not garner a market premium unless consumers are informed of the benefits of biofortificaiton and can recognize these crops. Hotz et al. (2012) and Low et al. (2007) test a multi-faceted intervention to encourage adoption of biofortified orange fleshed sweet potatoes (OSP), which are high in Vitamin A, in Uganda and Mozambique, respectively. Like groundnuts in Ghana, much of OSP production goes to home consumption. Both studies introduce free materials (vines), farmer training on production practices, and community education on child and maternal nutrition. The community education component not only targets farmers, but also traders and other potential market participants. Both studies find that the intervention package substantially increases OSP consumption and Vitamin A intake. Neither tests different components of the intervention independently. A more distant analog to adoption of practices to increase food safety is the adoption of cash crops with an uncertain (to the farmer) market price. In an evaluation of the DrumNet program in Kenya, Ashraf, Giné, and Karlan (2009) find that offering farmers credit, technical training, and the assurance of a high price does induce farmers to switch from subsistence to export crops. Like the OSP studies, the DrumNet study does not test these interventions separately with the exception of credit for inputs, which is offered as part of a package to one of two treatment groups.

Our study addresses a gap in the literature by investigating the barriers that prevent smallholder farmers from adopting practices to produce safer food. While others have shown how effective simple best practices can be at reducing aflatoxin risk in an African context

(Turner et al., 2005; Pretari, Hoffmann, and Tian, 2019), our paper investigates how farmers can be encouraged to adopt these practices. We demonstrate the impact of providing information on food safety (in an environment where little exists), and the additional impact of offering free access to technology. There is growing interest among donors and African governments in reducing aflatoxin risk for both health and economic reasons. Our findings demonstrate that information campaigns can induce farmers to improve practices. While spillovers across treatment groups limit our ability to detect the effect of a price premium for safer food versus provision of information alone, we can can say that in a market where such a premium exists, investment in a costly technology to improve food safety remains low, and encouraging farmers to sell to the premium market has little impact on practices. Providing farmers with effective tools, however, improves practices and reduces aflatoxin risk beyond the effect of information alone. Such an approach could be used in health programing by the public sector or nongovernmental organizations, or by buyers in the context of contract farming arrangements.

The remainder of this paper is organized as follows: In section 2 we provide additional background on aflatoxin prevention and detection, in section 3 we describe the interventions in detail, in section 4 we describe the study setting and data collection process, in section 5 we present our main results, in section 6 we test for heterogenous treatment effects, in 7 we discuss some implications of our results, and in section 8 we conclude.

2 Aflatoxin prevention and detection

Once aflatoxin is present in food, it is nearly impossible to destroy (Galvez et al., 2003). Aflatoxin is heat stable, and while fermentation and other processing techniques (Shetty, Hald, and Jespersen, 2007) and enterosorbents (Phillips et al., 2008) have potential for reducing exposure, these approaches face obstacles in terms of consumer acceptance and cost. Preventing contamination is thus the preferred approach to risk reduction.

Aflatoxin contamination can occur during cultivation or after harvest. During planting, farmers can use a biological agent ("Aflasafe") to reduce toxigenic molds (Wu and Khlangwiset, 2010). Typically, these agents are atoxigenic strains of *Aspergillus* species that outcompete toxigenic strains. At \$10-20 per acre, this approach is a promising solution, but must be adapted and approved for local conditions. The technology requires more work and inputs from farmers, as well as timely application, so its acceptance from farmers remains a question. In Ghana it was first approved for the 2019 growing season although it is not yet widely available (Aflasafe, 2018).

There are many simple and inexpensive practices that prevent the proliferation of aflatoxin-producing fungi after harvest. Controlling humidity is essential, and can be achieved by thoroughly drying the crop before storage, and making sure the storage area is well aerated and kept at a cool temperature (Strosnider et al., 2006; Turner et al., 2005; Udoh, Cardwell, and Ikotun, 2000). Using new storage containers (usually woven plastic or jute bags) or cleaning containers before each use helps prevent the introduction of mold spores or insect eggs, which can spread spores and physically damage nuts. As damaged nuts are more susceptible to mold, sorting out damaged or moldy nuts prior to storage is highly effective at preventing aflatoxin contamination (Wu and Khlangwiset, 2010). Applying insecticide to the storage area can also be effective for preventing further insect damage (Hell, Cardwell, and Poehling, 2003; Lamboni and Hell, 2009). A package of interventions including training and provision of post-harvest technologies including pallets, jute storage bags, and insecticide was shown effective for reducing aflatoxin contamination of groundnuts through field trials in the Gambia (Turner et al., 2005).[4] However, little is known about farmers' willingness to invest in aflatoxin-reducing technologies, particularly in settings where awareness of the problem is low.

A major barrier to compliance with aflatoxin standards is the high cost and difficulty of testing (Zheng, Richard, and Binder, 2006). Traditional quantitative tests (ELISA, fluo-

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[4] The package used in (Turner et al., 2005) cost approximately \$50 per household for an average of 1.25 MT of production.

rometric assay) give a continuous numeric value for aflatoxin content, and require a reader costing upwards of $2000 and test kits that cost $6 per sample or more. The recently developed Mobile Assay testing kit yields a continuous result and requires less capital investment ($100 per testing unit), but still costs $5 per test.[5] Rapid binary tests (lateral flow tests, flow-through immunoassay) do not require an expensive reader, but cost at least $6 per sample.

In Ghana, potential buyers of safe nuts include a ready-to-use therapeutic food (RUTF) factory and international food manufacturers such as Nestlé 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.[6] If technical and operational hurdles can be overcome, offering farmers premium prices could be a worthwhile investment for such firms. Subsidies for such efforts could also be warranted, as under the current approach to meeting safety requirements there is a good chance that contaminated nuts removed from high-value supply chains will be utilized in lower-value markets, concentrating exposure aflatoxin among poorer consumers.

3 Interventions

We test the effects of three interventions over the course of two years. In year 1, we test the effects of information, free provision of a recommended post-harvest technology (drying sheets), and a premium price offer. Outcomes in year 1 are post-harvest practices and aflatoxin levels. In year 2, after all farmers have received the information, we test the effects of drying sheet provision and the premium price offer on aflatoxin levels only.

In year 1 of the study, we formed three treatment groups and one control group. Given nonexistent awareness of aflatoxin among farmers during formative research, all three treat-

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[5] www.mobileassay.com

[6] The RUTF manufacturer, Project Peanut Butter, reports spending 13 percent of the value of nuts on sorting.

ment groups were provided with information about aflatoxin and how to prevent it. In addition, we provided free plastic drying sheets to the farmers in one of the groups and offered a price premium for safer nuts to a second. This design allows us to isolate the effect of receiving drying sheets or a premium price offer from that of receiving information alone. To achieve adequate statistical power for the detection of impacts on aflatoxin, we assigned treatment at the household level. This raises concerns about information spillovers, which we discuss in section 5.5 after the main results. Randomization into the control group (versus any of the three treatments) was stratified by village and baseline aflatoxin level using a re-sampling routine to improve balance along several variables (see Appendix A for details). The particular treatment group to which a household was assigned was determined through a random draw conducted after the information session, to which all treatment households were invited. Thus stratification for which treatment farmers received is done only by village.

Aflatoxin levels can vary greatly from year to year, and were extremely low throughout Ghana in the groundnut harvest following the initial round of interventions. This made it impossible to detect treatment effects on aflatoxin contamination. Using unanticipated additional funding received after year 1, we repeated the interventions the following year in a second attempt to capture impacts on aflatoxin. After the initial follow-up survey, and not anticipating a second year of data collection, control farmers were invited to information sessions to fulfill commitments made during the approval process for research on human subjects. This left three study arms in year 2: information only, drying sheet provision, and price premium. Because there was no longer a pure control group, in year 2 we can estimate the impact of drying sheet provision and the premium price offer conditional on receiving information, but not the impact of information itself. The year 2 interventions and how they were assigned are described in more detail in subsection 3.4.

3.1 Information

Two months before the year groundnut harvest (2015), we invited farmers assigned to treatment to participate in an information session. The research team visited farmers the day before the session and told them that they would have a chance to receive a gift related to groundnut farming at the meeting. At the time of invitation, farmers were asked whether or not they had planted groundnuts, how the season was progressing, and what quantity of groundnuts they expected to harvest. This last question determined how many drying sheets the farmer would receive if selected for the free provision treatment group. If the respondent was not expecting to harvest any groundnuts, a household member who was expecting to do so was invited instead. 725 of 752 households invited to send someone to the information session did so, and no farmers in the control group attended. The 27 households who did not send a representative to the session were later randomly assigned to one of the intervention groups using a random number generator for the purpose of ITT analysis, but did not receive the interventions.

A trained agricultural extension agent conducted the information session based on a script written with the research team. The agent first explained how aflatoxin contamination arises and the health consequences of dietary exposure. He clearly stated that aflatoxin cannot be substantially reduced through cooking or processing groundnuts, aside from pressing the nuts for oil and disposing of the remaining cake. He then described recommended practices for aflatoxin reduction during harvest, plucking (removing pods from vines), drying, and storage. The specific practices covered in the training are listed in Appendix B.

At the conclusion of the information session, participants drew numbers to determine their assignment to one of the three treatment groups: information only, drying sheet provision, or price premium. The latter two treatments are discussed in more detail below. The three groups were physically separated, and farmers took a pictorial quiz on post-harvest practices to reduce aflatoxin and then reviewed the correct answers with a research team member. After the quizzes, farmers in all treatment groups were told that drying sheets would be available for purchase in their village during the following two weeks at a price of 10 GHC (roughly \$2.50 at the time). A mutually agreeable time was arranged at which the researchers would return to offer the drying sheets for sale.[7] Participants were given a non-transferable eligibility coupon for sheet purchase. Farmers in all three treatment groups were reminded of best practices during a post-harvest visit immediately after the groundnut harvest (described in subsection 4.2.2).

3.2 Drying sheet provision

In year 1 we aimed to give farmers in the drying sheet provision group as many sheets as needed to dry their projected groundnut production, but no more. The goal was for farmers in this group to be able to dry all of their groundnuts on the sheets, while avoiding the distribution of excess sheets that might be given or sold to other farmers. Due to supply constraints, we limited the number of free drying sheets per farmer to six. This limit was binding for 126 of the 277 farmers assigned to this group. The sheets distributed for free were blue plastic woven tarps not available locally, whereas those sold were large black plastic sheets. This allows us to track the leakage of materials provided free of charge. We refer to both types as "drying sheets" in this paper.

3.3 Price premium

At the conclusion of the information session, a research team member explained to farmers in the price premium treatment group that there is new demand in Ghana for groundnuts with low levels of aflatoxin. The team member then told farmers that they would be eligible to sell their groundnuts at 15 percent above the prevailing market price for nuts that meet

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[7] The same drying sheets could be purchased in Tamale, the regional capital and commercial center, for 10 GHC. The study team did not observe drying sheets for sale in any of the villages or nearby towns. By covering the cost of distribution through research funds, we avoided the possibility that some farmers, knowing the price in Tamale was lower, would wait to purchase drying sheets there.

the Ghanian regulatory standard for aflatoxin of 15 ppb,[8] and led farmers through a table showing premium levels for various market prices.

Based on a market survey conducted the previous year, we set the main purchase period to be 2-3 months after the harvest, concurrent with the first follow-up survey. By this time, the impact of post-harvest practices on aflatoxin levels should be apparent, but most farmers are expected to still have groundnuts in storage. Enumerators gave farmers the phone number of a buying agent who would come to the village on demand to buy nuts after this time. We reminded farmers in this treatment group of the opportunity to sell at a premium price shorty after harvest during a post-harvest visit, and called them again several days before the follow-up survey and groundnut purchase visit. The buyer would be accompanied by a technician who would conduct aflatoxin tests in the village at the time of sale to determine if the buyer would purchase the groundnuts at a premium.

Despite the fact that nearly all farmers qualified for the premium, only 6 percent of farmers in the premium group actually sold their groundnuts through the study in year 1. This rate of sale was no different from farmers in other treatment groups who were offered the opportunity to sell groundnuts at the market price. There are several factors that could have prevented them from doing so: poor timing of the purchase visit and limited flexibility on the date of sale, a confusing and/or inadequate premium, and mistrust since this was the first time such an offer was made. In year 2 we attempted to make selling to a study buying agent more attractive.

3.4 Year 2 interventions

Treatment status in year 2 was randomly assigned after stratifying by year 1 treatment status and village. The randomization was conducted so that no farmer received drying sheets in both years, or drying sheets in year 1 and the market premium in year 2. We provided

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[8] This premium was set through discussions with groundnut buyers, but was financed using research funds, as it was not possible to match the timing and volume of supply from study farmers to demand from existing premium markets.

drying sheets to 64 farmers in the year 1 control group and 59 in the year 1 information only treatment. These farmers, plus the 277 farmers assigned to receive sheets in year 1, comprise the year 2 drying sheet provision treatment group.[9] In year 2, we offered the market premium to 119 farmers who had also received this offer in year 1, 60 farmers from the year 1 information only treatment, and 63 farmers from the year 1 control group. 118 farmers from the year 1 information only treatment, 119 farmers from the year 1 price premium treatment, and 126 farmers from the year 1 control group were neither given a drying sheet nor offered a market premium in year 2 and comprise the year 2 information only treatment. In total, there were 363 farmers in the year 2 information only treatment, 400 in the year 2 drying sheet treatment, and 242 in the year 2 market premium treatment. Table 1 shows the number of farmers assigned to each treatment in each year of the intervention.

The research team provided farmers in the drying sheets (market premium) treatment group with sheets (the opportunity to sell at the premium price) through door-to-door visits approximately one month before harvest. In addition, they reminded all farmers about the best practices on which they had previously been trained. All farmers were offered an opportunity to purchase (additional) drying sheets one to two weeks after this household visit.

To make the premium price offer more attractive in year 2, farmers were able to call the buyer at any time after harvest. The buyer would make as many visits as needed to the village to purchase nuts when farmers wished to sell. Instead of a percentage premium we offered an additional 25 GHC per bag. This flat rate, equal to 25 percent of the median sales price during the peak harvest month, was designed to be easier for farmers to understand than the previous percentage premium and its level was set to be high enough to induce farmers to sell earlier rather than waiting for the price to increase.[10]

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[9] The woven plastic tarps distributed to farmers are rugged and have a multi-year life.

[10] Groundnuts can increase in price by 30 percent or more from after one harvest to the period preceding the next year's harvest (SPRING, 2017).

4 Data

4.1 Study area and sample

In Ghana, groundnuts provide income for farmers and are an important source of macro and micronutrients (Florkowski and Kolavalli, 2013). Over the past decade, Ghana has produced an average of 500,000 MT of groundnuts annually, making it the tenth largest producer worldwide (FAOSTAT, 2016). Eighty percent of Ghanaians consume groundnuts in some form at least once a week (Jolly et al., 2009). 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 Business News, 2013).

Our study takes place in two of the three regions in northern Ghana: Northern Region and Upper East Region. Over 80 percent of national groundnut production occurs in Northern Region (Tsigbey, Brandenburg, and Clottey, 2003), which accounts for the majority of land in northern Ghana and 30 percent of the country's total land area. Upper East is about one-eight the size of Northern Region.[11] Northern Ghana is dry, with a single rainy season. In Northern Region the rainy season lasts from April/May to September/October, and in Upper East it lasts from May/June to October. It is during this time that groundnuts, as well as most other crops, are cultivated.

The initial sample consists of 1,005 farmers selected from 20 villages in Northern Region and 20 villages in Upper East. In each region we selected the five districts (the geographic unit below the region) closest to our base of operation (Tamale in Northern Region and Navrongo in Upper East). Within each district, we selected four villages at random that satisfied three criteria. First, we only included villages where a large proportion of households grow groundnuts according to the Ministry of Agriculture. Second, we only selected villages with between 100 and 300 households so that they would be large enough to contain at least 25 groundnut producing households, but small enough to conduct a village census. Third,

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[11] The third region in northern Ghana is Upper West, which was not included in our sample due to security concerns.

we included only villages within two hours of a base of operation to limit costs.

4.2 Data collection

Fieldwork for this study took place from December 2014 to May 2017. A project timeline that includes groundnut cultivation, interventions, and data collection activities can be found in Figure 1.

