Contracting and quality upgrading: evidence from an experiment in Senegal

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Abstract

Linking producers to export markets can improve incomes and welfare, but accessing these markets requires meeting international quality standards. In partnership with two groundnut farming cooperatives in Senegal, we implement an intervention that aims to address individual and market level barriers to quality upgrading, by encouraging adoption of a quality-improving technology. We conduct a randomized experiment to test whether this intervention induces adoption of the technology and improvements in production quality. Producers randomly offered the intervention are significantly more likely to purchase and use the technology. In areas where quality is otherwise lower due to agro-climatic conditions, producers in the treatment group are significantly more likely to comply with international quality standards. At the market level, the presence of quality insensitive buyers distorts incentives and undermines the relational contracting arrangement between farmers and cooperatives. We find that producers in the treatment group increase output sales to the cooperative on average, but this increase may be insufficient in magnitude to sustain the intervention in the long run, providing cautionary evidence of the challenges of contract farming in settings with volatile spot markets.

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1 Introduction

Linking producers to global value chains can improve productivity, increase incomes, and improve welfare (Minten et al., 2009; Reardon et al., 2009; Atkin et al., 2017; Barrett et al., 2020; World Bank, 2020). To participate in these value chains, however, producers must be able to meet international quality standards, which can present a major barrier to market access (Ferro et al., 2015; Fontagné et al., 2015; Bai, 2018; Fernandes et al., 2019). In this paper, we design and test an intervention that aims to increase producers' ability to meet quality standards and enter global value chains.

Improving production quality often requires producers to change practices or invest in new technologies. Existing evidence suggests improving market conditions and resolving producer uncertainty can increase technology adoption and production quality (Saenger et al., 2014; Atkin et al., 2017; Bernard et al., 2017; Abate et al., 2018; Macchiavello and Miquel-Florensa, 2019; Park et al., 2021; Bold et al., 2022; Hoffmann et al., 2022). Bundled interventions and contract farming arrangements may enable these changes by alleviating constraints, aligning incentives, and facilitating market access (Minten et al., 2009; Bellemare and Bloem, 2018; Arouna et al., 2021; Bellemare et al., 2021; Casaburi and Reed, 2020). However, sustaining contracting arrangements can be difficult in contexts with limited institutional capacity or robust spot markets (Fafchamps, 2004; Bellemare, 2010; Mujawamariya et al., 2013).

We present evidence that relieving individual constraints enables farmers to invest in quality-improving technology and improve compliance with food safety quality standards. The context of our study is groundnut cultivation in Senegal, a country where groundnuts are both the most valuable export crop and widely consumed locally.[1] We focus on one specific food safety quality standard—aflatoxin contamination—which affects both export market access and public health. Aflatoxins are a Group 1 human carcinogen (IARC, 1993, 2012; National Toxicology Program, 2016) produced by a fungus (*aspergillus flavus*) which contaminates staple crops including groundnuts, maize and rice.[2] Many countries impose aflatoxin standards for imported commodities, with the European Union's rules among the strictest in the world (Garcia-Alvarez-Coque et al., 2020). Despite the health and economic consequences of aflatoxin contamination, at baseline we find low awareness of the problem among groundnut farmers.

[1] Groundnuts are grown by more than half of households in extreme poverty, use more than 40% of cultivated land, and are widely consumed in a variety of forms in Senegal (World Bank, 2015). In 2018, Senegal was the 7th largest producer of groundnuts in the world (USDA Foreign Agricultural Service, 2020).

[2] One report called aflatoxins "amongst the most potent mutagenic and carcinogenic substances known" (EFSA, 2007). The carcinogenic risks of aflatoxin exposure are compounded by high rates of Hepatitis B in many low-income countries (Turner et al., 2003). Chronic exposure can also contribute to childhood malnutrition and immunosuppression (Gnonlonfin et al., 2013). Aflatoxin contamination is an increasingly salient concern for producers of a variety of staple crops. With climate change exacerbating changes in rainfall patterns (Clavel et al., 2013), aflatoxins may be responsible for up to one quarter of all liver cancer cases worldwide and more than four billion people may be chronically exposed (Williams et al., 2004; Liu and Wu, 2010; Liu et al., 2012).

In partnership with two farming cooperatives in the "groundnut basin" of Senegal, we inform farmers in 40 villages about a new quality-improving technology, the bio-control product Aflasafe®. This new technology allows farmers to treat their fields and prevent aflatoxin-causing *a. flavus* fungi from developing on crops. Aflasafe was not previously available in Senegal,[3] and agronomic evidence suggests it can reduce aflatoxin contamination significantly (Bandyopadhyay et al., 2019; Senghor et al., 2020). The technology is relatively low-cost[4] compared to other mitigation strategies, is simple to use, and may additionally provide lasting protection to crops during storage and transport.

To test the role of individual barriers to quality upgrading, we design a new bundled contracting intervention that builds on the existing model of our cooperative partners. These cooperatives typically sell inputs to farmers on credit, provide extension advice on their use, and purchase farmers' output for aggregation and resale. Resource-providing contracts like this are common in many agricultural value chains (Minot and Sawyer, 2016; de Janvry and Sadoulet, 2020). Our intervention supplements this arrangement by offering credit for the purchase of the quality-improving technology Aflasafe, training on how to use it, and a guaranteed price premium over the usual contracted price that cooperatives offer. We implement a cluster-randomized experiment to test this intervention with a sample of 396 farmers in 40 villages.

We find that the intervention is successful at resolving individual constraints to investment in quality. Take-up of the technology in control villages was relatively low at 10 percent.[5] By comparison, in treated villages, take-up was 89 percent. In other words, bundling input credit, information, and a price premium guarantee is sufficient to achieve nearly universal investments in quality upgrading for aflatoxin prevention in our context. This finding is in line with a growing body of evidence on the potential of bundled interventions (Abate et al., 2018; Deutschmann et al., 2021; J-PAL and CEGA, 2022; Suri and Udry, 2022).

Our study takes place in a context with market-level barriers to successful contracting. Inconsistent but high spot market prices regularly lead to breakdowns of the informal contracting relationship between producers and cooperatives. In Senegal, the primary driver of high spot market prices is growing demand from China. According to COMTRADE data on exports of unprocessed groundnuts, exports to China made up about 28 percent of total exports by weight on average in the first five years after Senegal lowered export barriers in 2010. In the subsequent five years from 2015 to 2019, exports to China grew to constitute 91 percent of total exports on average. Spot market buyers selling to the Chinese market

[3] After more than five years of efficacy trials in Senegal and more than ten years of development in Nigeria, led by the International Institute for Tropical Agriculture, Aflasafe SN-01 received regulatory approval and launched for commercial sale in 2019. Senegal is one of the first countries in Africa where Aflasafe is produced locally by a commercial partner.

[4] Treating one hectare of cropland costs about $17 USD at market price. The mean production on one hectare (about 900 kgs) is worth about $350 USD at 2018 market prices.

[5] This is not out of line with results from other studies of Aflasafe in particular (Hoffmann et al., 2018b) or smallholder technology adoption more generally.

generally do not reward aflatoxin reduction, given the limited observability of contamination levels without costly verification and the reportedly lax enforcement of aflatoxin standards for imports to China. However, increasingly strict food safety regulations in China may substantially impact spot market buyers' willingness to buy low-quality groundnuts in the future (Sun et al., 2021).

Given the important role of the spot market, and the potential for significant disruption to that market as the Chinese government increases enforcement of food safety standards, it is important to consider how our intervention impacts the commercialization decisions of farmers. Prices paid in spot markets vary considerably from season to season, but in the year of our study exceeded the government-set price floor by 43%. In Senegal, groundnut cooperatives typically purchase groundnuts at that government-set price floor and on-sell to the parastatal groundnut oil company. In the year of our study, producers in control group opted to sell 48% of their groundnut production outside the cooperative and just 12% to the cooperative. This is comparable to the previous year (52% on the spot market, 17% to the cooperative), and mirrors findings from Aflagah et al. (2022) demonstrating the difficulty cooperatives face in aggregating a large quantity of output.

Our intervention takes a small step towards addressing market-level challenges limiting successful contracting. Farmers in the treatment group had access to a minimum quality bonus of 40 CFA/kg conditional on the results of an aflatoxin quality test. This quality bonus was promised on top of the government-set price that cooperatives typically pay, representing a roughly 20% premium over that government price. Treated farmers increased total output sales to the cooperative by about 65% relative to farmers in the control group, selling 19% of their groundnut production to the cooperative. However, farmers in the treated group still elected to sell 41% of their output on the spot market which offers no aflatoxin-contingent pricing. Given high market prices outside the cooperatives, farmers with high-quality production faced a much smaller trade-off when choosing where to sell, whereas farmers with low-quality production were unambiguously better off selling on spot markets. Although our intervention improves output aggregation for the cooperative, the effect is small in magnitude. Our paper provides a cautionary tale, in line with findings in Ashraf et al. (2009) and Bernard et al. (2017), that resolving individual-level constraints for smallholder farmers may be insufficient when market-level forces undermine farmer incentives.

Given the contracting environment we study, with low capacity for external enforcement, understanding how contract success varies with informal norms of behavior is instructive about the mechanisms driving the average effect we uncover. Behavioral characteristics can play important roles in commercial relationships, particularly in the context of repeated interaction (Sobel, 2005; Leider et al., 2009; Finan and Schechter, 2012; Ligon and Schechter, 2012; Cabral et al., 2014). We hypothesize that reciprocity in particular may interact with the new contracting arrangement, if reciprocal farmers seek to reward the "kindness" of inclusion in the contracting scheme by selling more output to the cooperative. We measure intrinsic reciprocity using questions from the Global Preferences Survey (Falk et al., 2016, 2018). We find that treated high-reciprocity farmers are 27 percentage points more likely to sell any output to the cooperative, an effect more than twice as large as the average treatment effect we observe.

We also provide important evidence for the efficacy of the Aflasafe technology under realistic production conditions. Much of the existing evidence for its effectiveness stems from controlled agronomic field trials. We find that the intervention resulted in measurably higher-quality production, but only in high-risk areas. Our data collection confirms that aflatoxin contamination is indeed a problem in the groundnut basin of Senegal: less than 70 percent of farmers in the control group were in compliance with European Union import standards.[6] We focus on European standards because they are the strictest in the world, and Europe is among the most largest importing regions for groundnuts (CBI, 2022). Farmers in the treatment group were 12% more likely to comply with these strict standards, but the average effect is not statistically significant. However, in line with previous work (Waliyar et al., 2015; Magnan et al., 2021), we find that aflatoxin contamination is highly variable across space, even in the absence of any mitigation measures. Temperature and rainfall can significantly affect aflatoxin contamination risk (Cotty and Jaime-Garcia, 2007; Bowen and Hagan, 2015; Hendrix et al., 2019). Using satellite data on growing season temperature and precipitation, we estimate contamination risk using samples collected from control farmers. We then predict which villages experienced the highest average risk of contamination given growing-season temperature and rainfall. In areas where contamination risk was highest, the intervention has a large and statistically significant effect on standard compliance. In our preferred specification, treated farmers in high-risk areas produce groundnuts 49% more likely to comply with the strictest international standards compared to control farmers in the same areas.

We extend our analysis using administrative data from our partner cooperatives to show that demand for Aflasafe two years after our study persisted more strongly among farmers in our treatment group, but there was a significant drop-off in adoption and we find no evidence of spillovers.[7] In the follow-up season, the cooperatives distributed Aflasafe as they do other inputs, namely by first eliciting interest from all members, and then deciding how to allocate credit among those interested. Neither cooperative provided an explicit price premium guarantee. We match the villages and farmers from our study to the logs of both interest and purchases. We find that farmers in our treatment group were 95% more likely to purchase Aflasafe than farmers in the control group. We observe no evidence of spillovers:

[6] Although we focus on export market standards here, aflatoxin contamination is also highly relevant for local public health because most producers retain some production for home consumption. Previous work in Senegal found post-harvest aflatoxin contamination in groundnuts to be correlated with levels of aflatoxin-albumin adduct (AF-alb), a biomarker of aflatoxin exposure (Watson et al., 2015).

[7] The intervening year coincided with the arrival of COVID-19 in Senegal, and significant disruptions to the availability of all inputs and the ability for farmers to travel to purchase them.

demand among non-sampled farmers in treated villages was no higher than non-sampled farmers in control villages, nor when compared to villages not sampled for the original study. Despite the persistent increase in demand among treated farmers, adoption in this group was only 14%, suggesting a large majority of farmers in this group chose not to continue using Aflasafe. It could be that the absence of a price premium guarantee discouraged adoption, or that farmers' recent experiences with high spot market prices limited their interest in investing in the technology.

Our work contributes to the literature in three ways. First, we contribute to the substantial literature on agricultural technology adoption. Credit, information, and price uncertainty may all be relevant constraints limiting adoption of improved technologies in a particular context (Feder et al., 1985; Foster and Rosenzweig, 2010; Magruder, 2018). Credit in particular, by shifting the timing of payment or salience of the total cost, can increase adoption of a variety of technologies including fertilizer, bednets, and crop insurance (Duflo et al., 2011; Devoto et al., 2012; Tarozzi et al., 2014; Casaburi and Willis, 2018). A growing body of evidence suggests bundling interventions together to address several of these constraints can be highly effective at increasing technology adoption and farmer productivity (Abate et al., 2018; Deutschmann et al., 2021). In our setting, we study the introduction of a brand new technology into the market. We show that bundling credit, information, and price certainty in a contracting arrangement can be an effective tool for buyers to induce widespread adoption of the new technology and ultimately source larger quantities of higher-quality production.

Second, we contribute to a growing literature on contracting in settings with limited enforcement. Existing work suggests contract farming can be an effective avenue for farmers to improve productivity or quality (Arouna et al., 2021; Macchiavello and Miquel-Florensa, 2019).[8] Successful contracting typically depends on either effective institutions or informal relationships, often termed relational contracting (Brown et al., 2004; Michler and Wu, 2020). Previous work has additionally demonstrated the complementary nature of norms, incentives, and reciprocity in enforcing informal contracts (Charness and Haruvy, 2002; Fehr et al., 2009; Rigdon, 2009; Finan and Schechter, 2012; Kessler and Leider, 2012; Fahn, 2020). We contribute new field-experimental evidence that reciprocity and patience are determinants of relational contract success.

Third, we contribute to a small but important literature on the determinants of aflatoxin mitigation by smallholder farmers. Given the public health implications of widespread aflatoxin exposure, especially in low-income countries, it is of direct policy interest to understand the best strategies for reducing contamination. Previous work on bio-control technology in particular has found that a price premium alone, or a price premium bundled with index insurance, can induce modest increases in technology adoption (Hoffmann et al.,

[8] Contract farming can also affect other dimensions of farmer welfare, by increasing food security (Bellemare and Novak, 2017) or reducing income volatility (Bellemare et al., 2021).