In December 2014 (Northern Region) and January 2015 (Upper East) we conducted a baseline survey and collected groundnut samples from each household with any in store for aflatoxin testing. The year 1 interventions were conducted approximately two months before the groundnut harvest (July 2015 in Northern Region and August in Upper East). Immediately following the interventions, we began offering drying sheets for sale and recording these sales. Shortly after harvest (September 2015 in Northern Region and October in Upper East) we conducted a post-harvest observational survey. One year after the baseline survey, we conducted the year 1 follow-up survey and again collected groundnut samples for aflatoxin testing.

Year 2 interventions took place in August (Northern Region) and September (Upper East) 2016, and again we immediately began offering drying sheets for sale. There was no post-harvest observation in year 2, and only a brief endline survey conducted in May 2017 at the same time groundnuts were sampled for aflatoxin testing.[12]

4.2.1 Baseline survey

In each village, we randomly selected 25 groundnut farming households from a village census for inclusion in the study. Upon arriving at a selected household, enumerators asked to speak with the member who had harvested the most groundnuts in 2014 and still had some 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

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[12] The year 2 follow-up survey was shortened due to budget constraints, and was conducted much later than in year 1 due to funding delays.

household members had grown groundnuts and still had some in storage, a replacement household was selected from a randomly ordered backup list drawn from the village census. For backup households, the prioritization of which member to interview was the same, but the interview proceeded even if no member currently had any groundnuts stored. To encourage the baseline respondent to attend the information session described above, respondents were told that only this person would be eligible for a draw at the meeting through which free materials related to groundnut would be distributed.

The baseline survey contained questions on groundnut production, post-harvest practices, and marketing as well as demographics, asset ownership, and groundnut consumption. At the conclusion of each survey the enumerator asked to purchase a small sample of groundnuts for aflatoxin testing. When applicable, separate samples were taken for groundnuts intended for sale and groundnuts intended for home consumption. The enumerator took a sample representative of all groundnuts in storage intended for each use by randomly choosing bags and pulling groundnuts from multiple locations within each selected bag. Samples were then taken to the Opoku laboratory at University for Development Studies, ground using a laboratory-grade blender, and tested for aflatoxin using a fluorometric assay.[13] We surveyed 1,005 farmers at baseline and collected groundnut samples from 920 of them (the others no longer had groundnuts in store).

4.2.2 Post-harvest observation

Coinciding with the year 1 groundnut harvest, we conducted a short observational survey to directly observe drying and storage practices. Given that the various post-harvest activities of interest occur at different times, it was not possible to observe all practices for all households. Visits were unannounced and timed to maximize the probability of observing drying based on farmers' anticipated harvest dates. In addition to observing the surface on which nuts were being dried, the conditions under which they were stored, and the number

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[13] FluoroQuant reader and kits from Romer Labs, Union, MO.

of drying sheets in the household's possession, farmer-reported data on timing of harvest, length of time between uprooting and plucking, removal of visibly damaged or diseased nuts, and drying sheet purchase and possession were collected through a survey. If the farmer had not yet begun drying, the enumerator returned to the household for a second visit. Farmers assigned to any of the three treatment groups were reminded of best practices to prevent aflatoxin contamination during this visit, reinforcing messages from the training. The post-harvest observation was conducted for a total of 922 farmers. From these visits we have direct observations of drying sheet ownership or use for 900 farmers,[14] of drying practices for 267, and storage practices for 453. Other farmers had either not yet harvested or were no longer in possession of groundnuts.

4.2.3 Year 1 follow-up surveys and groundnut testing

One year after the baseline survey we conducted a follow-up survey containing many of the same questions about groundnut production, post-harvest practices, marketing, and consumption as the baseline survey. In addition, the survey contained questions about drying sheet purchase and use.

At the conclusion of the survey, enumerators attempted to purchase groundnuts at the market price (for the information only, drying sheet, and control groups) or at a premium price (for the price premium group). Very few farmers agreed to sell, and in this case enumerators instead purchased a small sample of groundnuts for aflatoxin testing. As at baseline, separate samples were taken for groundnuts intended for sale and home consumption when applicable. Because aflatoxin testing needed to be done at the point of sale, we used a mobile rapid testing procedure.[15] This method was validated by one of the authors prior to use in the present study, and also independently validated in several laboratories (PMIL,

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[14] For farmers whose drying practices were directly observed, this variable is defined as one if a drying sheet was being used. Farmers at other stages were asked to show any drying sheets they owned. This variable is missing for 22 farmers who were currently drying and claimed to be using a drying sheet, but whose drying practices could not be directly observed.

[15] Neogen test strips (Neogen, Lansing, MI) and Mobile Assay strip reader (Mobile Assay, Boulder, CO).

2015). We located 901 of the original 1,005 farmers for the year 1 follow-up survey and collected groundnut samples from 737 of them. The remaining 164 farmers no longer had groundnuts in their possession.

4.2.4 Year 2 follow-up survey and groundnut testing

Six months after the year 2 intervention we conducted a second follow-up survey with questions designed to understand farmers' expectations regarding the market premium treatment and their groundnut sales. This survey was far shorter than the previous follow-up survey, and took place several more months after harvest compared to year 1, due to funding constraints and delays. Enumerators collected groundnut samples at this time for aflatoxin testing, following the same protocol as before. Because data collection was done much later than in year 1, the vast majority of farmers no longer had groundnuts sorted out for multiple uses and a single sample was taken. We re-interviewed 928 of the original 1,005 farmers and collected groundnuts from 752 of them.

4.3 Baseline sample characteristics

Table 1 presents summary statistics for household demographic characteristics and groundnut production, post-harvest practices, and aflatoxin levels at baseline, and tests for balance across treatment arms. Column 1 contains full sample averages and columns 2 through 4 present the mean differences and standard errors between each of the year 1 treatments and the control group. Columns 5 and 6 show differences between year 2 treatment groups (sheet provision and price premium) and the year 2 information-only group.

Most households (84 percent) in the sample are male headed, but 32 percent of respondents—the primary groundnut producer in the household—are women. Only 21 percent of respondents have any formal education. On average respondents cultivate just under two acres of groundnuts, have approximately five tropical livestock units (TLU), and have been farming for 19 years.

At baseline, farmers generally do not report good groundnut post-harvest practices. Fifty-nine percent dry their groundnuts on the bare ground and only 1 percent use drying sheets. Only 16 percent hand sort their nuts before storing them, and 17 percent dispose of visibly bad nuts. Twenty-seven percent of the sample treat the storage area with pesticide and 44 percent store their groundnuts in new bags. On a more positive note, 81 percent report storing their groundnuts on raised pallets.

To test for balance between treatments we regress variable values at baseline on treatment status, first for year 1 treatments and then for year 2 treatments. As in the analysis below, we control for randomization strata (village dummies) and cluster standard errors at the village level to account for the sampling design. Of the 60 hypotheses tested for year 1 (20 variables times three treatments) we reject two (3.3 percent) at the 5 percent confidence level. For year 2, of the 40 hypotheses tested (20 variables times two treatments) we reject one (2.5 percent) at the 5 percent confidence level.In both cases the differences across groups is approximately what would be expected by chance.

4.4 Aflatoxin levels

Figure 2 shows the distributions of inverse hyperbolic sine transformed (IHST) aflatoxin levels in groundnut samples during the three rounds of data collection (baseline, year 1 follow-up, and year 2 follow-up) in each of the study regions. Levels are denoted on the x-axes with vertical lines at the EU and Ghanaian regulatory limits. We report values from all farmers at baseline, control farmers only at year 1 follow-up, and information only farmers at year 2 follow-up to avoid the inclusion of potential treatment effects.

Mean aflatoxin level for the entire study sample at baseline is 60 ppb, well above any regulatory standard. In the Northern region it is 100 ppb, and in the Upper East region it is 25 ppb. High mean aflatoxin levels are driven in a large part by long right tails in the distribution, indicative of infrequent but explosive outbreaks. The median level of aflatoxin for the entire sample is only 11 ppb, under the Ghanaian 15 ppb regulatory limit, and the difference in medians between regions is less pronounced: 14 ppb in Northern and 9.5 ppb in Upper East. Nevertheless, a substantial portion of sampled groundnuts are above the Ghanian limit in both regions: 46 percent in Northern and 22 percent in Upper east. Over 90 percent are above the European 4 ppb limit in both regions.

Aflatoxin levels can vary greatly from year to year. Baseline samples were taken from the 2014-2015 groundnut harvest, the year of the aforementioned reported trade ban imposed by the EU. In contrast, at year 1 follow-up aflatoxin levels are extremely low. Mean contamination is 2.8 ppb (3.7 ppb in Northern and 2.1 in Upper East). Less than 3 percent of samples are above 15 ppb (4.2 percent in Northern and 1.9 percent in Upper East) and less than 7 percent are above the European limit (10 percent in Northern and 5.7 percent in Upper East). Other research teams found similarly low aflatoxin levels in groundnuts throughout northern Ghana in 2016.[16] Given such low aflatoxin levels, it would be difficult to further reduce these through the study interventions.

To potentially observe intervention effects on aflatoxin levels we extended the study another year. In year 2 aflatoxin levels are higher than in year 1 but not nearly as high as at baseline. Mean contamination is 3.5 ppb (5.5 in Northern and 1.6 in Upper East). Six percent (7 percent) of samples are above 15 ppb (4 ppb), and these are nearly all of these are from the Northern Region. In fact, mean aflatoxin levels in Upper East are lower at year 2 follow-up than year 1 follow-up.

In all three years of groundnut samples, aflatoxin levels are higher in the Northern Region than Upper East.[17] For this reason we test for treatment effects on aflatoxin by region in the section to follow, as well as for the full sample.

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

[17] At baseline and year 2 follow-up these differences are significant at $p < 0.05$. At year 1 follow-up the difference is not significant ($p=0.12$).

4.5 Attrition and missing data

Table 2 contains attrition rates for different outcome data. The overall rate of attrition is 10.3 percent for the first follow-up survey, 8.3 percent for the post-harvest observation, and 7.7 percent for the year 2 follow-up survey. In none of these cases is attrition different between treatment groups with probability $p<0.05$. The largest difference across groups is for the year 1 follow-up survey: attrition for this survey is 3.9 percent lower in the drying sheets group than in the control group ($p=0.08$).

However, the proportion of households with missing aflatoxin data differs significantly across treatment groups. In both years, more households assigned to receive drying sheets still had groundnuts in store by the time samples were collected. In year 1, these households were 9 percentage points more likely to have nuts in store than those in the control group ($p=0.02$); in year 2, this gap was 7.5 percentage points ($p=0.02$). We interpret this difference as a treatment effect of drying sheet provision on post-harvest losses. A recent study in Malawi recorded a 13.7 percent loss in weight between harvest and storage (Tsusaka et al., 2017). Several causes of loss described in that study, including theft, rodent attack, and spillage, could have been mitigated by the use of drying sheets to transport the nuts and gather them up between and after drying intervals. Reduced exposure to soil and pests during the drying process may also have reduced losses during storage.

Given this evidence of differential availability of groundnut samples across treatment groups, we present Lee (2009) bounds for the treatment effect of drying sheet provision on aflatoxin contamination in subsection 5.4 below.[18].

We also test for differential determinants of attrition and missing data across treatments by regressing a binary variable indicating that an observation is missing on the baseline characteristics summarized in Table 1, and the interactions of these variables with each of

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[18] We calculate confidence intervals on bounds to account for the variance of the trimmed distribution, the variance of the trimming threshold, and the variance of how much of the distribution to trim using the method of Imbens and Manski (2004) as described in Lee (2009)

the treatment indicators.[19] Results are reported in Appendix Table C1. Of 234 hypotheses tested, we reject only nine at the 5 percent confidence level, and there is no clear pattern of systematic attrition by baseline characteristics.

5 Results

We begin by testing the impact of our intervention on purchase and ownership of plastic drying sheets. Using drying sheets to dry groundnuts was a focal point of the information intervention. The promoted sheets are an inexpensive and easy-to-use technology that we found to be effective at reducing aflatoxin levels in a pre-study pilot (Kanyam, 2016). While these drying sheets were available in the regional capital, they were only readily available in study villages through the research team.

We next test the impact of our interventions on post-harvest practices, both observed during the post-harvest observational survey, and reported by farmers in the year 1 follow-up survey. In section 2 we described a number of practices farmers can adopt after harvest to reduce aflatoxin risk. We test for impacts on 12 specific practices divided into four categories:

1. *Harvest practices*: Days until plucking harvested nuts from vines (bad), leaving harvested nuts in heap before plucking (bad)
2. *Drying practices*: Drying on dirt (bad), drying on sheets (good), drying on concrete (better than dirt, not as good as drying sheets), drying for at least seven sunny days (good)
3. *Sorting practices*: Sorting before storage, sorting before consuming, and disposing of the worst nuts (all good)
4. *Storage practices*: Treating the storage area with pesticide, using new bags to store groundnuts, storing groundnuts on raised pallets (all good)

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[19] To avoid collinearity, only one drying practice (drying on dirt) is included among the regressors.

In addition to testing individual practices, we test for effects on sets of practices — harvest, drying, sorting, storage, and overall practices —using normalized inverse-covariance weighted summary indices as described by Anderson (2008). These indices assign the most weight to practices that are more variable within the sample. Positive outcomes (such as drying on sheets) enter positively into an index whereas negative outcomes (such as drying on dirt) enter negatively. Using summary indices has several advantages. First, they allow us to test for overall effects on sets of related outcomes. Second, they reduce dimensionality because adding an individual practice to an index does not increase the number of hypotheses tested. Third, they can potentially increase power by aggregating several outcomes that may be small and on the margins of significance to a single outcome that is significantly impacted.

Finally, we test for impacts of aflatoxin contamination in groundnut samples collected from study farmers. Because of the long right tails common in aflatoxin distributions, we do this for both aflatoxin levels and IHST values. We also test for impacts on the probability of being above the Ghanaian (15 ppb) or European (4 ppb) regulatory limit using linear probability models.

For outcomes at year 1 we estimate the following:

$$y_{ij}^{F1} = \beta_I Info_{ij} + \beta_S Sheets_{ij} + \beta_M Prem_{ij} + \beta_1 y_{ij}^B + \beta_2 missing_{ij}^B + (X_i' \beta_x) + \theta_j + \varepsilon_{ij} \quad (1)$$

In equation 1, y^{F1} is the outcome at year 1 follow-up, $Info$, $Sheets$, and $Prem$ are the information only, drying sheet provision, and market premium treatments, respectively, y^B is the outcome at baseline, and $missing^B$ is a dummy variable for a missing baseline value. We control for village dummies θ, the treatment stratification variable.[20] ε_{ij} is an individual error

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[20] Whether a farmer was assigned any treatment or placed in the control group was determined by stratifying on village and baseline aflatoxin level as described in Appendix A. Baseline aflatoxin is uncorrelated with practices, and including this as an additional control affects neither the point estimates nor significance of our results. Further, this stratification is only relevant to the comparison of the year 1 control versus information treatments, as randomization among the three treatment groups was conducted through an unstratified draw. We do not include this variable as a stratification control due to concerns about stratification on irrelevant variables (Bruhn and McKenzie, 2009), but do allow the PDS LASSO machine learning method to select it (it does not).

term. We use the post-double-selection (PDS) LASSO machine learning method (Belloni, Chernozhukov, and Hansen, 2014) to select control variables to improve precision using the Stata command "pdslasso" (Ahrens, Hansen, and Schaffer, 2018). The vector X contains candidate control variables and consists of the normalized variables in table 1, the normalized variables used to test for heterogeneity detailed in section 6, their normalized squares, and missing variable dummies as suggested by Duflo (2018). The parentheses in equation 1 signify that inclusion of these variable depends on the selection made by the PDS LASSO algorithm.