2018b; Narayan et al., 2019; Hoffmann et al., 2022). More generally, information and price premiums can induce increased adoption of complementary aflatoxin mitigation strategies, like drying crops on a tarp or storing them in hermetic storage bags (Magnan et al., 2021; Bauchet et al., 2020). We find that bundling information, a guaranteed price premium, and credit is sufficient to induce widespread adoption of bio-control technology.

The remainder of the paper is organized as follows. Section 2 provides additional context about aflatoxin and groundnut cultivation in Senegal. Section 3 presents the design of the experiment, and Section 4 provides an overview of the key covariates and outcomes of interest. Section 5 presents the empirical strategy and Section 6 presents the short-run results of our study. Section 7 shows results from administrative data two years after our study, and Section 8 concludes.

2 Context

2.1 Groundnuts in Senegal

Groundnut cultivation has represented a significant fraction of economic activity in Senegal since well before independence.[9] However, as quality standards and the nature of the global groundnut market shifted from oil and processed material to whole nuts, Senegal's share of the international groundnut trade fell from 17 percent in the early 1960s to a low of less than 1 percent in the 1990s. More recently, after easing export restrictions on whole nuts, Senegal has approached 10 percent of world trade in nuts, but with high levels of inter-annual volatility. (World Bank, 2017).[10] Groundnut productivity largely stagnated after the 1960s and Senegal's share of world groundnut production has remained roughly stable at 2-3 percent since the 1990s (Kelly et al., 1996; World Bank, 2017).

The center of groundnut production is the city of Kaolack and the surrounding region, aptly termed the "groundnut basin." Shifting rainfall patterns in the groundnut basin since the 1980s have increased the risk of *a. flavus* development and aflatoxin contamination (Clavel et al., 2013). Consequently, dietary aflatoxin exposure in the groundnut basin is particularly high (Watson et al., 2015). Despite significant work to identify seed varieties more resistant to aflatoxin, agronomists have thus far failed to identify any variety which was completely resistant to aflatoxin contamination (Waliyar et al., 1994; Anderson et al., 1995; Holbrook et al., 2000; Clavel et al., 2013), although new work shows promise in developing aflatoxin-resistant seeds (Sharma et al., 2018).

[9]Cultivation of groundnuts began in Senegal in the 1840s and grew quickly into a major export during the era of French colonial rule (Brooks, 1975).

[10]Despite changes in the nature of the global market, the domestic market is still largely structured to protect groundnut oil producers (including a large state-owned company), with high implicit taxation eroding incentives for non-oilseed production (Masters, 2007; World Bank, 2017). However, in a sign of shifting priorities for rural producers and firms, repeated efforts to impose an export tax on whole nuts have largely failed under public pressure (Fofana et al., 2018).

Groundnut farmers in Senegal are typically members of a cooperative or rural-producers organization. Groundnut cooperatives in Senegal have roots in post-colonial political economy; the first president invested heavily in rural welfare through a robust state-controlled system of cooperatives (Casswell, 1984). In subsequent decades, state involvement in the cooperatives declined. Productivity also lagged as development of new seed varieties slowed and the parastatal groundnut oil producer faced a series of financial difficulties. In recent decades, many cooperative organizations have provided at best limited benefits to members (Bernard et al., 2008). However, work by the Senegalese government and international organizations has resulted in a new class of cooperative organizations more active in input provision and output commercialization (Clavel and Gaye, 2018; Eclosio, 2018). These cooperatives distribute seeds, fertilizer, and pesticides to farmers, typically on credit repayable in kind after harvest. Farmers express their input needs in the months before planting, and the cooperatives aggregate farmer requests to purchase inputs in bulk and re-sell them to farmers. These cooperatives also provide extension services to farmers, with trained technicians on staff and lead farmers active in many villages. They aim to commercialize output collectively, but in practice often pay only the government-set price floor and resell output to the quality-insensitive state-owned groundnut company.[11]

In this setting, farmer non-compliance with relational contracts (i.e., side-selling to buyers other than the cooperative) is common, but inconsistent, as spot market prices (shown in Figure 1) can vary significantly from one year to the next. Cooperatives may punish complete non-compliance by restricting future access to credit or other services like plow rental. However, the main channel by which cooperatives encourage compliance is positive in nature: namely, access to trials and new technologies. Baseline data in our sample suggests groundnut farmers in Senegal are generally willing to adopt technologies: more than 70 percent use fertilizer, 60 percent use pesticides or other products, 47 percent use improved seed varieties,[12] 98 percent use an animal-driven seeder, and 100 percent use an animal-driven plow. Many of the "new class" cooperatives in Senegal are active in developing and testing new seed varieties, new farming techniques, and new contracting arrangements (Clavel and Gaye, 2018; Eclosio, 2018). Conversations with cooperative leaders suggest they prefer to allocate access to these trials to farmers they see as reliable or highly skilled.

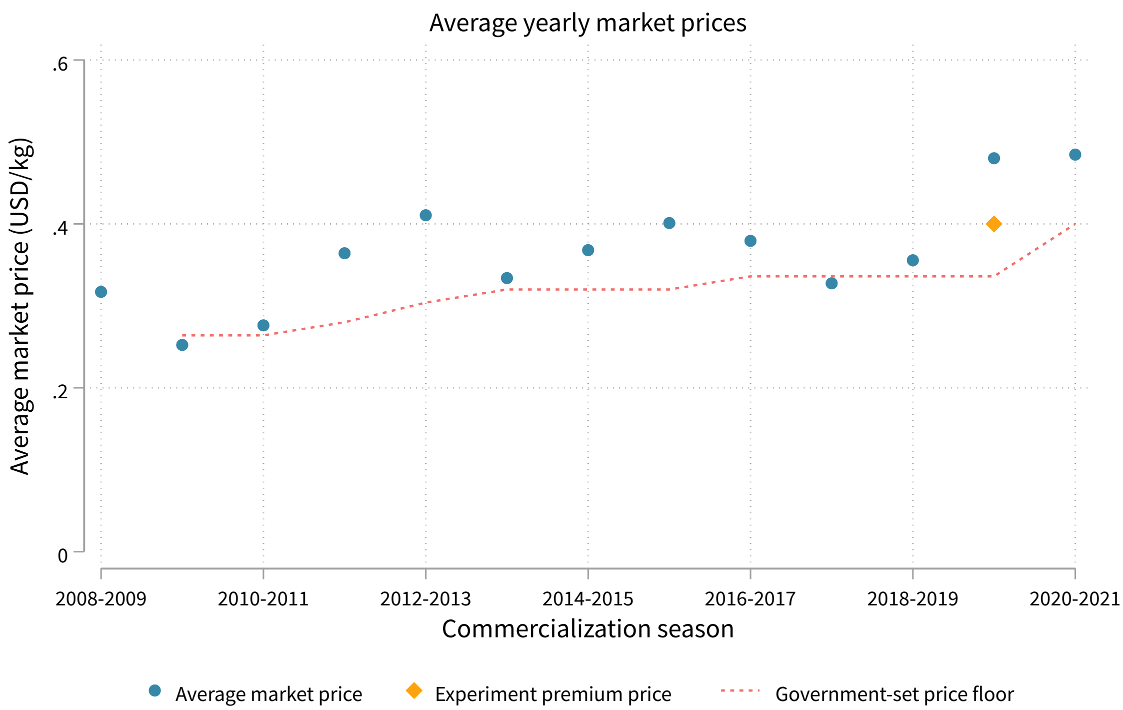
2.2 Aflatoxins

The quality measure we study in this paper is aflatoxin contamination. Aflatoxins are toxic compounds produced by *aspergillus flavus*, a fungus which contaminates crops from soil and

[11]The price floors that cooperatives and oil-press companies in Senegal follow are set annually by the National Inter-professional Groundnut Committee (CNIA), with some debate over how much the state influences the price chosen each year (Diagana, 2008). We show how these price floors compare to average annual market prices in Figure 1.

[12]Many "improved" seed varieties widely used in the groundnut basin of Senegal are old varieties, introduced more than 30 years ago. However, 13 percent of farmers report participating in a seed trial at baseline.

Figure 1: Average annual market prices and government-set floor prices



Source: Commissariat à la Sécurité Alimentaire survey data and Comité National Interprofessionnel de l'Arachide reports. The market prices are averaged over the period November to May of each commercialization season and include all observations from the Kaolack and Fatick regions.

spreads during storage (Frisvad et al., 2019). Aflatoxins affect a variety of staple and cash crops including maize, rice, and groundnuts (Udomkun et al., 2017). Across sub-Saharan Africa, research has found consistently high levels of human and animal aflatoxin exposure (Watson et al., 2015; Sirma et al., 2018; Blankson et al., 2019). Aflatoxin exposure has a variety of impacts on human and livestock health. Acute exposure to high levels of aflatoxins can be deadly (Probst et al., 2010; Kamala et al., 2018). Chronic exposure to lower levels of aflatoxins can cause child stunting, cancer, and immunosuppression (Coursaget et al., 1993; Wild, 2002; Hoffmann et al., 2018a; Voth-Gaeddert et al., 2018; Watson et al., 2018).[13] Aflatoxin exposure via contaminated feed products also affects livestock health and can transmit to humans via milk products (Bryden, 2012).

Governments and large buyers of crops across Africa have identified aflatoxin control as a key public health challenge (Partnership for Aflatoxin Control in Africa, 2015). The European Union began implementing harmonized aflatoxin standards in 2002 (Otsuki et al., 2001), with significant effects on Senegalese firms seeking to export whole groundnuts to European markets (Mbaye, 2005). This is not a problem unique to Senegal: existing work suggests firms and agricultural exporters are often constrained by stricter product standards in destination markets (Ferro et al., 2015; Fontagné et al., 2015; Fernandes et al., 2019).[14] African producers and exporters were particularly impacted by changes in EU standards (Agyekum and Jolly, 2017).

Aflatoxins are difficult to control because they are not directly observable: contaminated crops can look, smell, and taste identical to non-contaminated crops. Chemical tests for aflatoxins exist, but are not widely available, and the costs of consumable materials and testing equipment are non-trivial.[15] Early conversations with exporters and agro-processors during the design phase of this project suggest many are concerned about aflatoxins and eager to source low-aflatoxin groundnuts, but lacked the means to reliably identify them in the value chain.

Fragmented value chains between smallholder farmers and consumers, agro-processors and exporters make aflatoxin control along the chain a challenging and potentially costly proposition. Existing research on reducing aflatoxin incidence at the farmer level has found that low-cost practices (such as drying crops on a tarp) can reduce aflatoxin contamination (Turner et al., 2005; Magnan et al., 2021; Pretari et al., 2019; Bauchet et al., 2020; Jordan et al., 2020). However, the market rewards for a small farmer to reduce aflatoxin contamination are unclear. Consumer demand for reduced aflatoxin in local markets is inconsistent (Prieto et al., 2019; Hoffmann et al., 2020b,a). Contaminated crops are often sold to consumers in powdered or transformed form (Florkowski, 2014). Exporters and other quality-sensitive

[13]One study hypothesizes that reducing aflatoxin exposure to non-detectable levels could reduce liver cancer cases in high-risk areas by 23% (Liu et al., 2012).

[14]In addition, previous work in Senegal found that tightening standards for fruit and vegetable exports to the EU induced structural changes in the supply chain (Maertens and Swinnen, 2009).

[15]In 2016, ICRISAT announced a new low-cost aflatoxin test kit that would be available for less than $2 per test (compared to $20-25 per test for existing kits). However, this technology is not yet widely available.

buyers typically do not work with small farmers directly.

2.3 Bio-control for aflatoxin reduction

Agronomists have developed a new bio-control technology to fight against aflatoxin contamination.[16] Marketed under the umbrella brand name *Aflasafe*, this technology is designed to limit the development of toxic strains of *aspergillus flavus* in fields (Bandyopadhyay et al., 2019). In each country where Aflasafe has launched,[17] local strains of *a. flavus* are first collected to identify competitive strains which do not produce aflatoxins. These strains are isolated and replicated to produce products like Aflasafe SN-01, which launched in Senegal and the Gambia in 2019 after more than five years of efficacy trials (Senghor et al., 2020). The technology uses sterilized seeds (which will not grow) as a delivery mechanism, with the concentrated Aflasafe treatment applied as a seed coating. To protect a plot, farmers broadcast the Aflasafe-coated sterile seeds in the field 4-6 weeks after planting. The atoxigenic Aflasafe strains spread in the fields and prevent the aflatoxin-causing strains from developing on crops.

Compared to existing aflatoxin control strategies, Aflasafe has two key advantages. First, it may provide lasting aflatoxin protection even if storage conditions along the value chain are not always ideal. Agronomic research in Senegal has found that, even if non-treated and treated samples show similar aflatoxin levels immediately post-harvest, poor storage conditions will cause measurable differences in contamination in a matter of weeks.[18] Second, Aflasafe may be more cost effective than hermetic storage bags, another proposed solution for aflatoxin control. Treating one hectare of groundnuts with Aflasafe costs about $17 USD at current market prices. By comparison, purchasing hermetic bags in Senegal to store the production from one hectare may cost $40 or more (Bauchet et al., 2020).[19]

3 Research Design

We implemented this project in partnership with two cooperatives located in the groundnut basin of Senegal, in the Kaolack and Fatick regions (Figure 2). These cooperatives are active in providing services to members, including input distribution, access to credit, and agricultural extension support. They focus primarily or exclusively on groundnut production.

[16] While this technology is new for African contexts, similar aflatoxin bio-control products have been used commercially in the United States for more than 20 years in a variety of crops (Dorner and Lamb, 2006; Dorner, 2009; Doster et al., 2014).

[17] As of September 2020, localized versions of Aflasafe are on sale in seven countries in Africa, with development at various stages in thirteen more.

[18] Source: preliminary research results and correspondence from IITA agronomic field staff in Senegal. It is worth noting, however, that this result is not conclusive in the literature: at least one study found that bio-control technology alone is insufficient to offer lasting aflatoxin protection during storage (Kinyungu et al., 2019).

[19] If farmers are able to re-use hermetic storage bags for several years, the cost of the two strategies becomes comparable.

In what follows, we refer to our partner cooperatives as Northern and Southern, indicating their location relative to the Saloum river. Each cooperative is organized into village sections, where each section typically has a president and one or more lead farmers.[20] Each cooperative has a membership of at least 1500 farmers divided into more than 50 village-level sections. Using the membership lists of each cooperative as a sampling frame, we selected a study sample of farmers from 40 villages. We initially sampled 10 farmers per village, with 5 replacement farmers available, and ended up with a final sample of 396 participating farmers after the baseline.