For outcomes at year 2 we estimate the following:

$$y_{ij}^{F2} = \beta_S Sheets2_{ij} + \beta_M Prem2_{ij} + \beta_1 y_{ij}^B + \beta_2 missing_{ij}^B + (X_i' \beta_x) + \theta_j + \varepsilon_{ij} \tag{2}$$

In equation 2, y^{F2} is the outcome at year 2 follow-up, $Sheets$ and $Prem$ are the year 2 drying sheet provision and market premium treatments, respectively. Recall that after the year 1 follow-up survey, control farmers received the information treatment. The variables y^B and $missing^B$ are as above. We again control for village dummies θ and use the PDS LASSO method to select other controls from X. For both years results obtained using ANCOVA with y^B and $missing^B$ as the only controls are very similar although less precise, and are shown in Appendix Appendix D.

5.1 Drying sheet purchases

One objective of this study is to test whether training or market rewards induce farmers to invest in a new technology (drying sheets). To accomplish this, we offered to sell farmers drying sheets. We offered these at the same price as they were available in the Tamale, regional capital.

Table 3 shows treatment effects on sheet acquisition and ownership. In year 1, 14 percent of farmers in the information group purchased drying sheets through the project according to sales records(control group farmers were not given an opportunity to do so through the study). However, 8 percent of farmers assigned to the control group reported buying at least one drying sheet. While farmers were not asked about the source of purchased drying sheets, none reported buying the blue sheets distributed for free though the study. Most (84 percent) of farmers who bought drying sheets reported they had purchased the black type available for sale in Tamale as well as through the study. This suggests that any spillover effects on drying sheet ownership among the control group occurred through the information treatment and potentially the opportunity to purchase drying sheets locally, rather than the distribution of drying sheets for free.[21]

The information treatment increases the probability that a farmer reports purchasing at least one drying sheet by 10 percentage points (column 2). Receiving sheets for free or being offered a market premium had no further effect on the probability of purchase, although the point estimate is negative for the former and positive for the latter. The probability of observing drying sheets at farmers' compounds in the information treatment group is 6.8 percentage points higher than in the control group, and the probability in the drying sheet provision group is 62 percentage points higher than in the information treatment group. The market premium treatment has no effect on observed sheet ownership.

In year 2 farmers had another opportunity to purchase drying sheets through the study. Six percent of farmers purchased at least one, but there is no discernible difference in this outcome between treatment groups (point estimates of treatment dummies on any purchase are negative; results not shown). It appears that by year two, almost all of the farmers motivated to purchase a drying sheet had already done so.

5.2 Post-harvest practices

Table 4 shows estimated treatment effects on indices for harvesting (column 1), drying (column 2), sorting (column 3), and storage (column 4) practices; column 5 shows treatment

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[21] Spillovers are further discussed in Section 5.5 below.

effects on the index of good practices overall. Tables 5 and 6 detail impacts on the specific practices of which the indices in Table 4 are constructed.

All three treatments improve post-harvest practices overall. Looking at the four practice subsets, we see no impact of any of the interventions on harvesting practices, which were quite good among the control group leaving little room for improvement: only 13 percent of farmers left their harvested nuts in a pile prior to plucking, and the average number of days between harvest and plucking was 2.3. Drying practices are greatly improved by both free distribution of drying sheets and by the offer of a food safety premium, but information alone has no impact on this group of practices. The key practice in this category, drying groundnuts on a plastic sheet, requires a cash outlay. Farmers who were neither given drying sheets nor motivated by the promise of a premium price may not have seen this as a worthwhile expense. In contrast, farmers assigned to the information only group did improve sorting practices relative to control farmers. Sorting nuts is typically done by household members and involves no cash expense. Neither free drying sheets nor the market premium have any marginal impact on sorting practices, but providing drying sheets does improve storage practices. This suggests that once they have improved the quality of their groundnuts through good drying practices, farmers are motivated to maintain this quality during storage.

Turning to the impacts on specific harvesting and drying practices (table 5) , we see that giving farmers free drying sheets unsurprisingly shifts drying from the ground to these sheets. Farmers in the information only treatment are also more likely to report, and to be observed, drying their groundnuts on sheets. The offer of a premium price has no marginal impact on reported or observed drying sheet use, but does increase the number of days over which groundnuts were dried. Combining the effects of the information and market premium interventions, the impact on average drying time is less than half a day.

Impacts on individual sorting and storage practices, shown in Table 6, exhibit differences between treatments that is masked in the indices presented in Table 4. Sorting before storage, which prevents the spread of aflatoxin in a farmer's groundnut stock, is strongly affected by the information treatment, but giving out free drying sheets or offering a market premium has no additional effect. Information and the provision of drying sheets together nearly double the probability that farmers dispose of their worst nuts, though neither intervention on its own has a significant impact on this outcome.

Similar to recommended drying practices, several of the recommended storage practices require capital inputs, albeit modest ones. Information alone has no effect on the probability of treating the storage area with pesticides or using new storage containers, but does increase reported storage of groundnuts off the ground, which can be achieved using materials already owned by farmers. We see no impact on the observational variable for this outcome, and attribute the discrepancy to the more specific criterion (storage on a platform) used in the post-harvest observation instrument.

Provision of free drying sheets increases the likelihood that farmers report treating their groundnut storage area with pesticides, suggesting crowding in of investment rather than crowding out; the farmer has used a drying sheet to produce better nuts and wants to maintain that quality through better storage practices. The market premium treatment also increases pesticide use significantly. Neither provision of drying sheets nor the market premium treatment have any additional impact on the likelihood of storing groundnuts off the ground beyond that of information alone.

5.3 Aflatoxin levels

Overall, aflatoxin contamination levels in the study area were very low in year 1, presumably 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 in Ghana, and only 4.6 percent of samples were above 15 ppb. Given the low overall level of contamination, there was little room for improvement through better practices, and between-group differences in aflatoxin levels are difficult to detect. Table 7 contains estimates of treatment effects on aflatoxin, IHST aflatoxin, probability of exceeding the Ghanaian regulatory limit of 15 ppb, and probability of exceeding the EU limit of 4 ppb. Results show that the experimental interventions had no effect on aflatoxin levels in the first year of the intervention, despite improving post-harvest practices. In fact, we observe slightly higher aflatoxin levels among farmers assigned to receive drying sheets, relative to those in the control group ($p<0.1$). This difference likely due to attrition, which we discuss below.

In year 2 aflatoxin levels were higher in Northern Region, but even lower than year 1 levels in Upper East. Estimates shown in Table 9 for the overall sample indicate that both provision of drying sheets, and the offer of a price incentive, led to marginally significant ($p<0.1$) reductions in the probably of exceeding the EU limit, and in the case of drying sheets, also reduced the probability of exceeding the Ghanaian standard.

When we look at results for Northern Region, where the mean level of contamination was 5.5 ppb, we see stronger effects in terms of magnitude for both interventions, and for the drying sheets intervention, statistical significance. Provision of drying sheets reduces contamination by 2.8 ppb compared to information alone, and the point estimate for the market premium treatment is a reduction of 2.5 ppb ($p=0.12$). When we use the IHST of aflatoxin contamination to account for the right skewed distribution of this outcome, we observe a 25 percent decrease in aflatoxin for the drying sheet treatment ($p<0.1$) and a 26 percent decrease for the market premium treatment ($p=0.104$). Considering the allowable aflatoxin thresholds under various jurisdictions, we find that provision of drying sheets reduces the probability of exceeding the Ghanaian limit by 7 percentage points and the EU limit by 6 percentage points ($p<0.1$). Point estimates of the effect of the market incentive treatment are similar but not significantly different from zero ($p=0.146$ and $p = 0.131$). In Upper East neither treatment has any effect on aflatoxin contamination, however measured.

5.4 Lee bounds

Due to the differential availability of groundnut samples described in subsection 4.5 above, we estimate Lee (2009) bounds for the 90 and 95 percent confidence intervals of the effect of drying sheet provision (table 10). The true effect of drying sheet distribution is likely to be stronger than the estimates reported in Table 9 suggest, for the following reason. If the negative association between drying sheet provision and availability of groundnuts for sampling reflects a treatment effect on post-harvest losses, this implies that nuts which would have been lost to observation in the control group remained in the stores of farmers who were given drying sheets. Post-harvest losses may be purely physical, as in the case of spillage or theft between harvest and storage, or may include elements of both physical loss and quality degradation. One one hand, if sample availability was affected only through physical losses, the relative quality of the missing nuts in the control group and the available nuts in the treatment group could be considered equivalent, implying no attrition bias. On the other hand, if the physical losses experienced by farmers in the control group were accompanied by quality degradation, as would be the case if these nuts had been consumed by insects during storage, it seems reasonable to expect that had the quality of the missing nuts been observable, it would have been worse than the quality of those which could be observed, leading our estimates of drying sheet provision to be biased toward zero. The bounds provide an estimate of how much larger the true estimates may be than the point estimates presented above. Further, they allow us to see whether, in the less likely event that attrition biases our results away from zero, the results still hold.

For year 1, the bounds span (and are approximately centered on) zero, indicating that provision of drying sheets had no impact on aflatoxin levels, and that the positive point estimates in Table 7 are likely driven by attrition. For year 2, the estimated lower bounds of the 90 percent confidence interval show that this intervention may have reduced aflatoxin by as much as 34 percent overall, and by 74 percent in Northern region, based on the IHST aflatoxin estimates.

The upper bound estimates shown in Table 10 confirm that the effects of drying sheet provision in year 2 are generally robust to potential attrition bias away from zero. The upper bound of the estimate for ppb aflatoxin in the Northern region is below zero at the 5 percent confidence level, and the estimates for IHST aflatoxin in the Northern region is below zero at the 10 percent confidence level. The upper bound of the estimated effect of the intervention exceeding the Ghanaian and EU limits is below zero at the 10 percent confidence level for the entire sample, and at the 5 percent confidence level for the Northern region.

5.5 Spillovers

Given our within-village experimental variations, several types of spillovers may affect our results. First, information about aflatoxin and good post-harvest practices could have been communicated by treatment group study participants to those assigned to the control group. Second, the drying sheets distributed to those assigned to receive them could have been given, sold, or lent to participants assigned to other treatment arms. Finally, it is possible that participants in the premium price arm could have sold groundnuts on behalf of study participants not assigned to this treatment.

In Table 11 we examine changes in practices reported by farmers in the control group between baseline and year 1 follow-up (column 1), comparing them to changes in the treatment groups (columns 2-4). We observe a 3.6 percentage point reported increase in drying sheet use among those in the control group, though based on observational data, the difference is less than 1 percentage point. A much larger impact, in both the reported and observed data, is observed for practices that do not require the use of additional materials. The proportion of control group farmers who dry their groundnuts directly on the soil (as opposed to on a concrete surface, roof, or drying sheet) falls from 60 percent (reported) at baseline to 28 percent (reported) and 20 percent (observed) at follow-up. The change over time in this variable is similar across treatments. The proportion of farmers in the control group who report hand-sorting their groundnuts approximately doubles between the baseline and year 1 follow-up surveys; the increase in other treatment groups is closer to a threefold increase from baseline. Behaviors that entail a non-effort cost, including disposal of the worst nuts, application of insecticide to the storage area, use of new containers, and storage on pallets do not increase over time among control group farmers whereas they do increase for treatment farmers; in fact the use of pallets appears to decrease in the control group.

Observational data collected during the post-harvest visit shows that on average, farmers in the sheets distribution group were able to show 70 percent of the sheets they had been given, and 61 percent had at least as many as the number they had been given, suggesting some leakage of study materials. However, the extent to which this leakage affected access to drying sheets among participants in the other treatment groups is low. Only 2 percent of study farmers who had not been assigned to receive drying sheets had at least one blue sheet of the type distributed in their possession.

Almost all farmers who sold groundnuts through the study in year 1 did so at the time of the follow-up survey, making it difficult for farmers assigned to other treatments to sell through them. The fact that the rate of sale was similar across groups in year 1 suggests an absence of spillovers in access to the premium price offer. In year 2 farmers in the premium group were reminded of the opportunity to sell at a higher price and provided with the buying agent's contact information both prior to and after the follow-up survey. This effort appeared to increase sales, but also led to significant spillovers in take-up of the premium offer. While administrative records show that some purchases from farmers outside of the premium treatment occurred, these amounted to only 4 percent of the total. But many more farmers in the information only and drying sheets group claimed to have sold nuts at a premium price during the year 2 follow-up survey, and over 62 percent of these farmers provided the correct answer to a question about the value of the premium, a share similar to those in the premium treatment group. This suggests that word about the premium spread across treatment groups, and that a significant number of farmers outside the premium group were able to sell their groundnuts through others who had been assigned to this treatment.

This was suspected by field staff, who reported that the same farmers sometimes called the buying agent repeatedly to sell more nuts a few days after their initial sale. Despite this, farmers in the price premium group were at least one third more likely to report having called the premium buyer and more than twice as likely to report selling their nuts through this channel as others (table 8, columns 2 and 3). As we only have data on knowledge or farmer perceptions about access to the premium price offer in year 2, we cannot rule out that such spillovers also occurred in year 1. We therefore interpret observed impacts of the price premium treatment as the effects of encouraging farmers to sell through a premium market channel, in the context of its existence and widespread knowledge about it.

6 Heterogenous treatment effects

6.1 Potential dimensions of heterogeneous impact

Understanding heterogenous treatment effects can help us understand for whom or where an intervention is effective so that practitioners can focus intervention effort on those most affected, or modify the intervention to reach those who are less affected. It can also help shed light on the mechanisms through which an intervention works, and barriers to its effectiveness. We test for heterogenous treatment effects using machine learning techniques developed by Chernozhukov et al. (2018). These techniques, which we discuss in greater detail in the following subsection, allow us to test for heterogeneity along many dimensions while avoiding concerns typically associated with multiple hypothesis testing. With this in mind we test for heterogenous treatment effects on two key outcomes: the best practice index in year 1 and aflatoxin levels in year 2. For covariates, consider a host of covariates we believe might be correlated with treatment effects, including these outcomes at baseline.

Testing for heterogeneity by outcomes at baseline allows us to see if improvements in practices were concentrated among those with the most room for improvement or among those doing relatively well. If it is the case that the interventions mostly improve post-harvest practices among those who already have generally good practices, the impact on aflatoxin levels may be low because those most at risk are not affected. Similarly, we look at aflatoxin levels at baseline to see if improvements are concentrated among those who experienced relatively high levels of aflatoxin at baseline, or among those who had lower levels to begin with.

There are both health and income benefits to adopting good post-harvest practices, and impact heterogeneity could help understand which of these considerations most influence farmer behavior regarding aflatoxin management. Health risks associated with aflatoxin described during the information sessions included cancer, liver disease, and possible impacts on child growth. We therefore look at how many small children (ages 0-4) are in the household as a dimension of potential heterogeneity. We also include farmer gender, as there is some evidence that women place a higher priority on health and nutrition than men (Meinzen-Dick et al., 2012). Furthermore, we consider baseline household groundnut consumption per capita over the 2-3 months following the harvest, as the vast majority of such consumption is from the farmer's own production. If health concerns drive intervention effects, we would expect these to be stronger in households that consume more groundnuts.

Gender could also affect impact through channels unrelated to concerns about health. For instance, even if sheets are given to a female farmer it is possible they would be used by a male in her household (although we see no evidence of this in the data). It is also possible that differences in market access for men and women could lead to gender-specific effects of the market premium treatment. We test for heterogeneity by whether or not the farmer has any formal education (which 21 percent of the sample does). More educated farmers might better understand and appreciate the dangers posed by aflatoxin, or better understand why and how to implement best practices. We also include years of farming experience, which is closely related to age, as a potential dimension of heterogeneity. The association between experience (or age) could run either way. On one hand, more experienced farmers may be set in their ways and less willing to try a new practice. On the other hand, more experienced farmers may be better equipped to adopt a new practice because they have a better understanding of how to apply it.

There are several reasons why farm size and groundnut production at baseline may be important dimensions of heterogeneity. Farmers with low production capacity may not be in a position to sell groundnuts after meeting household consumption needs, and therefore may not be swayed by the opportunity to sell higher quality groundnuts at a premium price. On the contrary, if farmers view the main benefit of adopting best practices to be health related and the costs of adoption are increasing in scale, those with greater production may be less inclined to adopt. Furthermore, while we did our best to allocate an adequate number of drying sheets to farmers in the free provision treatment, distribution was capped at six (enough for approximately six bags). In year 1, 30 percent of farmers produced more than six bags, and 8 percent of farmers produced more than 12 bags. If farmers were only able to dry some of their groundnut production on sheets, the effect of this intervention could be muted for larger farmers. We also consider several covariates related to marketing. First, we consider a binary variable for whether a farmer sold any groundnuts at baseline and the quantity sold because farmers who already sell groundnuts are more likely to be impacted by the offer of a market premium, and the potential impact of this offer is increasing in quantity sold.