We assigned 20 villages each to treatment and control groups.[21] Village randomization was stratified at the rural commune level, the smallest level of administrative division at the rural level. All sampled farmers were offered a free aflatoxin test, and all farmers received the same information about Aflasafe. Farmers in the treatment villages were eligible to purchase Aflasafe on credit, repayable in cash or in kind after harvest. They were also promised a minimum price premium, relative to the state-set price typically offered by cooperatives, of 40 CFA (about $0.07) per kg conditional on the results of an aflatoxin test.[22] Farmers in control villages were eligible to purchase Aflasafe, but had to pay up front. They were also informed that they could have their production tested for aflatoxins, but with no promise of a price premium. Farmers in the treated group additionally received an ex-ante promise of assistance applying the product from trained cooperative extension agents.[23]

We conducted a baseline survey in June and July 2019, collecting detailed information about farming practices in the previous season and plans for the current season, as well as aflatoxin awareness, involvement with and trust in the cooperative, and reciprocity. We introduced Aflasafe to farmers at the end of the baseline survey. First, enumerators read a script explaining the health risks caused by aflatoxin exposure. Then, they explained how Aflasafe works, discussed with farmers how to use it, and showed farmers a video which demonstrated how to apply Aflasafe to a field.[24] Finally, they distributed to each farmer a ticket they could redeem with the cooperative to access 10kg of Aflasafe (to be paid cash or on credit, depending on treatment status), sufficient to treat one hectare of groundnuts.[25] Farmers learned the details of their treatment assignment upon receiving this ticket, which

[20] Lead farmers and village presidents are typically the channels by which the cooperatives diffuse information about practices and new technologies.

[21] Because *aspergillus flavus* can spread between neighboring fields, we chose to randomize treatment at the village level rather than the individual level.

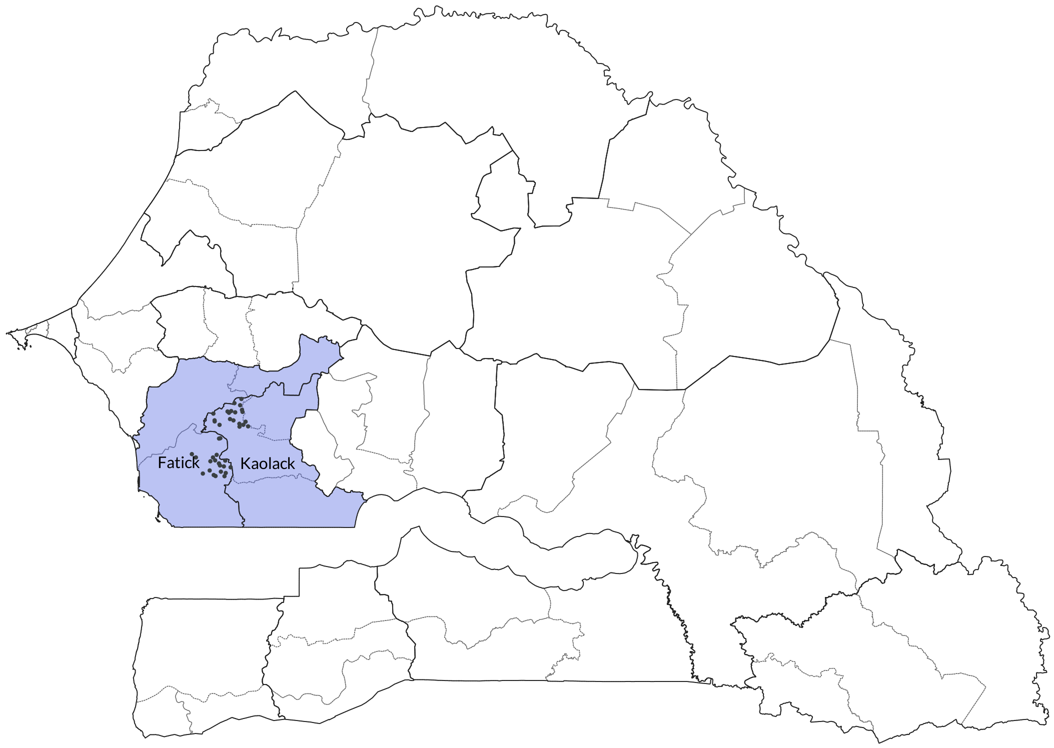
[22] This is a gross premium, not inclusive of the amount farmers need to repay to cover the cost of their Aflasafe purchase. At market prices in the season we study, farmers who chose to repay their credit in kind would need to sell an additional 40-48 kgs to their cooperative.

[23] After farmers made adoption decisions, both groups received a similar level of help applying the product. The difference between the two groups is the ex-ante promise of assistance.

[24] The full script (translated to English) is shown in Appendix D. The video can be seen here: video link (Wolof).

[25] Due to project budget constraints and to ease logistics, we standardized the bundle offer to farmers as a single package of 10kg. Given the highly limited supply of Aflasafe in Senegal in the year of our study, farmers could not have sourced an additional quantity from other sources.

Figure 2: Study regions and sampled villages



included a unique code for each farmer as well as a reminder about the contract terms for treated farmers.

Next, in August 2019 we called all participants to inform them that Aflasafe had become available at their cooperative[26] and remind them of the terms of their treatment assignment. We additionally asked for the date they planted their groundnuts, and informed them of the suggested window for Aflasafe application based on their planting date (roughly six weeks after planting).

Aflasafe distribution was managed directly by the cooperatives, and was run similarly to how other inputs are distributed. This means that farmers in villages near to the cooperatives go directly to the warehouse to pick up inputs, whereas for villages further from the warehouse, the cooperative collects orders in advance and organizes a delivery by truck. Enumerators were present in the headquarters of each cooperative during distribution to ensure treatment status was respected (i.e., that control-group farmers who had to purchase the product up front did pay up front, and treatment-group farmers who could receive

[26]When we initially surveyed farmers during the baseline survey, we expected Aflasafe to be available for them no later than the end of July. Due to delays in production by the local manufacturer, the product was not actually available until late August.

product on credit received the product on credit).

After the product was distributed, extension agents from each cooperative visited each village to help farmers apply the product correctly. Although the application process is simple—farmers broadcast 10kg of the product relatively uniformly over one hectare—cooperative agents wanted to ensure farmers were well-informed about the process. These trained agents helped ensure correct application and recorded the date on which farmers applied the product. All adopting farmers received the same extension support from the cooperative.

After harvest, in December 2019 and January 2020, we sampled and tested the groundnuts to determine aflatoxin levels for farmers in the sample. Some farmers delivered groundnuts for sale to the cooperative, and for these farmers we collected a sample from the groundnuts delivered for sale. However, market conditions meant buyers outside the cooperative were often paying farmers higher prices, so many farmers elected to sell their groundnuts elsewhere and simply reimburse the cooperative in cash to cover their credit. For these farmers, we worked with village section presidents and agents from the cooperative to collect samples. Despite offering farmers a significant premium for a sample sufficient to measure aflatoxin levels, we were ultimately only able to test 83% of farmers. Some attrition at this stage was due to crop failure, whereas others reported selling their entire crop before we tried to collect a sample. To test the level of aflatoxin, we conducted lateral flow tests using a Neogen Raptor reader and standard sampling and testing procedures used by IITA for all Aflasafe development activities.

Farmers from treated and control villages who chose to adopt Aflasafe and achieved aflatoxin levels less than 4 parts per billion (ppb) received a premium price from the cooperative for their certified groundnuts.[27] This premium was paid only for bags delivered to the cooperative in advance of testing, and the resulting bags were sampled and certified following the test. Farmers were paid 250-275 CFA ($0.43-0.47) per kg for their certified production - the final price was set by each cooperative depending on their logistical overhead costs. This represented a significant premium over the government-set price of 210 CFA ($0.36) per kg, although anecdotal reports suggest high export demand from Chinese buyers resulted in comparable prices in local markets irrespective of aflatoxin levels.