Finally, we test for heterogeneity by region. As shown in the previous section, treatment effects on aflatoxin levels in year 2 were much stronger in Northern Region than in Upper East, presumably because in Upper East background levels were too low to allow for improvement. Regional heterogeneity in treatment effects on best practice adoption could also exist, as the two regions are distinct in several important ways (slightly different growing seasons, different religions, different household compound structures, and different market access).

6.2 Machine learning approach

Recent developments in machine learning (Athey and Imbens, 2016; Chernozhukov et al., 2018; Wager and Athey, 2018) allow for the analysis of heterogenous treatment effects along many dimensions while avoiding problems typically associated with *ex post* sample splitting (e.g., overfitting and multiple hypothesis testing). *Ex ante* selection of a limited number of variables on which to test for heterogenous impacts mitigates these problems, but can also severely limit the scope of analysis. The method of Chernozhukov et al. (2018) is appealing because it divides the sample into those most and least affected based on the correlation of treatment impact with a potentially large set of variables, and then tests for differences in these variables between the most and least affected groups. This stands in contrast to estimating conditional average treatment effects (CATEs) themselves (e.g., the average treatment effect for women farmers without a formal education in Northern Region). Instead, this method estimates and makes statistical inference on three features of CATEs using proxy predictors: (1) the best linear predictor (BLP) of conditional average treatment effects (CATEs), (2) the average treatment effects by impact group (group average treatment effects, or GATEs), and (3) the average characteristics of the most and least impacted (classification analysis, or CLAN). The approach is generic in that it can be used with a wide variety of machine learning methods. Below is a very brief explanation of how the method is used to estimate the above features followed by specifics of our application.

Linear Predictor: An outcome that is potentially a function of covariates and a treatment effect conditional on covariates can be written as:

$$Y = b_0(Z) + Ds_0(Z) + U, E[U|Z, D] = 0 \tag{3}$$

where Z is a vector of covariates, D a treatment indicator, and U is an error term. In 3, $b_0(Z)$ is the conditional average outcome in the absence of treatment and $s_0(Z)$ is the CATE. The Chernozhukov et al. (2018) approach randomly divides the data into a main and auxiliary sample and then uses any number of machine learning techniques on the auxiliary sample to estimate "proxy predictors" of $b_0(Z)$ and $s_0(Z)$ denoted as $B(Z)$ and $S(Z)$. These proxy predictors are then used to estimate the coefficients of the BLP with data from the main sample using linear regression:

$$Y = \alpha' X_1 + \beta_1(D - p(Z)) + \beta_2(D - p(Z))(S(Z) - \mathrm{E}S) + \varepsilon \tag{4}$$

where X_1 contains a vector of ones, $B(Z)$, and variables meant to improve precision (village indicators in our case). $p(Z)$ is the probability of treatment conditional on covariates. From 4, the average treatment effect (ATE) is estimated as $\hat{\beta_1}$ and a heterogeneity predictor loading parameter is estimated as $\hat{\beta_2}$. This heterogeneity loading parameter indicates how well the covariates in Z determine heterogenous treatment effects. $\hat{\beta}_2 = 1$ indicates perfect prediction of CATEs by the proxy predictor $S(Z)$ and $\hat{\beta}_2 = 0$ indicates no heterogeneity based on the covariates in Z.

Average Treatment Effects: The method then uses the covariates in Z to create groups ordered by predicated treatment effect magnitude $S(Z)$ to explain as much variation in CATEs as possible. The user sets the number of ordered groups K and estimates:

$$Y = \alpha' X_1 + \sum_{k=1}^{K} \gamma_k (D - p(Z)) G_k + \varepsilon \tag{5}$$

where G_k is a dummy variable for membership in group k. The most and least impacted groups are compared so that a rejection of $\hat{\gamma}_K - \hat{\gamma}_1 = 0$ indicates significantly different CATEs for the most and least affected groups.

Analysis: We are interested in the differences in the variables comprising Z between those most and least affected by the treatment. We can define $\delta_1 = \mathrm{E}[Z|G_1]$ as the average value of a particular covariate for the least affected group and $\delta_K = \mathrm{E}[Z|G_K]$ as the average value of that covariate for the most affected group. Rejecting $\hat{\delta}_K - \hat{\delta}_1 = 0$ for a covariate in Z means there is difference in that dimension between the most and least affected groups.

The Chernozhukov et al. (2018) method conducts the above estimation procedure over many iterations, each with a different random split of the data into main and auxiliary samples. The reported estimates are the medians over all of these iterations. With regards to statistical inference, the reported confidence intervals consist of the median lower and upper bounds, and reported p-values are calculated as the α at which half of all realized p-values are smaller than $\alpha/2$. This accounts for uncertainty in both estimation and random partitioning of the data.

The method allows for flexibility in its application in several ways. First is the choice of ML methods. Given our small sample size, the number of covariates we include in Z is relatively large. We therefore use two penalized methods—ridge regression and least absolute shrinkage and selection operator (LASSO)—using the R package "caret" with default tuning parameters. Ridge regression generally performs better for predicting both the BLP and GATEs (Appendix Table E1), so we present these results. For GATEs and CLAN, we set $K = 2$ to keep subgroups as large as possible.[22] For each estimation we use 100 different splits of the data. Similarly to the analysis presented in 5, we include village fixed effects and cluster standard errors at the village level.

We conduct our analysis for two outcomes: the overall good practice index for year 1 and aflatoxin levels in PPB for year 2. Because we have multiple treatments we separately apply the method for each treatment using the appropriate subsample. For year 1 we estimate:

$$y_{ij}^{F1} = \beta_T T_{ij} + Z'\beta_Z + \theta_j + \epsilon_{ij} \tag{6}$$

separately for $T = (Info, Sheets, Prem)$ and exclude observations in the other two treatment groups from the subsample. Thus, $\hat{\beta}_{Sheet}$ and $\hat{\beta}_{Prem}$ are estimated effects of the treatments inclusive of information, not the effects conditional on information. In equation 6, Z is the vector of covariates (including y_{ij}^{B}) on which we test for heterogeneity, and θ_j are

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[22] Using terciles yields nearly identical GATEs.

village dummies. For year 2 we estimate

$$y_{ij}^{F2} = \beta_T T_{ij} + Z'\beta_Z + \theta_j + \epsilon_{ij} \tag{7}$$

where $T = (Sheets2, Prem2)$. For each regression we exclude the other treatment group from the subsample. Recall that in year 2 all farmers had information so these effects are conditional on information rather than inclusive of information.

6.3 Heterogeneity results and discussion

Our tests for overall heterogeneity using both BLP and GATEs (Appendix Table E2) show no evidence that the covariates in Z describe heterogeneity in the impacts of the any of the three treatments on farmer practices in year 1. All six hypotheses tested ($\beta_2 = 0$ and $\delta_2 - \delta_1 = 0$ for each of three treatments) yield p-values of over 0.87. We also find no evidence of heterogenous effects of the market premium treatment on aflatoxin in year 2, with a p-value of 0.82 for $\beta_2 = 0$ and a p-value of 0.64 for $\gamma_K - \gamma_1 = 0$. We do find some evidence of heterogenous impacts of the drying sheet intervention on aflatoxin levels in year 2, rejecting both $\beta_2 = 0$ (p=0.097) and $\gamma_K - \gamma_1 = 0$ (p=0.078) at the 0.1 confidence level. We therefore focus our analysis on heterogeneity of this effect. We refer to CLAN results farmer regarding practices in year 1 for supporting evidence, and include the full results in Appendix tables E3 and E4. It is important to keep in mind that while CLAN shows significant differences in some dimensions of Z between those most affected by year 1 treatments and the price premium treatment in year 2, the GATEs themselves are not statistically significant.

GATEs show that the half of farmers most affected by the receiving drying sheets experienced an average reduction in aflatoxin of 7.8 ppb, whereas the least affected experienced an non-significant increase of 1.4 ppb (p=0.92). Our CLAN results for these impacts can be found in Table 12, columns 1-3. CLAN is descriptive in that it compares average levels of the covariates in Z between most and least affected. As with traditional heterogeneity analysis, it is not possible to determine which covariates cause heterogeneity. For example, CLAN could show that farmers most affected by the the intervention are more likely to be male, have more acreage in groundnuts, and are more likely to sell groundnuts. If these variables are correlated with each other, as is the case, we cannot say which of them drive heterogeneity. To parse out the mechanisms through which heterogeneity may arise, we conduct CLAN within categories of Z that are both strongly associated with heterogenous treatment effects and correlated with other variables in Z. Specifically, we conduct CLAN using only Northern (columns 4-6) and male (columns 7-9) farmers, and focus our discussion on the dimensions of heterogeneity that hold within these categories. Nevertheless, causal claims about which variables drive heterogenous effects involve some speculation and should be interpreted accordingly.

We find that farmers most affected by receiving drying sheets had significantly higher levels of aflatoxin at baseline than those least affected. This is encouraging, if unsurprising, as these farmers had the most room for improvement. There is no statistically significant difference in impact based on post-harvest practices at baseline (p=0.22), although the point estimate indicates the practices of those most impacted by the intervention were worse. CLAN results for the impact of year 1 treatments on best practices also show that those most impacted by all three treatments had higher levels of aflatoxin at baseline, although again the differences are not statistically significant (Appendix Table E3).

Farmers most impacted by the drying sheet intervention have more children under five and larger households overall. They also consume 50 percent more groundnuts per capita. These dimensions of heterogeneity could be due to the importance and/or salience of health benefits from aflatoxin reduction, or could simply reflect correlation among household size and composition, groundnut consumption, and other covariates associated with heterogenous impact. We note that the CLAN results for farmer practices in year 1 do not align with these dimensions of heterogeneity. Regardless of causality, this finding indicates that the intervention disproportionately affected those most vulnerable to the health risks associated with aflatoxin.

Households most affected by the drying sheet treatment had 80 percent more acres in groundnut at baseline, produced 70 percent more groundnuts, and sold 175 percent more groundnuts. This shows that the intervention disproportionally affected those who have the greatest impact on the safety of the marketed food supply, as well as those consuming more of their own groundnuts. CLAN results for farmer practices in year 1 show a similar pattern. Those most impacted by the interventions had more acreage in groundnut and higher production. For the information only treatment we see no difference between those most and least impacted in terms of quantity sold, but we do see at least a marginally significant difference on this variable for the other two treatments.

As expected, those most impacted by the drying sheet intervention are much more likely to be in Northern Region than in Upper East. Of farmers most affected, 66 percent are in Northern Region, whereas of farmers least affected, only 31 percent are. Because of this strong regional heterogeneity, it is not evident that other dimensions of heterogeneity we detect are a result of regional differences in other covariates or unobserved regional effects. To verify that heterogeneity on other covariates exists when regional effects are accounted for we conduct the same analysis using only the Northern Region subsample. Because the dataset is smaller we expect much less precise prediction. We cannot reject that $\beta_2 = 0$ (p=0.50) or that $\delta_2 - \delta_1 = 0$ (p=0.37) (Appendix Table E2, second panel), but we still see differences along many of the same variables in the CLAN results (table 12, columns 4-6). Farmers within Northern Region most affected by the intervention had higher levels of aflatoxin at baseline (110 PPB) than those less impacted (28.4 PPB), have more children under five and larger households overall, and are more likely to be male (91 percent) than the least impacted farmers (52 percent). Acreage, production, quantity sold, and quantity consumed are not significantly different between the most and least affected farmers when looking at only the Northern Region, although point estimates have the same direction as in the full sample. From this we conclude that the heterogeneity along dimensions of family structure is not driven by regional differences. Heterogeneity driven by farm characteristics does, however, appear to be largely driven by regional differences, possibly based on variation in soil ecology or climate.

Strikingly, in a sample consisting of 32 percent female farmers, only 14 percent of the most affected group are female compared to 50 percent of the least affected group. We do not believe, however, that drying sheets were diverted away from female farmers to males in their families or communities. Regressing drying sheet use (both reported and observed) onto gender for farmers in the drying sheet treatment group yields coefficients very close to zero.[23] Furthermore, CLAN results for all year 1 treatments on farmer practices show absolutely no gender difference between those most and least affected. Gender is correlated with many other variables that describe heterogeneity (including as acreage in groundnut, groundnut produced, groundnut sold, and region) and thus may not play a role beyond the relationship between gender and these other covariates. One way to informally test this is to examine CLAN results for male farmers only and check if the same heterogeneity exists along these dimensions. Again, because of the smaller sample size, precision is lower for this sub-sample analysis. We cannot reject that $\beta_2 = 0$ (p=0.28) or that $\delta_2 - \delta_1 = 0$ (p=0.23) (Appendix Table E2, second panel). Nevertheless the CLAN results (table 12, columns 7-9) are informative as they are are strikingly similar to those for the full sample. This indicates that variables correlated with gender rather than gender itself drive heterogeneity. If they did not, one would expect differences along these dimensions to be less pronounced in the sub-sample of male farmers.

7 Discussion

The results presented above show that simply providing information can significantly improve the food safety practices of smallholders. Provision of inputs and, to a lesser extent, market incentives, can strengthen these impacts. In this section, we discuss the costs of these

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[23] These results are available from the authors upon request.

interventions, and consider the business case for their implementation.

Evidence from smallholder inclusion in value chains for high-value horticultural produce provides some insights about how growing demand for safer food and increased pressure to comply with regulations could support improved aflatoxin control by groundnut farmers. This literature finds that farmers are generally unable to achieve food safety and other quality requirements without assistance such as training and input provision by aggregators in the context of contractual supply relationships (Boselie, Henson, and Weatherspoon, 2003). Rainfed groundnut production systems face far greater yield risk than the irrigated horticultural systems in which this type of contract farming arrangement has taken root. Conversations with multiple aggregators in northern Ghana indicate that limited opportunities to sell groundnuts at a premium price, and the risk of drought-related harvest failure, are reasons for their reluctance to provide farmers with inputs. However, the provision of training and post-harvest inputs may be profitable in the context of an assured market if the cost of achieving compliance is low enough relative to the price premium for aflatoxin-safe nuts.

We calculate the cost of providing drying sheets per bag of safer groundnuts produced. Approximately one standard bag of groundnut, which sells for 100 GHC at harvest time, can be dried on a single sheet. Training costs include wages (100 GHC/day for a skilled worker in this region) and transport (50 GHC for daily motorcycle hire). Conservatively assuming that two groups of 25 farmers can be trained per day, that a drying sheet purchased for 10 GHC can be used for two seasons, and that farmers sell three bags of groundnut on average, the cost of providing sheets plus training is 6 GHC per bag. Compared to the base price, the break-even market premium for aflatoxin-safe groundnuts is thus 6 percent. This is far less than the 13 percent cost of sorting nuts down to safe levels reported by Project Peanut Butter in a year with high overall aflatoxin levels.

Whether the reduction in contamination achieved by providing farmers with drying sheets is sufficient to bring groundnuts into regulatory compliance with aflatoxin standards depends on the extent of contamination in a given year, and on how the effect of drying sheet use translates when aflatoxin levels are high. Assuming that the effect is proportional and constant across years, the 50 percent estimated reduction in aflatoxin we find in Northern Region would have reduced the proportion of samples above the regulatory limit from 0.33 to 0.12 in the baseline year, when aflatoxin levels were much higher. The total sample average would have dropped from four times the regulatory limit to twice the regulatory limit. How much this reduction would decrease sorting costs depends on the size of the lots being tested and the reduction in sorting cost for lots still above, but closer to, the regulatory limit. If the aggregator were to test many small lots, most would be below the regulatory limit and not require sorting. Testing, however, would be more expensive. On the other end of the spectrum, if the aggregator tested only one large lot, the sample average would still be higher than the regulatory limit, although much lower than it would have been without drying sheets, and thus still require less sorting. If sorting costs are proportionate to the quantity of nuts that need to be removed to reach the regulatory limit, a drop from from 60 ppb to 30 ppb would reduce sorting costs by two-thirds, or from 13 percent to 4.3 percent. The remaining sorting cost plus the cost of drying sheet provision would therefore be 10.4 percent.