Finally, we conducted an endline survey with farmers in June 2020. This endline survey was conducted by phone due to the COVID-19 crisis. We collected aggregate farmer-level estimates of groundnut production, output sales, and revenue. We also elicited endline awareness of aflatoxin and recall of their aflatoxin test results.

[27] For control farmers, this was unexpected, as they received no guarantee of a price premium at baseline. If the premium available from reselling these low-aflatoxin groundnuts was less than the premium promised to treatment group farmers, control farmers would have received a lower price.

4 Data

In this section we describe the characteristics of the study population and the market environment. We additionally present information and summary statistics about the outcomes of interest.

4.1 Baseline

Table 1 presents summary statistics and baseline balance tests. The characteristics of our sample motivate the importance of our project. In particular, note that the median farmer does not have a savings account (either in a bank or with a mobile money provider), consumes some of his output, and was unaware of aflatoxin at baseline. Most farmers have experience adopting fertilizer and pesticides, but yields-per-acre are relatively low by global standards at about 900 kgs/hectare.[28]

We elicited several measures of potential behavioral mechanisms, following our Pre-Analysis Plan, using questions drawn from Falk et al. (2016, 2018). In particular, we elicited measures of intrinsic reciprocity, patience, and risk aversion (see Appendix D.2 for the exact question wording we used). Intrinsic reciprocity plays an important role in repeated interactions, and individuals may reward past kindness or punish past unkindness (Sobel, 2005; Cabral et al., 2014). We hypothesized that highly reciprocal individuals may be more affected by a contract offer; namely, high-reciprocity treated farmers may be more likely to adopt the technology and sell output to the cooperative. We additionally hypothesized that patience and risk aversion would moderate adoption decisions: for control farmers, adoption required payment now for a possible benefit in the future, whereas treated farmers could delay payment until harvest and had more certainty about the potential benefits.

Table 1 additionally presents balance tests. We test for balance individually and jointly across treatment and control groups. We find only one variable (reciprocity) with a statistically significant difference at the 10% level. To test joint balance, we first implement the conventional asymptotic test, regressing the treatment dummy on all the variables presented in Table 1, with commune dummies included and standard errors clustered at the village level. Despite failing to find a significant difference in any individual variable, this test does reject that treatment is jointly orthogonal to all baseline variables. However, as Hansen and Bowers (2008) point out, when the number of covariates is "large" relative to the number of clusters, asymptotic tests may over-reject the null. Therefore we additionally conduct a randomization inference procedure (Heß, 2017), taking placebo draws of treatment status at the village level (stratified by commune), and repeating the regression of placebo treatment status on the set of baseline covariates to generate an empirical CDF of F-statistics. We fail to reject the null of joint orthogonality using this approach. There is some disagreement in

[28] Groundnut yields in China (the largest producer in the world) recently exceeded 3.5 metric tons per hectare. By comparison, yields in India (the second largest producer) are more comparable at 1-1.3 metric tons per hectare (USDA Foreign Agricultural Service, 2020).

Table 1: Baseline balance and summary statistics

Variable	(1) Control Mean (SD)	(2) Treatment Mean (SD)	Difference (2)-(1) [p-value]
Demographic variables			
Married (0/1)	0.92 (0.27)	0.91 (0.29)	-0.01 [0.62]
Polygamous marriage (0/1)	0.38 (0.49)	0.46 (0.50)	0.09 [0.14]
Female (0/1)	0.36 (0.48)	0.31 (0.46)	-0.04 [0.52]
Household head (0/1)	0.63 (0.48)	0.62 (0.49)	-0.01 [0.82]
Completed secondary school [resp.] (0/1)	0.11 (0.31)	0.10 (0.30)	0.00 [0.91]
Completed sec. school [any in HH] (0/1)	0.57 (0.50)	0.60 (0.49)	0.02 [0.79]
Household size	16.17 (10.11)	16.39 (9.33)	0.13 [0.89]
Children in household	6.63 (4.77)	6.99 (5.11)	0.31 [0.56]
Age	49.11 (13.01)	47.66 (12.82)	-1.48 [0.32]
Agricultural variables			
Aware of aflatoxin (0/1)	0.09 (0.29)	0.13 (0.34)	0.04 [0.25]
Savings account (0/1)	0.34 (0.47)	0.31 (0.46)	-0.03 [0.57]
Lead farmer (0/1)	0.11 (0.31)	0.15 (0.35)	0.03 [0.45]
Used fertilizer (0/1)	0.66 (0.47)	0.75 (0.43)	0.08 [0.17]
Used pesticides (0/1)	0.62 (0.49)	0.58 (0.50)	-0.04 [0.51]
Consumes some output (0/1)	0.72 (0.45)	0.74 (0.44)	-0.01 [0.90]
Sold to cooperative (0/1)	0.29 (0.46)	0.40 (0.49)	0.10 [0.14]
Sold to other traders (0/1)	0.77 (0.42)	0.75 (0.43)	-0.01 [0.87]
Kept as seeds or given away (0/1)	0.71 (0.46)	0.71 (0.46)	0.01 [0.78]
Groundnut hectares cultivated	3.56 (2.64)	3.40 (2.52)	-0.09 [0.74]
Groundnut yield (kgs/hectare)	859.31 (678.48)	909.49 (922.68)	36.87 [0.59]
Recent cooperative member	0.30 (0.46)	0.24 (0.43)	-0.06 [0.55]
Behavioral variables			
Risk loving (0/1)	0.21 (0.41)	0.24 (0.43)	0.03 [0.34]
Patient (0/1)	0.79 (0.41)	0.78 (0.41)	-0.01 [0.78]
Reciprocal (0/1)	0.45 (0.21)	0.49 (0.25)	0.04* [0.06]
p-value, F-test of joint orthogonality across groups (asymptotic)			0.00
p-value, F-test of joint orthogonality across groups (empirical CDF)			0.55
Number of observations			396

Note: standard errors for differences for each baseline variable are clustered at the treatment assignment (village) level. Individual balance tests include commune fixed effects to account for randomization stratified at commune level. The p-value for the asymtotic test that observations are jointly orthogonal across groups is estimated using OLS, with treatment assignment as the dependent variable, all baseline covariates as independent variables, commune fixed effects, and standard errors clustered at the treatment assignment level. The p-value for the empirical CDF test is estimated using 1000 placebo draws that re-assign treatment at the village level, within commune strata, and computing the share of placebo F-statistics larger than the actual test statistic (Hansen and Bowers, 2008).

the literature about how to account for balance, or imbalance, in a randomized trial (Imai et al., 2008; Bruhn and McKenzie, 2009; Mutz et al., 2019; Snyder and Zhuo, 2020). In our preferred specifications below, we control only for commune, the level at which cluster randomization was stratified. However, we also present results which control for all baseline covariates shown in Table 1, which rarely leads to any change in the sign, magnitude, or statistical significance of our results.