At the current cost of aflatoxin testing, testing at the farm gate is not economically feasible. Testing could potentially be conducted at the level of the farmer group; this would imply higher testing costs relative to unconditional purchase of nuts from farmers to whom drying sheets have been provided, since testing would either need to be conducted at the farmer group aggregation center prior to purchase, or involve a separate trip to gather samples prior to purchase. Further, the impact of a group-level price incentive is likely to be lower than the individual incentive tested in this study. Because of this uncertainty, we do not calculate the break-even point for aflatoxin testing.

Another potential barrier to the success of a market incentive at the farmer level is uncertainty faced by farmers. First, for many food safety hazards, contamination above a regulatory threshold is a stochastic process. The risk to individual farmers that adopting improved practices does not result in produce that meets a buyer's requirement is even greater than that faced by aggregators, whose risk is spread over many farmers. Second, there is a risk that the buyer does not follow through on the promise to pay a premium, despite the farmer achieving compliance. From the farmer's perspective, this risk is especially great in the first season the premium is offered. Both types of risk reduce the expected utility associated with adoption, and may depress farmers' investment in technologies and practices to improve food safety. Further, the existence of a market premium for safer food does not necessarily translate into incentives for farmers to adopt good practices, or to a safer overall food supply. Interviews with groundnut traders during the formative stage of this research indicated that it is common to remove visibly damaged nuts from lots destined for high-value uses or markets, and direct the outsorts to lower-value uses. This does not reduce the overall level of aflatoxin in the food supply and could in fact increase exposure among poorer consumers.

In contrast, offering subsidized (or free) food safety enhancing inputs to farmers up-front is risk-free from the farmers' perspective. As demonstrated through this study, providing free technology can be highly effective for reducing contamination, both through a direct impact on technology use and through a crowding-in effect on other good practices. The need to provide a number of services to smallholder farmers in order to facilitate their inclusion in value chains that reward quality attributes has been noted by others to include extension, aggregation of produce, and possibly provision of inputs (Barrett et al., 2012). When we offered drying sheets at a slightly subsidized price, however, demand was very low. Further research will be needed to determine what level of subsidization is necessary to induce farmers to invest in technology themselves.

8 Concluding Remarks

The health burden due to foodborne disease is large and concentrated in low and middle-income countries. Increasing awareness of this problem is leading both firms and governments to begin imposing requirements that agricultural produce in low and middle-income countries meets safety standards. However, there are several reasons why farmers may not adopt practices and technologies to produce safer food. They may not be aware of food safety threats and how to prevent them, they may not be rewarded by the market for doing so, and they may not be able make the necessary investments in technology. In this study we use a randomized controlled trial in northern Ghana over two years to test three interventions, each designed to deal with one of these hurdles.

We find that providing farmers with information improves some agricultural practices, and offering market incentives has an additional impact. Providing farmers with drying sheets substantially improves drying practices, and also improves some storage practices, providing evidence that in this case, external subsidies crowd in additional private investment.

In the year we collected data on post-harvest practices, aflatoxin levels were too low throughout the study area to detect any impact of the interventions on aflatoxin contamination. In the following year we tested two of the interventions again in the same sample of farmers, and found that drying sheet provision reduced aflatoxin contamination in the high-contamination region by 25-50 percent. We find that reductions are highest among larger households, households with more young children, and households with higher aflatoxin levels at baseline. Thus, reductions in aflatoxin are greatest for households that stand to benefit the most.

The offer of a premium price appears to have had a similar impact in terms of magnitude, but this effect is not statistically significant. We note that estimated effects of the premium price offer may be biased toward zero due to the impossibility of excluding other farmers from this opportunity in the context of our within-village experimental design.

Both input provision and rewarding quality in the market show promise for lowering aflatoxin contamination in the groundnut value chain. While farmers in this study did react to a market incentive by adopting better post-harvest practices, the possibility of paying a premium based on farm-level aflatoxin testing appears distant given the current cost of testing and lack of testing infrastructure. However, with institutional and technological improvements, this may become a possibility, and future research should address how to accelerate this process. In the meantime, educating farmers about aflatoxin prevention and providing them with assistance to acquire key inputs is a viable strategy to improve the safety of food produced by African smallholder farmers.

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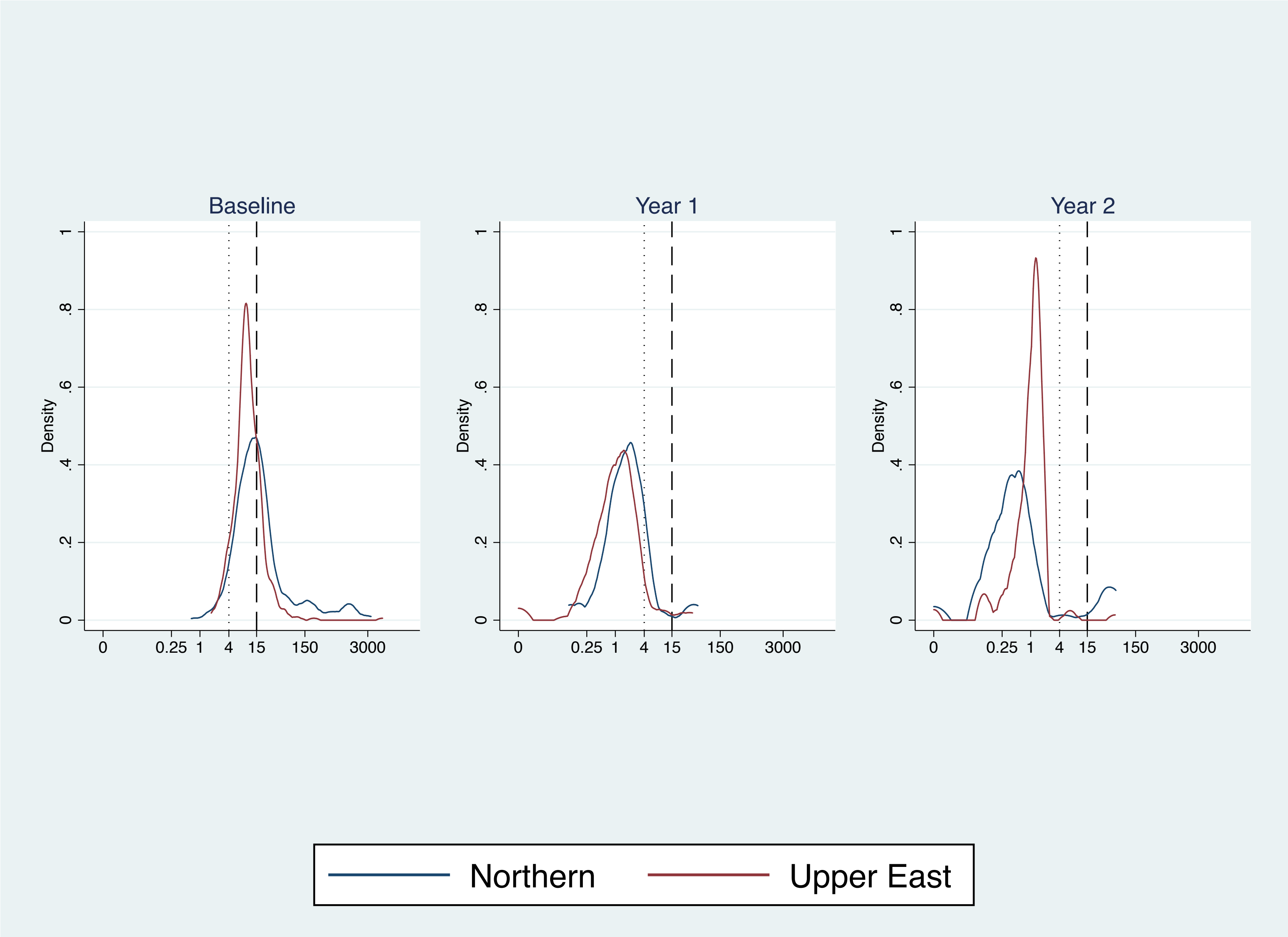
Figures and tables

Figure 1: Study timeline

				Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Year 1	Farming	Northern						Planting					Harvest					
		Upper East							Planting					Harvest				
	Interventions	Northern	Control													Info		Treatment reassigned
			Info								Info					Purch. 1		
			Sheets								Info/Sheets					Purch. 1		
			Prem.								Info/Prem.					Purch. 1		
		Upper east	Control														Info	
			Info									Info					Purch. 1	
			Sheets									Info/Sheets					Purch. 1	
			Prem.									Info/Prem.					Purch. 1	
	Data collection	Northern		Baseline								Sell sheets	Obs.			Endline 1		
		Upper East			Baseline								Sell sheets	Obs.			Endline 1	
				2014							2015							2016

				Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Year 2	Farming	Northern			Planting					Harvest								
		Upper East				Planting					Harvest							
	Interventions	Northern	Control	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
			Info						Info					Purch. 2				
			Sheets						Info/Tarps					Purch. 2				
			Prem.						Info/Prem.					Purch. 2				
		Upper east	Control	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
			Info							Info				Purch. 2				
			Sheets							Info/Sheets				Purch. 2				
			Prem.							Info/Prem.				Purch. 2				
	Data collection	Northern							Sheet sales	Sheet sales								Endline 2
		Upper East								Sheet sales	Sheet sales							Endline 2
									2016							2017		

Figure 2: Aflatoxin (IHST) levels at baseline and after years 1 and 2



Notes: All treatments for baseline (N=920), Control only for year 1 (N=176) and Information only group only for year 2 (N=261). Dotted line at 4 PPB is the EU standard. Dashed line at 15 PPB is the Ghanaian standard.

Table 1: Descriptive statistics and balance tests

	(1)	(2)	(3)	(4)	(5)	(6)
		Year 1 treatments			Year 2 treatments	
	All	Info	Sheets	Premium	Sheets	Premium
Female	0.32	0.03	-0.01	0.04	-0.02	0.02
	(0.01)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
Male HH head	0.84	-0.01	0.02	0.01	0.01	0.02
	(0.01)	(0.03)	(0.03)	(0.03)	(0.02)	(0.03)
HH size	5.19	0.19	-0.06	-0.02	-0.06	0.14
	(0.09)	(0.24)	(0.28)	(0.22)	(0.25)	(0.25)
Kids under 5	0.45	0.08	0.10	0.06	0.02	-0.02
	(0.03)	(0.08)	(0.09)	(0.08)	(0.05)	(0.06)
Any formal education	0.21	0.05	0.09**	0.05	0.02	-0.01
	(0.01)	(0.03)	(0.04)	(0.03)	(0.03)	(0.03)
Years farming	18.75	0.80	1.12	0.26	1.23	0.31
	(0.39)	(1.12)	(1.28)	(1.22)	(0.95)	(0.88)
Acres groundnuts	1.88	0.11	0.25	0.03	0.27**	0.11
	(0.05)	(0.12)	(0.15)	(0.11)	(0.12)	(0.12)
Production (jute bags)	5.79	-0.03	0.41	0.17	0.30	0.61
	(0.21)	(0.50)	(0.55)	(0.47)	(0.36)	(0.52)
Sold any groundnuts	0.43	-0.03	0.02	-0.03	0.04	0.05
	(0.02)	(0.04)	(0.04)	(0.05)	(0.03)	(0.04)
Qty sold (jute bags)	1.30	0.15	0.26	0.41*	0.17	0.55*
	(0.09)	(0.19)	(0.17)	(0.23)	(0.18)	(0.28)
Livestock (TLU)	4.96	-0.52	-0.86	1.65	-0.70	-0.23
	(0.36)	(0.56)	(0.67)	(1.22)	(0.71)	(1.37)
Dry on roof	0.49	0.01	0.00	0.00	-0.01	0.00
	(0.02)	(0.05)	(0.04)	(0.05)	(0.04)	(0.04)
Dry on sheet	0.01	0.00	0.01	0.00	0.00	0.01
	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Dry on dirt	-0.59	0.02	0.01	0.01	-0.00	-0.01
	(0.02)	(0.04)	(0.04)	(0.05)	(0.04)	(0.05)
Hand sort	0.16	0.01	-0.00	0.04	-0.02	0.01
	(0.01)	(0.04)	(0.03)	(0.03)	(0.02)	(0.03)
Dispose bad nuts	0.17	0.04	-0.01	0.04	-0.03	0.01
	(0.01)	(0.03)	(0.04)	(0.03)	(0.03)	(0.03)
Treat storage	0.27	-0.00	0.05	-0.01	-0.01	-0.02
	(0.01)	(0.04)	(0.04)	(0.04)	(0.03)	(0.03)
Use new bags	0.44	-0.05	0.08*	0.10**	0.03	0.00
	(0.02)	(0.05)	(0.04)	(0.04)	(0.04)	(0.04)
Store off-ground	0.81	-0.02	0.02	0.01	0.01	-0.01
	(0.01)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Aflatoxin (PPB)	60.08	-1.68	15.93	-0.08	17.68	8.77
	(10.55)	(19.69)	(34.90)	(27.38)	(22.82)	(23.65)
N	1,005	237	277	238	400	242

Notes: Clustered (village) standard errors in parentheses. *,**,*** denote significant differences between treatments at the 10%, 5%, and 1% confidence level.

Table 2: Sample attrition by treatment

	(1)	(2)	(3)	(4)	(5)
		Year 1 data		Year 2 data	
	Observation	Survey	G'nut sample	Survey	G'nut sample
Information	-0.021*	0.005	-0.043		
	(0.013)	(0.025)	(0.034)		
Drying sheets	-0.014	-0.039*	-0.091**	-0.030*	-0.075**
	(0.016)	(0.022)	(0.036)	(0.017)	(0.030)
Premium	-0.005	0.006	-0.024	-0.016	0.002
	(0.020)	(0.029)	(0.042)	(0.021)	(0.032)
Control mean	0.091	0.111	0.304	0.285	0.285
	(0.018)	(0.020)	(0.029)	(0.028)	(0.028)
N	1,005	1,005	1,005	1,005	1,005

Notes: Coefficients on indicators for Information, Sheets, and Premium treatments shown. Stratification (village) dummies included in all regressions. Clustered (village) standard errors in parentheses. *,**,*** denote significant differences between treatments at 10%, 5%, and 1% confidence level.

Table 3: Treatment effects on drying sheet purchase, fabrication, borrowing, and ownership

	(1)	(2)	(3)	(4)	(5)	(6)
	Any sheets purchased		Any sheets	Any sheets	Any sheets	Any sheets
	Records	Reported	made	borrowed	purchase elsewhere	owned (observed)
Information	0.144***	0.097***	-0.014	-0.029	0.009	0.068**
	(0.028)	(0.036)	(0.019)	(0.030)	(0.028)	(0.026)
Drying sheets|Info	-0.006	-0.034	-0.011	-0.045*	-0.019	0.618***
	(0.035)	(0.036)	(0.018)	(0.024)	(0.027)	(0.042)
Premium|Info	0.012	0.039	0.018	0.019	0.020	0.028
	(0.028)	(0.033)	(0.016)	(0.025)	(0.026)	(0.023)
Drying sheets+Info	0.138***	0.063**	-0.025	-0.074***	-0.010	0.685***
	(0.032)	(0.028)	(0.017)	(0.023)	(0.022)	(0.041)
Premium+Info	0.156***	0.136***	0.003	-0.010	0.029	0.096***
	(0.030)	(0.036)	(0.021)	(0.025)	(0.025)	(0.028)
Control mean	0.000	0.084	0.058	0.116	0.084	0.075
	(0.000)	(0.279)	(0.234)	(0.320)	(0.279)	(0.264)
N	1,005	901	901	901	901	900

Notes: Post-double-selection LASSO method used to select control variables (estimates not shown). Drying sheets+info and Premium+Info are linear combinations of estimates. Stratification (village) dummies included in all regressions. Clustered (village) standard errors in parentheses. *,**,*** denote significance at the 10%, 5%, and 1% confidence level.

Table 4: Treatment effects on good practice indices

	(1) Harvest	(2) Drying	(3) Sorting	(4) Storage	(5) Overall
Information	0.023	-0.023	0.245**	0.224**	0.206**
	(0.080)	(0.098)	(0.113)	(0.095)	(0.098)
Drying sheets|Info	0.111	0.462***	0.024	0.214***	0.405***
	(0.083)	(0.072)	(0.124)	(0.080)	(0.080)
Premium|Info	0.032	0.199**	-0.049	0.115	0.151*
	(0.082)	(0.098)	(0.135)	(0.076)	(0.087)
Drying sheets+Info	0.134**	0.439***	0.270**	0.439***	0.611***
	(0.063)	(0.084)	(0.116)	(0.089)	(0.089)
Premium+Info	0.056	0.176**	0.197*	0.339***	0.358***
	(0.082)	(0.081)	(0.106)	(0.094)	(0.075)
Control mean	-0.000	-0.000	0.000	0.000	-0.000
	(1.000)	(1.000)	(1.000)	(1.000)	(1.000)
N	901	901	901	901	901

Notes: Outcomes are inverse covariance weighted summary indices. Post-double-selection LASSO method used to select control variables (estimates not shown). Drying sheets+info and Premium+Info are linear combinations of parameter estimates. Stratification (village) dummies included in all regressions. Clustered (village) standard errors in parentheses. *,**,*** denote significance at the 10%, 5%, and 1% confidence level.

Table 5: Treatment effects on harvest and drying practices

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Days until plucking	Leave in pile	Dry on dirt Observed	Dry on dirt Reported	Dry on sheet Observed	Dry on sheet Reported	Drying days
Information	-0.037	-0.008	-0.021	0.037	0.054*	0.084***	0.081
	(0.167)	(0.036)	(0.066)	(0.046)	(0.032)	(0.022)	(0.167)
Drying sheets|Info	-0.209	-0.027	-0.071	-0.195***	0.470***	0.538***	0.164
	(0.155)	(0.036)	(0.062)	(0.035)	(0.075)	(0.037)	(0.140)
Premium|Info	-0.044	-0.013	0.043	-0.068	0.017	-0.019	0.277**
	(0.172)	(0.037)	(0.057)	(0.043)	(0.040)	(0.027)	(0.140)
Drying sheets+Info	-0.246*	-0.035	-0.093**	-0.158***	0.524***	0.622***	0.245
	(0.139)	(0.028)	(0.041)	(0.041)	(0.074)	(0.033)	(0.150)
Premium+Info	-0.080	-0.021	0.022	-0.031	0.071**	0.064***	0.358**
	(0.206)	(0.028)	(0.037)	(0.034)	(0.033)	(0.024)	(0.176)
Control mean	2.253	0.138	0.200	0.280	0.015	0.044	4.987
	(2.170)	(0.345)	(0.403)	(0.450)	(0.124)	(0.207)	(2.030)
N	901	901	267	901	267	901	901

Notes: Post-double-selection LASSO method used to select control variables (estimates not shown). Drying sheets+info and Premium+Info are linear combinations of estimates. Stratification (village) dummies included in all regressions. Clustered (village) standard errors in parentheses; *,**,*** denote significance at the 10%, 5%, and 1% confidence level.

Table 6: Treatment effects on sorting and storage

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Sort before		Dispose	treat	New	Store off-grounds	
	storage	consumption	worst	storage	containers	Observed	Reported
Information	0.129***	0.034	0.067	0.003	0.044	0.035	0.125***
	(0.044)	(0.044)	(0.043)	(0.047)	(0.053)	(0.070)	(0.043)
Drying sheets|Info	0.012	-0.048	0.066	0.144***	0.070	0.019	0.017
	(0.047)	(0.042)	(0.044)	(0.042)	(0.046)	(0.060)	(0.038)
Premium|Info	0.017	-0.022	-0.028	0.087**	0.026	-0.032	0.019
	(0.047)	(0.045)	(0.046)	(0.042)	(0.051)	(0.064)	(0.038)
Drying sheets+Info	0.141***	-0.015	0.133***	0.147***	0.113***	0.054	0.142***
	(0.047)	(0.044)	(0.039)	(0.040)	(0.042)	(0.061)	(0.041)
Premium+Info	0.146***	0.011	0.039	0.090**	0.070	0.003	0.143***
	(0.047)	(0.045)	(0.039)	(0.039)	(0.051)	(0.074)	(0.037)
Control mean	0.342	0.578	0.147	0.280	0.542	0.598	0.689
	(0.476)	(0.495)	(0.355)	(0.450)	(0.499)	(0.492)	(0.464)
N	901	901	901	901	901	445	901

Notes: Post-double-selection LASSO method used to select control variables (estimates not shown). Drying sheets+info and Premium+Info are linear combinations of estimates. Stratification (village) dummies included in all regressions. Clustered (village) standard errors in parentheses. *,**,*** denote significance at the 10%, 5%, and 1% confidence level.

Table 7: Aflatoxin levels (year 1)

	(1) PPB	(2) IHST(PPB)	(3) > 15 PPB	(4) > 4 PPB
Information	0.291	-0.073	0.012	0.005
	(0.665)	(0.094)	(0.016)	(0.024)
Drying sheets|Info	0.925	0.148*	0.019	0.025
	(0.770)	(0.085)	(0.015)	(0.023)
Premium|Info	0.807	0.144*	0.014	0.008
	(0.821)	(0.085)	(0.021)	(0.025)
Drying sheets+Info	1.215*	0.076	0.031*	0.030
	(0.641)	(0.087)	(0.016)	(0.021)
Premium+Info	1.097	0.071	0.027	0.014
	(0.812)	(0.108)	(0.019)	(0.027)
Control mean	2.777	0.350	0.028	0.074
	(6.663)	(1.014)	(0.167)	(0.262)
N	737	737	737	737

Notes: Post-double-selection LASSO method used to select control variables (estimates not shown). Drying sheets+info and Premium+Info are linear combinations of parameter estimates. Stratification (village) dummies included in all regressions. Clustered (village) standard errors in parentheses. *,**,*** denote significance at the 10%, 5%, and 1% confidence level.

Table 8: Selling groundnuts to project buyer (year 2)

	(1) Called premium buyer	(2) Sold to buyer	(3) Knew correct premium
Drying sheets|Info	0.063*	0.032	0.070
	(0.036)	(0.022)	(0.047)
Premium|Info	0.119***	0.108***	0.069
	(0.042)	(0.036)	(0.061)
Info only mean	0.179	0.073	0.594
	(0.384)	(0.260)	(0.493)
N	928	928	476

Notes: Post-double-selection LASSO method used to select control variables (estimates not shown). Drying sheets+info and Premium+Info are linear combinations of parameter estimates. Stratification (village) dummies included in all regressions. Clustered (village) standard errors in parentheses. *,**,*** denote significance at the 10%, 5%, and 1% confidence level.

Table 9: Aflatoxin levels (year 2)

	(1) PPB	(2) IHST(PPB)	(3) > 15 PPB	(4) > 4 PPB
Drying sheets|Info	-1.032	-0.086	-0.028*	-0.029*
	(0.811)	(0.076)	(0.017)	(0.017)
Premium|Info	-1.165	-0.116	-0.025	-0.036*
	(0.905)	(0.089)	(0.020)	(0.022)
Control mean	3.545	0.928	0.061	0.073
	(11.059)	(1.002)	(0.240)	(0.260)
Drying sheets|Info (Upper East)	0.570	0.067	0.010	-0.004
	(0.744)	(0.064)	(0.014)	(0.011)
Premium|Info (Upper East)	0.154	0.032	0.003	-0.012
	(0.675)	(0.059)	(0.013)	(0.016)
Control mean (Upper East)	1.565	0.938	0.008	0.023
	(4.926)	(0.522)	(0.087)	(0.150)
Drying sheets|Info (Northern)	-2.762**	-0.249*	-0.069**	-0.057*
	(1.370)	(0.130)	(0.029)	(0.032)
Premium|Info (Northern)	-2.529	-0.263	-0.054	-0.061
	(1.632)	(0.162)	(0.037)	(0.040)
Control mean (Northern)	5.540	0.918	0.115	0.123
	(14.631)	(1.322)	(0.321)	(0.330)
N	752	752	752	752

Notes: Post-double-selection LASSO method used to select control variables (estimates not shown). Drying sheets+info and Premium+Info are linear combinations of parameter estimates. Stratification (village) dummies included in all regressions. Clustered (village) standard errors in parentheses; *,**,*** denote significance at the 10%, 5%, and 1% confidence level.

Table 10: Lee bounds for estimate of drying sheet intervention on aflatoxin levels

	(1)		(2)		(3)		(4)	
	PPB		IHST(PPB)		>15 PPB		>4 PPB	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
90% confidence interval								
Drying sheets year 1	-1.463	2.879	-0.325	0.435	-0.076	0.090	-0.029	0.072
Drying sheets year 2	-3.639	0.347	-0.342	0.110	-0.093	-0.002	-0.080	-0.003
Drying sheets year 2 (Upper East)	-1.099	1.678	-0.096	0.239	-0.038	0.020	-0.018	0.033
Drying sheets year 2 (Northern)	-7.214	-0.867	-0.739	-0.077	-0.204	-0.019	-0.163	-0.034
95% confidence interval								
Drying sheets year 1	-1.733	3.057	-0.374	0.494	-0.089	0.096	-0.037	0.077
Drying sheets year 2	-4.204	0.874	-0.392	0.159	-0.107	0.011	-0.093	0.009
Drying sheets year 2 (Upper East)	-1.403	2.009	-0.125	0.275	-0.049	0.025	-0.026	0.037
Drying sheets year 2 (Northern)	-8.193	-0.018	-0.840	0.003	-0.230	0.000	-0.184	-0.017

Notes: Bounded point estimates obtained using post-double-selection LASSO method with only drying sheet treatment and control (year 1) or info only (year 2) groups with village (strata) fixed effects. Regional estimates obtained using regional subsamples only. Standard errors calculated and added to point estimates following Imbens and Manski (2004) as recommended by Lee (2009).

Table 11: Practices by treatment group at baseline and follow up

height	(1)	(2)	(3)	(4)	
	Control	Information	Drying sheets	Premium	N
BL dries on sheet	0.008	0.013	0.014	0.008	1,005
EL dries on sheet	0.044	0.129	0.672	0.110	901
Obs dries on sheet	0.015	0.060	0.514	0.049	267
BL dries on dirt	0.597	0.586	0.585	0.592	1,005
EL dries on dirt	0.280	0.314	0.125	0.252	901
Obs dries on dirt	0.200	0.194	0.216	0.295	267
BL hand sorts	0.146	0.165	0.144	0.185	1,005
EL hand sorts	0.342	0.462	0.484	0.481	901
BL disposes worst	0.150	0.198	0.144	0.193	1,005
EL disposes worst	0.147	0.224	0.281	0.190	901
BL applies insecticide	0.253	0.257	0.307	0.248	1,005
EL applies insecticide	0.280	0.267	0.430	0.357	901
BL uses new container	0.411	0.354	0.491	0.500	1,005
EL uses new container	0.449	0.500	0.578	0.519	901
BL stores on Store off-ground	0.806	0.793	0.830	0.811	1,005
EL stores on Store off-ground	0.689	0.814	0.832	0.829	901
Obs stores on Store off-ground	0.598	0.625	0.656	0.598	445

Notes: Information treatment refers to information only.

Table 12: Classification analysis of group average treatment effects of drying sheet receipt on year 2 aflatoxin (PPB)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Full sample			Northern region			Males only	
	Most Affected	Least Affected	Difference	Most Affected	Least Affected	Difference	Most Affected	Least Affected	Difference
GATEs	-7.779	1.438	9.316	-9.689	1.738	-10.780	-9.959	-0.097	-9.747
	(-13.65,-1.551)	(-1.884,5.510)	(-17.02,-1.798)	(-19.64,-0.497)	(-6.622,11.23)	(-25.42,2.680)	(-19.15,-1.199)	(-3.713,3.983)	(-20.14,0.365)
	[0.081]	[0.916]	[0.078]	[0.180]	[1.000]	[0.130]	[1.000]	[0.229]	
Good practice index	-0.094	0.091	-0.195	-0.121	0.142	-0.242	-0.147	0.153	-0.312
	(-0.230,0.043)	(-0.054,0.231)	(-0.395,0.004)	(-0.335,0.090)	(-0.072,0.355)	(-0.536,0.054)	(-0.332,0.031)	(-0.030,0.331)	(-0.563,0.058)
			[0.216]			[0.348]			[0.086]
Aflatoxin (PPB)	85.51	14.62	70.25	109.90	28.42	83.45	70.67	14.57	56.12
	(50.91,116.6)	(-15.15,54.04)	(20.44,115.1)	(61.61,164.4)	(-18.10,82.54)	(12.98,154.9)	(41.63,101.2)	(-12.90,45.49)	(15.92, 95.95)
			[0.042]			[0.098]			[0.042]
Male	0.861	0.500	0.340	0.913	0.507	0.420			
	(0.802,0.920)	(0.442,0.560)	(0.257,0.426)	(0.832,0.994)	(0.424,0.585)	(0.301,0.530)			
			[0.000]			[0.000]			
Any formal education	0.215	0.240	-0.031	0.145	0.116	0.043	0.194	0.352	-0.148
	(0.157,0.270)	(0.182,0.297)	(0.111,-0.051)	(0.083,0.217)	(0.053,0.190)	(-0.052,0.137)	(0.121,0.268)	(0.280,0.426)	(-0.253,0.046)
			[1.000]			[0.882]			[0.882]
Household size	6.399	3.892	2.545	7.152	4.362	2.862	6.617	4.077	2.577
	(6.039,6.759)	(3.512,4.267)	(2.013,3.068)	(6.566,7.760)	(3.755,4.967)	(2.064,3.707)	(6.134,7.095)	(3.610,4.564)	(1.874,3.247)
			[0.000]			[0.000]			[0.000]
Kids under five	0.667	0.226	0.448	0.754	0.312	0.420	0.653	0.286	0.347
years old	(0.570,0.774)	(0.115,0.327)	(0.303,0.596)	(0.593,0.932)	(0.150,0.477)	(0.187,0.657)	(0.517,0.797)	(0.152,0.420)	(0.161,0.557)
			[0.000]			[0.007]			[0.004]
Experience	18.00	21.56	-3.382	18.75	16.95	1.862	18.55	21.71	-3.327
	(16.30,19.75)	(19.81,23.20)	(-5.836,0.969)	(14.49,19.35)	(16.32,21.19)	(1.469,5.243)	(16.38,20.73)	(19.49,23.91)	(-6.388,0.272)
			[0.044]			[0.716]			[0.149]
Acres groundnuts	2.258	1.424	0.845	2.725	2.196	0.471	2.493	1.542	0.988
	(2.038,2.479)	(1.187,1.651)	(0.566,1.118)	(1.814,2.600)	(2.334,3.052)	(-0.065,1.074)	(2.199,2.761)	(1.220,1.859)	(0.574,1.359)
			[0.000]			[0.308]			[0.000]
Groundnut production	7.004	4.118	2.991	9.052	8.054	0.920	7.893	4.590	2.919
(bags)	(6.143,7.827)	(3.206,5.020)	(1.804,4.240)	(7.429,10.57)	(6.420,9.577)	(1.401,3.245)	(6.677,8.947)	(3.526,5.812)	(1.213,4.599)
			[0.000]			[1.000]			[0.010]
Sell any groundnuts	0.542	0.271	0.267	0.645	0.609	0.029	0.592	0.306	0.296
	(0.476,0.609)	(0.206,0.336)	(0.175,0.360)	(0.549,0.741)	(0.516,0.706)	(0.107,0.165)	(0.514,0.672)	(0.226,0.385)	(0.183,0.409)
			[0.000]			[1.000]			[0.000]
Quantity sold	1.615	0.593	1.074	2.373	1.459	0.835	2.029	0.811	1.194
	(1.289,1.968)	(0.216,0.956)	(0.607,1.604)	(1.734,3.061)	(0.863,2.172)	(0.078,1.781)	(1.508,2.482)	(0.277,1.292)	(0.444,1.936)
			[0.001]			[0.288]			[0.013]
Groundnut consumption	0.006	0.004	0.002	0.007	0.005	0.002	0.006	0.004	0.002
per capita (bowls)	(0.005,0.007)	(0.003,0.005)	(0.000,0.004)	(0.004,0.009)	(0.003,0.007)	(0.001,0.004)	(0.005,0.007)	(0.003,0.005)	(0.00,0.004)
			[0.083]			[0.793]			[1.000]
Livestock (TLU)	5.366	4.169	1.317	5.244	3.631	1.131	5.248	5.224	-0.053
	(4.181,6.584)	(2.953,5.457)	(0.463,3.197)	(3.116,7.281)	(1.988,5.689)	(1.334,3.828)	(3.738,6.731)	(3.775,6.654)	(-2.101,1.987)
			[0.464]			[0.879]			[1.000]
Northern	0.660	0.309	0.361				0.750	0.224	0.526
	(0.596,0.724)	(0.245,0.373)	(0.270,0.452)				(0.682,0.822)	(0.155,0.298)	(0.425,0.626)
			[0.000]						[0.000]

Notes: GATEs calculated for two groups. Median levels of covariate in most and least affected group are reported. Difference is median of most minus median of least affected. 10% confidence intervals in parentheses, p-values in brackets.