4.2 Adoption and Intentions

Next, we turn to our primary outcome measure: adoption of the new technology. We observe two potential measures of adoption, based on administrative data and self-reported endline data. The administrative measure relies on two datasets shared by our partner cooperatives: the administrative logs from distribution, and field visit logs by extension agents. These two datasets coincide for 94% of observations.[29] In the analysis that follows, we use a harmonized measure which flags a farmer as having adopted if either the distribution logs or field visit logs indicate adoption. However, results are robust to using each underlying log file individually.[30] The second measure relies instead on the self-reported use of Aflasafe from the endline survey. As Figure B.2 demonstrates, self-reported Aflasafe use is slightly higher for control farmers and slightly lower for treated farmers compared to the administrative measure. The difference in these two measures could indicate some leakage from treated farmers to control farmers, even though treatment was randomized at village level and adopting farmers received assistance and supervision applying the product.[31]

4.3 Quality

The quality measure we study is aflatoxin contamination. As described above in Section 3, we collected samples from farmers in the first six weeks of the commercialization season and tested them for aflatoxin. Our primary quality-related outcome of interest is whether or not farmers produced groundnuts in compliance with the strict European Union standards for aflatoxin contamination. Figure 3 shows that only 66% of control group farmers were in compliance with those standards, suggesting high incidence of contamination. This result is in line with results from agronomic trials conducted elsewhere in Senegal in the same year (see Figure B.1).

We focus on a binary measure of quality standard compliance for two reasons. First, this is the most salient threshold for exporters, and therefore of particular importance for farmers and intermediaries seeking to access the lucrative European market. Second, our testing

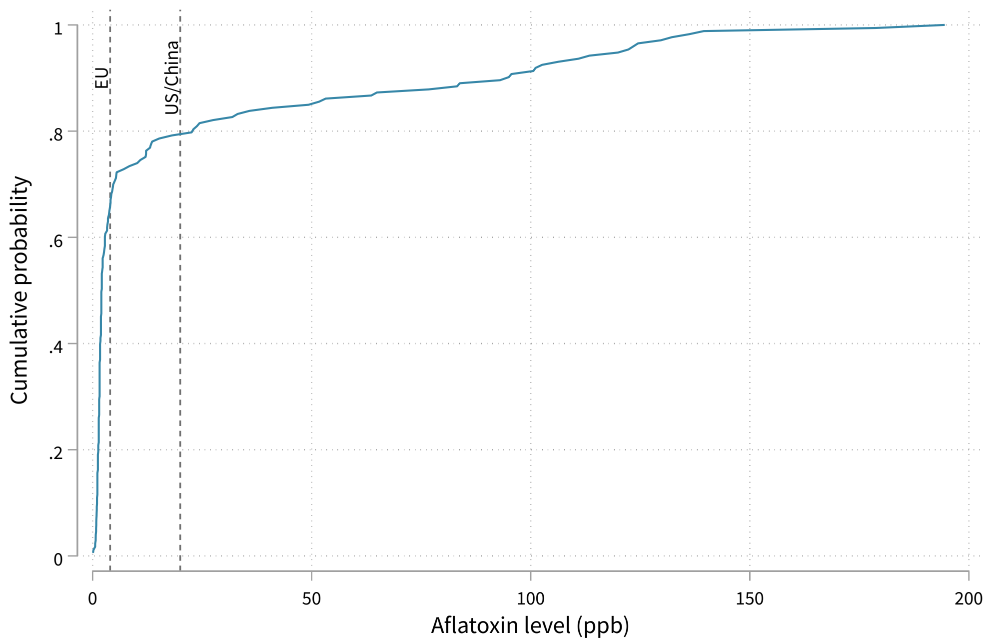
[29] For the other 6%, about 2% are flagged as purchasing Aflasafe without applying it, and about 4% are flagged as receiving extension assistance applying Aflasafe without purchasing it.

[30] We additionally sent enumerators to audit a randomly-selected 50% of villages and confirm the technology was distributed and applied. In each village, they spoke to up to two randomly-selected adopters and non-adopters (as defined by the field visit logs). In only one case did they find a respondent flagged as a non-adopter in field visit logs but who reported receiving and applying the technology. In one case they also found a respondent flagged as an adopter who received but elected not to apply the technology.

[31] To rule out spatial spillovers in adoption, we estimate a regression specification similar to the one used in Miguel and Kremer (2004), in which we include the average treatment status or adoption decision in nearby villages. After controlling for a village's treatment status, these additional variables have no statistically significant effect on self-reported or admin data adoption.

procedure has a minimum level of detection of 2 parts per billion (well below the EU quality standard). That is, any results below 2 only tell us that the sample was not contaminated, but do not tell us the exact level of aflatoxin detected. This does not affect our analysis of the EU cutoff, but does affect our analysis of the continuous outcome. Importantly, 160 out of 328 samples tested fall below 2 ppb, so this potentially impacts a large portion of our sample. We set any test results equal to the midpoint (1 ppb) if the recorded result was less than or equal to 2 ppb.

Figure 3: Distribution of aflatoxin levels among farmers in the control group

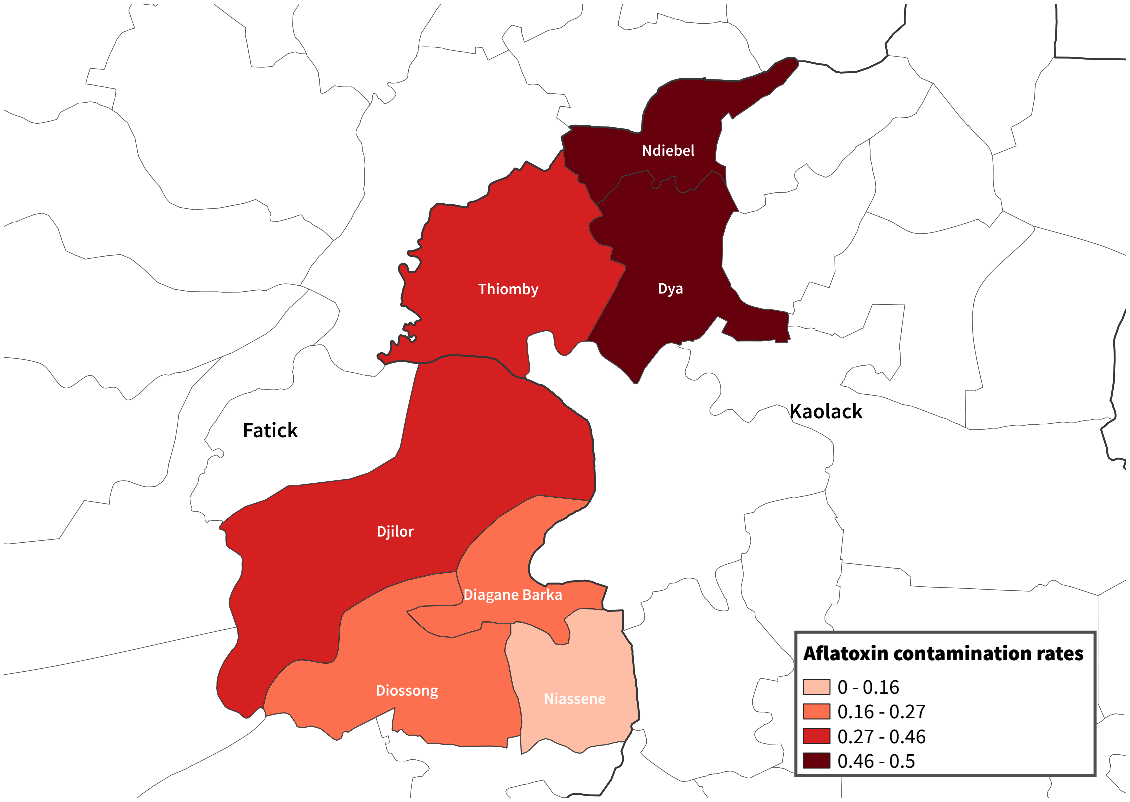


Note: This figure shows the result of aflatoxin tests done on samples collected from farmers in the control group. The first line, marked "EU", corresponds to the legal limit on aflatoxins imposed by the European Union (4 ppb). The second line, marked "US/China", corresponds to the legal limit on aflatoxins imposed by the US and China (20 ppb).