Appendix A Stratification procedure

To obtain better balance between treatment and control, we stratify our randomization as follows. First, we generate strata of four households within each village based on aflatoxin levels recorded at baseline. Next, we randomly assign three out of four households to receive treatment and the fourth to control. Which treatment the household received was determined in a public lottery at the end of the information session, and therefore randomization across treatment groups was not stratified. For villages that did not have 20 or 24 farmers, either 20 households (for those with between 21-23 households) or 24 household (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. Next, we run 1000 re-randomizations to ensure balance along aflatoxin levels and a number of post-harvest practices, which are also outcomes of interest for this study. From these 1000 re-randomizations we eliminate any where the p-value for aflatoxin level was below 0.8. Of the remaining randomizations, we select the one with the maximum minimum p-value following Bruhn and McKenzie (2009).

Appendix B Information session content

The following is a summary of specific practices covered in the information session organized by production stage.

1. Harvest
   - Harvest when leaves begin wilting and turning yellow.
   - Check inside of ten sample pods to confirm crop is ready for harvest.
2. Plucking
   - Pluck pods from vines as soon as possible after harvesting.
   - Do not leave pods exposed to soil while waiting to pluck.
   - As you pluck, remove and discard visibly damaged pods (shriveled, have holes, broken, moldy, discolored)
3. Drying
   - Dry on a clean surface: use a drying sheet if possible, or otherwise a concrete slab or rooftop. Do not dry on bare dirt.
   - Dry on a smooth surface that will prevent water from puddling.
   - Avoid breaking pods when spreading them on the drying surface; use a rake, not feet.
   - Sort out visibly damaged pods from the drying area and dispose of them.
   - Protect pods from the rain; either bring them in or cover them with thatch (traditional) or drying sheet. Once the rain has stopped, spread them again immediately and dry the covering surface, is applicable.
4. Storage

- Use new bags or clean bags by turning them inside out and laying them out under the sun to kill insect eggs and mold.
- Remove and discard visibly damaged nuts before putting them in bags.
- Remove old stock from storage area before adding new stock.
- Store bags on raised platforms that allow for airflow (locally available or home made pallets).
- Store bags away from walls of storage area.

Appendix C Attrition

Table C1: Attrition by treatment group and baseline characteristics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	2016									2017			
	PH observation			Follow-up survey			G'nut sample			Follow-up survey		G'nut sample	
	Info	Sheets	Premium	Info	Sheets	Premium	Info	Sheets	Premium	Sheets	Premium	Sheets	Premium
Male	0.004	0.001	0.068	0.064	-0.029	-0.005	0.142*	0.051	0.034	-0.009	0.021	-0.022	-0.020
	(0.036)	(0.034)	(0.044)	(0.058)	(0.053)	(0.048)	(0.077)	(0.080)	(0.092)	(0.034)	(0.050)	(0.066)	(0.075)
Male HH head	-0.056	-0.027	-0.123	0.022	0.006	0.002	0.043	0.060	-0.017	-0.037	0.047	-0.019	0.140
	(0.044)	(0.049)	(0.076)	(0.082)	(0.066)	(0.069)	(0.109)	(0.090)	(0.102)	(0.063)	(0.060)	(0.081)	(0.087)
HH size	0.002	0.013**	0.010	-0.008	-0.004	-0.013	-0.012	-0.014	-0.013	-0.004	-0.002	0.007	-0.004
	(0.005)	(0.006)	(0.006)	(0.009)	(0.008)	(0.008)	(0.012)	(0.013)	(0.012)	(0.008)	(0.007)	(0.011)	(0.013)
Any formal education	-0.017	0.006	0.038	-0.047	-0.021	0.033	-0.174	-0.115	-0.063	-0.085	-0.073	-0.155*	-0.072
	(0.040)	(0.047)	(0.048)	(0.037)	(0.059)	(0.074)	(0.134)	(0.107)	(0.132)	(0.051)	(0.072)	(0.084)	(0.102)
Experience	0.000	-0.000	0.001	-0.001	-0.000	-0.001	0.000	0.002	0.002	-0.001	-0.001	-0.003	0.003
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)
Acres	-0.018	-0.013	0.009	0.010	0.012	0.079**	0.039	-0.002	0.036	-0.019	-0.020	-0.036	-0.045
	(0.020)	(0.020)	(0.026)	(0.029)	(0.027)	(0.037)	(0.040)	(0.036)	(0.058)	(0.022)	(0.030)	(0.034)	(0.048)
Qty produced	0.004	0.003	0.001	0.007	-0.003	-0.020**	-0.003	-0.001	-0.015	0.004	0.000	0.012	-0.003
	(0.005)	(0.004)	(0.005)	(0.012)	(0.009)	(0.009)	(0.016)	(0.009)	(0.015)	(0.006)	(0.005)	(0.008)	(0.011)
Sold any	0.073	0.069*	0.050	-0.044	-0.033	0.022	-0.024	0.025	0.011	-0.055	-0.049	-0.019	-0.126
	(0.045)	(0.037)	(0.035)	(0.058)	(0.066)	(0.093)	(0.083)	(0.086)	(0.105)	(0.051)	(0.052)	(0.084)	(0.087)
Qty sold	-0.011	-0.012	-0.011	-0.036*	-0.016	-0.001	-0.030	-0.005	0.010	0.001	0.006	-0.003	0.026
	(0.008)	(0.008)	(0.007)	(0.018)	(0.017)	(0.019)	(0.024)	(0.022)	(0.021)	(0.009)	(0.007)	(0.017)	(0.016)
Livestock (TLU)	-0.005	-0.005*	-0.006*	-0.002	0.001	0.001	-0.007*	-0.004	-0.001	-0.000	-0.000	0.004	0.002
	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)	(0.004)	(0.003)	(0.004)	(0.001)	(0.001)	(0.003)	(0.003)
Dry dirt	0.023	0.015	-0.026	0.023	0.011	0.010	0.063	0.004	0.077	-0.012	-0.058	-0.080	-0.062
	(0.036)	(0.038)	(0.044)	(0.060)	(0.045)	(0.069)	(0.081)	(0.087)	(0.099)	(0.033)	(0.043)	(0.062)	(0.074)
Hand sort	-0.082	-0.130**	-0.105**	0.020	-0.067	0.028	-0.016	-0.040	0.065	0.022	0.089*	0.136	0.264**
	(0.050)	(0.051)	(0.051)	(0.088)	(0.067)	(0.071)	(0.143)	(0.123)	(0.126)	(0.064)	(0.045)	(0.111)	(0.118)
Dispose	-0.002	0.069	0.012	0.008	0.128*	0.139*	0.091	0.139	0.109	0.012	-0.077	-0.118	-0.081
	(0.041)	(0.060)	(0.050)	(0.057)	(0.069)	(0.076)	(0.134)	(0.111)	(0.137)	(0.050)	(0.074)	(0.078)	(0.138)
treat	0.032	0.028	0.093*	0.019	0.048	0.132	0.058	0.079	0.072	0.049	0.042	0.034	-0.089
	(0.050)	(0.044)	(0.051)	(0.079)	(0.066)	(0.085)	(0.105)	(0.073)	(0.105)	(0.049)	(0.058)	(0.070)	(0.081)
New cont	-0.010	-0.067	-0.010	0.012	-0.075*	0.023	-0.061	-0.090	-0.080	0.062*	-0.001	0.002	-0.080
	(0.040)	(0.041)	(0.037)	(0.052)	(0.045)	(0.038)	(0.086)	(0.075)	(0.071)	(0.036)	(0.039)	(0.085)	(0.074)
Palets	0.032	-0.035	0.001	0.030	0.014	-0.040	-0.034	-0.085	0.004	0.062	0.063	0.040	0.068
	(0.042)	(0.040)	(0.046)	(0.084)	(0.058)	(0.086)	(0.102)	(0.110)	(0.111)	(0.050)	(0.067)	(0.082)	(0.085)
Aflatoxin (100 PPB)	-0.003	0.001	-0.000	0.006	0.005	-0.006	-0.013*	-0.017	-0.039**	-0.010	-0.004	-0.012	-0.010
	(0.003)	(0.003)	(0.003)	(0.009)	(0.003)	(0.006)	(0.008)	(0.011)	(0.015)	(0.008)	(0.013)	(0.008)	(0.014)
Missing afla	0.025	0.118**	0.057	0.040	0.223**	0.021	-0.050	0.210	-0.008	0.044	0.048	0.085	-0.079
	(0.026)	(0.056)	(0.057)	(0.107)	(0.109)	(0.099)	(0.151)	(0.162)	(0.152)	(0.080)	(0.110)	(0.077)	(0.111)

Notes: Each set of columns (1-3, 4-6, 7-9, 10-11, and 12-13) contains estimates from a single regression of attrition on treatments x covariate interactions. Stratification (village) dummies included in all regressions. Clustered (village) standard errors in parentheses. *,**,*** denote significance at the 10%, 5%, and 1% confidence level.

Appendix D ANCOVA regressions

Table D1: Treatment effects on drying sheet purchase, fabrication, borrowing, and ownership

	(1)	(2)	(3)	(4)	(5)	(6)
	Any sheets purchased		Any sheets	Any sheets	Any sheets	Number sheets
	Records	Reported	made	borrowed	purchase elsewhere	owned (observed)
Information	0.144***	0.097**	-0.014	-0.029	0.009	0.068**
	(0.029)	(0.037)	(0.020)	(0.031)	(0.029)	(0.027)
Drying sheets|Info	-0.006	-0.033	-0.011	-0.045*	-0.019	0.619***
	(0.036)	(0.038)	(0.018)	(0.025)	(0.029)	(0.044)
Premium|Info	0.013	0.038	0.017	0.018	0.019	0.024
	(0.029)	(0.034)	(0.016)	(0.026)	(0.027)	(0.023)
Drying sheets+Info	0.138***	0.064**	-0.025	-0.074***	-0.010	0.687***
	(0.033)	(0.029)	(0.017)	(0.023)	(0.023)	(0.042)
Premium+Info	0.157***	0.134***	0.003	-0.011	0.029	0.092***
	(0.030)	(0.037)	(0.022)	(0.026)	(0.026)	(0.029)
Control mean	0.000	0.084	0.058	0.116	0.084	0.075
	(0.000)	(0.279)	(0.234)	(0.320)	(0.279)	(0.264)
N	1,005	901	901	901	901	900

Notes: ANCOVA regressions. Drying sheets+info and Premium+Info are linear combinations of parameter estimates. Stratification (village) dummies included in all regressions. Clustered (village) standard errors in parentheses. *,**,*** denote significance at the 10%, 5%, and 1% confidence level.

Table D2: Treatment effects on good practice indices

	(1) Harvest	(2) Drying	(3) Sorting	(4) Storage	(5) Overall
Information	0.023	-0.023	0.239*	0.221**	0.205**
	(0.083)	(0.102)	(0.119)	(0.100)	(0.101)
Drying sheets|Info	0.110	0.462***	0.024	0.219**	0.403***
	(0.086)	(0.075)	(0.128)	(0.084)	(0.083)
Premium|Info	0.032	0.201*	-0.045	0.124	0.156*
	(0.085)	(0.102)	(0.143)	(0.080)	(0.091)
Drying sheets+Info	0.133**	0.439***	0.262**	0.441***	0.609***
	(0.066)	(0.087)	(0.119)	(0.093)	(0.092)
Premium+Info	0.056	0.178**	0.194	0.345***	0.362***
	(0.085)	(0.084)	(0.116)	(0.097)	(0.077)
Control mean	-0.000	-0.000	0.000	0.000	-0.000
	(1.000)	(1.000)	(1.000)	(1.000)	(1.000)
N	901	901	901	901	901

Notes: Outcomes are inverse covariance weighted summary indices. Drying sheets+info and Premium+Info are linear combinations of estimates. ANCOVA regressions. Stratification (village) dummies included in all regressions. Clustered (village) standard errors in parentheses. *,**,*** denote significance at the 10%, 5%, and 1% confidence level.

Table D3: Treatment effects on harvest and drying practices

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Days until		Dry on dirt		Dry on sheet		
	plucking	Leave in pile	Observed	Reported	Observed	Reported	Drying days
Information	-0.037	-0.008	-0.024	0.038	0.055	0.084***	0.082
	(0.174)	(0.037)	(0.073)	(0.048)	(0.035)	(0.022)	(0.173)
Drying sheets|Info	-0.204	-0.028	-0.073	-0.194***	0.469***	0.539***	0.168
	(0.161)	(0.037)	(0.067)	(0.036)	(0.082)	(0.039)	(0.146)
Premium|Info	-0.039	-0.015	0.054	-0.071	0.014	-0.020	0.271*
	(0.178)	(0.038)	(0.064)	(0.045)	(0.043)	(0.028)	(0.146)
Drying sheets+Info	-0.241	-0.036	-0.097**	-0.156***	0.524***	0.623***	0.250
	(0.145)	(0.029)	(0.046)	(0.043)	(0.082)	(0.035)	(0.155)
Premium+Info	-0.075	-0.023	0.030	-0.033	0.069*	0.064**	0.354*
	(0.214)	(0.029)	(0.040)	(0.035)	(0.035)	(0.025)	(0.182)
Control mean	2.253	0.138	0.200	0.280	0.015	0.044	4.987
	(2.170)	(0.345)	(0.403)	(0.450)	(0.124)	(0.207)	(2.030)
N	901	901	267	901	267	901	901

Notes: ANCOVA regressions. Drying sheets+info and Premium+Info are linear combinations of parameter estimates. Stratification (village) dummies included in all regressions. Clustered (village) standard errors in parentheses. *,**,*** denote significance at the 10%, 5%, and 1% confidence level.

Table D4: Treatment effects on sorting and storage

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Sort before		Dispose	treat	New	Store off-grounds	
	storage	consumption	worst	storage	containers	Observed	Reported
Information	0.126***	0.033	0.064	0.003	0.043	0.029	0.125***
	(0.046)	(0.046)	(0.045)	(0.049)	(0.055)	(0.075)	(0.045)
Drying sheets|Info	0.013	-0.051	0.067	0.143***	0.072	0.029	0.018
	(0.049)	(0.043)	(0.046)	(0.044)	(0.049)	(0.063)	(0.039)
Premium|Info	0.015	-0.020	-0.026	0.085*	0.030	-0.027	0.020
	(0.051)	(0.047)	(0.048)	(0.043)	(0.052)	(0.069)	(0.039)
Drying sheets+Info	0.140***	-0.018	0.132***	0.146***	0.115**	0.058	0.143***
	(0.050)	(0.045)	(0.040)	(0.041)	(0.044)	(0.065)	(0.042)
Premium+Info	0.141***	0.013	0.038	0.088**	0.073	0.002	0.144***
	(0.051)	(0.046)	(0.042)	(0.041)	(0.053)	(0.082)	(0.039)
Control mean	0.342	0.578	0.147	0.280	0.542	0.598	0.689
	(0.476)	(0.495)	(0.355)	(0.450)	(0.499)	(0.492)	(0.464)
N	901	901	901	901	901	445	901

Notes: ANCOVA regressions. Drying sheets+info and Premium+Info are linear combinations of parameter estimates. Stratification (village) dummies included in all regressions. Clustered (village) standard errors in parentheses. *,**,*** denote significance at the 10%, 5%, and 1% confidence level.

Table D5: Aflatoxin levels (year 1)

	(1) PPB	(2) IHST(PPB)	(3) > 15 PPB	(4) > 4 PPB
Information	0.330	-0.065	0.015	0.006
	(0.705)	(0.096)	(0.017)	(0.025)
Drying sheets|Info	0.939	0.148	0.018	0.025
	(0.786)	(0.088)	(0.016)	(0.023)
Premium|Info	0.679	0.132	0.008	0.005
	(0.852)	(0.088)	(0.022)	(0.026)
Drying sheets+Info	1.269*	0.083	0.034**	0.032
	(0.644)	(0.090)	(0.016)	(0.021)
Premium+Info	1.009	0.067	0.024	0.011
	(0.840)	(0.112)	(0.019)	(0.027)
Control mean	2.777	0.350	0.028	0.074
	(6.663)	(1.014)	(0.167)	(0.262)
N	737	737	737	737

Notes: ANCOVA regressions. Drying sheets+info and Premium+Info are linear combinations of parameter estimates. Stratification (village) dummies included in all regressions. Clustered (village) standard errors in parentheses. *,**,*** denote significance at the 10%, 5%, and 1% confidence level.

Table D6: Selling groundnuts to project buyer (year 2)

noalign	(1) Called premium buyer	(2) Sold to buyer	(3) Knew correct premium
Drying sheets|Info	0.044	0.000	0.073
	(0.055)	(0.026)	(0.068)
Premium|Info	0.119***	0.107***	0.052
	(0.041)	(0.038)	(0.066)
Info only mean	0.179	0.073	0.594
	(0.384)	(0.260)	(0.493)
N	928	928	476

Notes: ANCOVA regressions. Drying sheets+info and Premium+Info are linear combinations of parameter estimates. Stratification (village) dummies included in all regressions. Clustered (village) standard errors in parentheses. *,**,*** denote significance at the 10%, 5%, and 1% confidence level.

Table D7: Aflatoxin levels (year 2)

	(1) PPB	(2) IHST(PPB)	(3) > 15 PPB	(4) > 4 PPB
Drying sheets|Info	-1.062	-0.089	-0.029	-0.030*
	(0.844)	(0.078)	(0.018)	(0.018)
Premium|Info	-1.029	-0.102	-0.022	-0.033
	(0.959)	(0.093)	(0.021)	(0.022)
Control mean	3.545	0.928	0.061	0.073
	(11.059)	(1.002)	(0.240)	(0.260)
Drying sheets|Info (Upper East)	0.527	0.069	0.010	-0.003
	(0.763)	(0.065)	(0.014)	(0.011)
Premium|Info (Upper East)	0.128	0.029	0.003	-0.013
	(0.712)	(0.062)	(0.014)	(0.017)
Control mean (Upper East)	1.565	0.938	0.008	0.023
	(4.926)	(0.522)	(0.087)	(0.150)
Drying sheets|Info (Northern)	-2.766*	-0.257*	-0.071**	-0.059*
	(1.437)	(0.136)	(0.031)	(0.034)
Premium|Info (Northern)	-2.196	-0.234	-0.047	-0.053
	(1.738)	(0.170)	(0.038)	(0.041)
Control mean (Northern)	5.540	0.918	0.115	0.123
	(14.631)	(1.322)	(0.321)	(0.330)
N	752	752	752	752

Notes: ANCOVA regressions. Drying sheets+info and Premium+Info are linear combinations of estimates. Stratification (village) dummies included in all regressions. Clustered (village) standard errors in parentheses. *,**,*** denote significance at the 10%, 5%, and 1% confidence level.

Appendix E Machine learning goodness of fit and heterogeneity detection

Table E1: Goodness of fit for Ridge and LASSO machine learning methods

	BLP		GATES	
	Ridge	LASSO	Ridge	LASSO
Info year 1	0.105	0.102	0.071	0.080
Drying sheet year 1	0.464	0.460	0.079	0.111
Premium year 1	0.186	0.182	0.103	0.105
Drying sheet year 2	19.220	11.030	3.236	2.028
Drying sheet year 2 (Northern)	45.040	37.240	3.473	2.827
Drying sheet year 2 (males)	35.270	31.630	3.017	2.014
Price premium year 2	14.310	12.200	1.675	1.537

Notes: Best linear predictor (BLP) goodness of fit captures correlation between the actual sample conditional average treatment effect and the estimated conditional average treatment effect. Grouped average treatment effects (GATEs) measures goodness of fit by how well the the division of the sample into two groups (most and least affected) explains the outcome.

Table E2: Best linear prediction and group average treatment effects heterogeneity detection

	BLP		GATES		
	ATE (β_1)	HET (β_2)	Most (γ_2)	Least (γ_1)	Diff. ($\gamma_2 - \gamma_1$)
Outcome variable: Overall good practice index (year 1)					
Info	0.203	0.082	0.205	0.190	0.029
	(-0.060,0.462)	(-1.904,1.986)	(-0.346,0.765)	(-0.347,0.737)	(-0.757,0.805)
	[0.412]	[1.000]	[1.000]	[1.000]	[1.000]
Drying sheet year 1	0.611	0.620	0.804	0.527	0.259
	(0.387,0.850)	(-0.793,1.937)	(0.289,1.341)	(0.090,0.995)	(-0.384,0.958)
	[0.000]	[0.874]	[0.024]	[0.096]	[0.971]
Premium	0.358	0.548	0.518	0.245	0.237
	(0.143,0.581)	(-0.748,2.002)	(-0.055,1.027)	(-0.203,0.690)	(-0.559,0.984)
	[0.019]	[1.000]	[0.271]	[0.738]	[1.000]
Outcome variable: Aflatoxin (PPB) (year 2)					
Drying sheet	-1.232	0.361	-7.779	1.438	-9.316
	(-3.119,0.919)	(0.059,0.721)	(-13.65,-1.551)	(-1.884,5.510)	(-17.02,-1.798)
	[0.642]	[0.097]	[0.081]	[0.916]	[0.078]
Drying sheet (Northern only)	-3.184	0.258	-9.689	1.738	-10.780
	(-6.560,0.625)	(-0.118,0.683)	(-19.64,-0.497)	(-6.622,11.23)	(-25.42,2.680)
	[0.343]	[0.499]	[0.180]	[1.000]	[0.370]
Drying sheet (males)	-3.084	0.349	-9.959	-0.097	-9.747
	(-6.468,-0.107)	(-0.039,0.730)	(-19.15,-1.199)	(-3.713,3.983)	(-20.14,0.365)
	[0.182]	[0.278]	[0.130]	[1.000]	[0.229]
Premium	-1.080	0.181	-5.667	-0.155	-5.394
	(-3.836,1.432)	(-0.177,0.573)	(-12.56,1.534)	(-4.568,3.138)	(-14.56,3.626)
	[0.969]	[0.822]	[0.366]	[1.000]	[0.638]

Notes: ATE refers to average treatment effect and HET to heterogeneity loading parameter. Most and least affected refers to ATE among most and least affected. Difference refers to ATE of most affected minus ATE of least affected. 90% confidence intervals in parentheses, p-values in brackets.

Table E3: Classification analysis of group average treatment effects of interventions on year 1 good practice index

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Information only			Drying sheets			Premium	
	Most Affected	Least Affected	Difference	Most Affected	Least Affected	Difference	Most Affected	Least Affected	Difference
GATEs	0.205	0.190	0.029	0.804	0.527	0.259	0.518	0.245	0.237
	(-0.346,0.765)	(-0.347,0.737)	(-0.757,0.805)	(0.289,1.341)	(0.090,0.995)	(-0.384,0.958)	(-0.055,1.027)	(-0.203,0.690)	(-0.559,0.984)
	[1.000]	[1.000]	[1.000]	[0.024]	[0.096]	[0.971]	[0.271]	[0.738]	[1.000]
Good practice index	-0.078	0.076	-0.148	0.083	0.082	0.007	0.025	0.131	-0.047
	(-0.237,0.082)	(-0.100,0.240)	(-0.387,0.102)	(-0.081,0.242)	(-0.089,0.243)	(-0.214,0.252)	(-0.152,0.198)	(-0.036,0.302)	(-0.319,0.187)
			[0.692]			[1.000]			[1.000]
Aflatoxin (PPB)	25.29	66.31	-36.01	36.75	81.55	-39.03	17.01	78.46	-52.99
	(-7.324,70.01)	(29.74,107.2)	(-87.80,6.626)	(-12.89,87.03)	(29.52,137.4)	(-117.4,31.79)	(-13.47,65.24)	(39.26,117.5)	(-106.3,-3.216)
			[0.442]			[0.588]			[0.155]
Male	0.676	0.685	-0.028	0.674	0.710	-0.051	0.667	0.679	-0.012
	(0.602,0.751)	(0.610,0.759)	(-0.131,0.083)	(0.597,0.742)	(0.638,0.783)	(-0.155,0.055)	(0.587,0.741)	(0.603,0.758)	(-0.124,0.096)
			[1.000]			[0.917]			[1.000]
Any formal education	0.194	0.167	0.037	0.292	0.133	0.158	0.213	0.139	0.073
	(0.136,0.255)	(0.102,0.231)	(-0.052,0.122)	(0.225,0.352)	(0.070,0.194)	(0.069,0.245)	(0.152,0.273)	(0.078,0.203)	(-0.014,0.159)
			[0.961]			[0.007]			[0.327]
Household size	4.735	5.741	-1.051	4.887	5.392	-0.589	4.880	5.514	-0.588
	(4.278,5.181)	(5.294,6.193)	(-1.698,-0.424)	(4.436,5.369)	(4.961,5.838)	(-1.234,0.061)	(4.372,5.381)	(5.007,5.990)	(-1.274,0.169)
			[0.013]			[0.276]			[0.433]
Kids under five years old	0.312	0.534	-0.227	0.413	0.492	-0.083	0.407	0.435	-0.056
	(0.189,0.432)	(0.417,0.656)	(-0.409,-0.050)	(0.289,0.547)	(0.363,0.609)	(-0.271,0.091)	(0.279,0.529)	(0.314,0.554)	(-0.225,0.121)
			[0.068]			[0.897]			[1.000]
Experience	20.70	17.76	2.880	19.99	18.80	1.261	21.34	18.09	3.579
	(18.67,22.77)	(15.76,19.77)	(-0.163,5.585)	(17.99,21.84)	(16.85,20.69)	(-1.433,3.900)	(19.30,23.38)	(16.03,20.07)	(0.762,6.345)
			[0.235]			[0.869]			[0.079]
Acres groundnuts	1.636	1.968	-0.454	1.392	2.325	-0.958	1.416	2.152	-0.700
	(1.398,1.846)	(1.744,2.187)	(-0.762,-0.095)	(1.129,1.711)	(2.061,2.563)	(-1.285,-0.550)	(1.216,1.617)	(1.935,2.332)	(-1.003,-0.372)
			[0.069]			[0.000]			[0.001]
Groundnut production (bags)	4.644	6.103	-1.523	3.778	7.488	-3.753	3.993	7.177	-3.672
	(3.705,5.474)	(5.250,6.910)	(-2.954,-0.242)	(2.651,4.907)	(6.539,8.471)	(-5.139,-2.279)	(2.678,4.904)	(6.239,8.094)	(-5.045,-1.821)
			[0.114]			[0.000]			[0.000]
Sell any groundnuts	0.458	0.398	0.032	0.338	0.567	-0.221	0.324	0.523	-0.203
	(0.379,0.537)	(0.316,0.480)	(-0.080,0.145)	(0.264,0.411)	(0.493,0.640)	(-0.323,-0.117)	(0.247,0.402)	(0.450,0.599)	(-0.315,-0.091)
			[0.834]			[0.003]			[0.007]
Quantity sold	1.048	1.135	0.012	0.681	1.630	-0.985	0.800	1.576	-0.754
	(0.703,1.390)	(0.725,1.480)	(-0.479,0.474)	(0.285,1.090)	(1.324,1.968)	(-1.519,-0.446)	(0.406,1.239)	(1.186,1.955)	(-1.346,-0.123)
			[1.000]			[0.010]			[0.112]
Groundnut consumption per capita (bowls)	0.005	0.006	-0.002	0.004	0.006	-0.002	0.004	0.007	-0.003
	(0.003,0.006)	(0.005,0.008)	(-0.004,0.000)	(0.003,0.006)	(0.005,0.008)	(-0.004,0.000)	(0.002,0.006)	(0.006,0.009)	(-0.005,-0.001)
			[0.425]			[0.304]			[0.049]
Livestock (TLU)	4.741	4.759	0.042	4.379	4.133	0.325	5.329	6.223	-0.807
	(3.467,6.107)	(3.402,6.153)	(-1.906,1.935)	(3.166,5.717)	(2.859,5.475)	(-1.360,2.211)	(3.384,7.456)	(4.063,8.378)	(-3.685,2.107)
			[1.000]			[1.000]			[1.000]
Northern	0.231	0.694	-0.472	0.092	0.846	-0.742	0.116	0.829	-0.681
	(0.162,0.302)	(0.622,0.767)	(-0.571,-0.373)	(0.040,0.143)	(0.799,0.890)	(-0.813,-0.670)	(0.059,0.174)	(0.778,0.880)	(-0.763,-0.599)
			[0.000]			[0.000]			[0.000]

Notes: GATEs calculated for two groups. Median level of covariate in most and least affected group are reported. Difference is median of most minus median of least affected. 90% confidence intervals in parentheses, p-values in brackets.

Table E4: Classification analysis of group average treatment effects of market premium offer on year 2 aflatoxin (PPB)

	(1) Most Affected	(2) Least Affected	(3) Difference
GATEs	-5.667	-0.155	-5.394
	(-12.56,1.534)	(-4.568,3.138)	(-14.56,3.626)
	[0.366]	[1.000]	[0.638]
Good practice index	-0.178	0.243	-0.402
	(-0.331,-0.021)	(0.085,0.394)	(-0.629,-0.178)
			[0.006]
Aflatoxin (PPB)	71.38	15.21	55.39
	(35.16,108.1)	(-16.99,58.57)	(6.677,106.3)
			[0.116]
Male	0.880	0.435	0.454
	(0.814,0.947)	(0.366,0.498)	(0.357,0.550)
			[0.000]
Any formal education	0.148	0.222	-0.074
	(0.085,0.207)	(0.160,0.282)	(-0.163,0.011)
			[0.300]
Household size	6.352	4.185	2.259
	(5.898,6.818)	(3.708,4.667)	(1.589,2.936)
			[0.000]
Kids under five	0.569	0.315	0.241
years old	(0.437,0.703)	(0.184,0.444)	(0.063,0.411)
			[0.050]
Experience	20.47	17.86	2.551
	(18.52,22.46)	(15.88,19.88)	(-0.258,5.415)
			[0.269]
Acres groundnuts	2.238	1.406	0.871
	(2.018,2.428)	(1.197,1.615)	(0.561,1.153)
			[0.000]
Groundnut production	7.715	4.141	3.499
(bags)	(6.633,8.772)	(3.175,5.151)	(2.039,4.881)
			[0.000]
Sell any groundnuts	0.509	0.324	0.185
	(0.432,0.588)	(0.247,0.401)	(0.076,0.295)
			[0.011]
Quantity sold	2.026	0.539	1.460
	(1.602,2.437)	(0.108,0.960)	(0.895,2.073)
			[0.000]
Groundnut consumption	0.006	0.004	0.003
per capita (bowls)	(0.005,0.008)	(0.002,0.005)	(0.001,0.005)
			[0.054]
Livestock (TLU)	6.878	4.074	2.349
	(4.455,9.236)	(2.260,6.064)	(-0.371,5.589)
			[0.299]
Northern	0.616	0.398	0.218
	(0.538,0.693)	(0.320,0.477)	(0.107,0.327)
			[0.002]

Notes: GATEs calculated for two groups. Median level of covariate in most and least affected group are reported. Difference is median of most minus median of least affected. 90% confidence intervals in parentheses, p-values in brackets.

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