In the absence of Aflasafe use, aflatoxin levels can vary significantly across space and time. Figure 4 shows the commune-level average rates of contamination among control farmers in our sample. The figure demonstrates that average rates of EU phytosanitary standard non-compliance range from below 16 percent in one commune to more than 46 percent in others. This is not out of line with previous findings in the literature. Magnan et al. (2021) observe even higher spatial variation in contamination among groundnut samples in Ghana over three seasons. Waliyar et al. (2015) find 59-66 percent of groundnut samples with contamination above 4 parts per billion in different districts in Mali across two seasons.

An additional issue with measuring the effects of the contract on quality is sample attrition. As mentioned above, for farmers who delivered output to the cooperative, we

Figure 4: Incidence of aflatoxin contamination in control villages varies by commune



Note: This figure shows commune-level average rates of non-compliance with EU phytosanitary standards for aflatoxin contamination (4 parts per billion). The sample is restricted to control group farmers. The color scale groups communes by quartile of contamination rates.

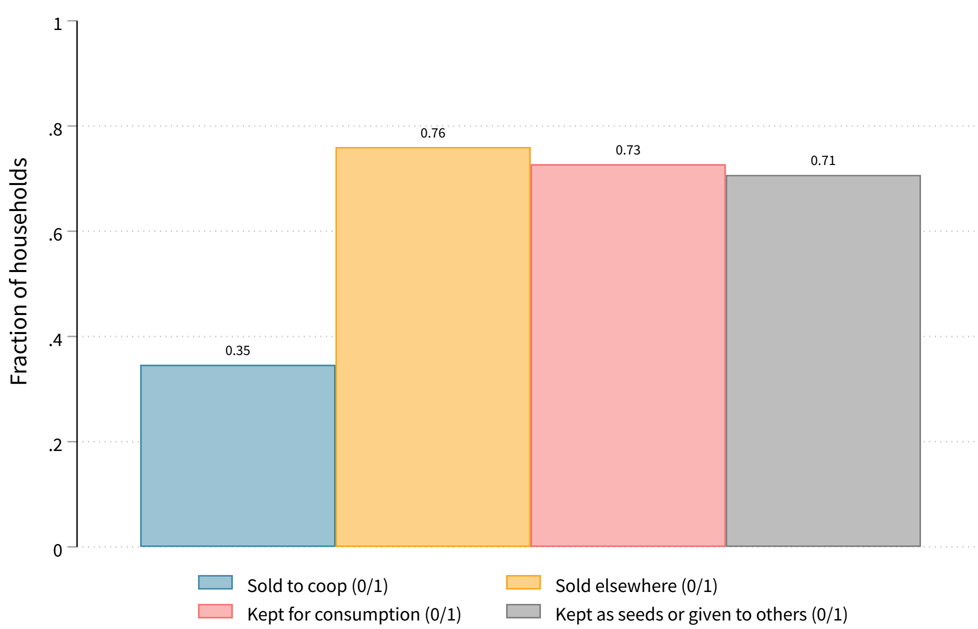
sampled that output to test for aflatoxin levels. However, with many farmers electing to sell no output to the cooperative, we had to adapt our data collection strategy to collect samples from these farmers. We offered a significant premium to purchase a 1 kg sample from all farmers, not only those who delivered output for sale to the cooperative. In the end, we collected samples from 83% of participating farmers. Some farmers who did not deliver a sample experienced very low yields or total crop failure due to a challenging rainy season. Based on endline survey data, four percent of farmers had zero output, and a further eleven percent of farmers harvested only enough to cover the median baseline quantity kept for seeds and home consumption. Just under half of our attrition falls in this category. Other farmers, facing unusually high spot market prices at the start of the commercialization season, reportedly quickly sold their entire output before we re-contacted them to request a sample. Treated farmers were significantly less likely to deliver a sample for testing (11 percentage points) than control farmers. It is possible that treated farmers with particularly high quality were more easily able to sell their output for a high price on the spot market. Conversely, it is possible that treated farmers with particularly low quality did not wish to undergo quality certification for reputational reasons. Below, in Section 6.3.1, we discuss a variety of techniques to assess the robustness of our results given this attrition.

4.4 Commercialization Behavior

Finally, we consider farmers' commercialization decisions. As shown above in Table 1, at baseline farmers typically sold some output via the cooperatives and some output via other traders. Figure 5 shows the fraction of farmers that sold their output to the cooperative and to other buyers, as well as keeping some output for consumption and as seeds. This suggests many farmers who are ostensibly active cooperative members are not selling any output to the cooperative, and instead selling to other local buyers. Figure 6 shows how the mean farmer allocated their output across sales, consumption, and other uses at baseline.

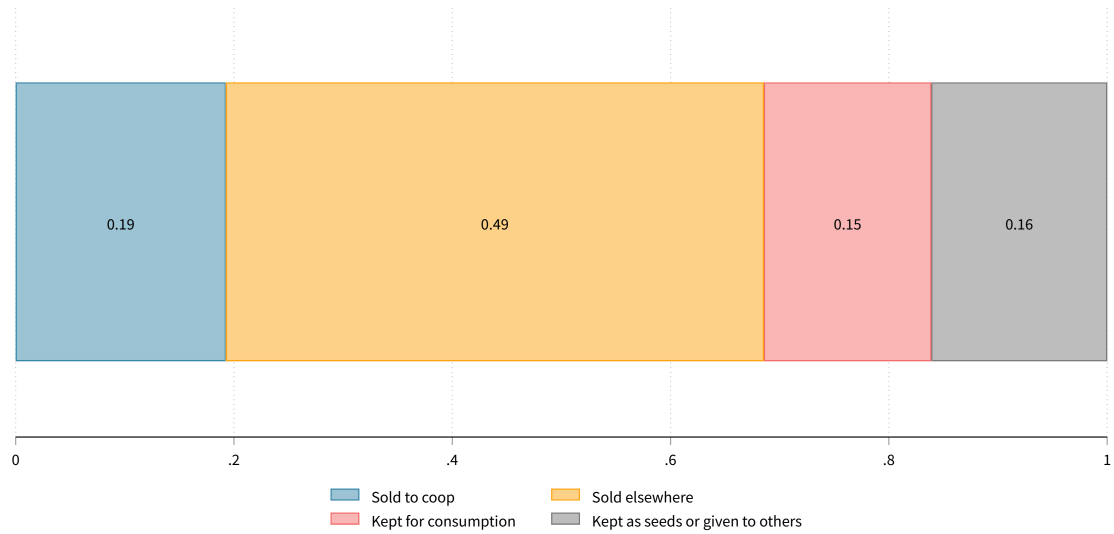
These figures suggest several notable features of our setting. First, as in Aflagah et al. (2019), we find that farmers allocate a large fraction of their output to commercial sale outside of their cooperatives, and only a small fraction to the cooperatives. Second, there is a small but important fraction of output that is kept for home consumption. This is particularly relevant given that consumption of aflatoxin-contaminated crops can affect health of adults and children. Similarly, farmers keep a fraction for seeds or giveaways.[32] The quantity in levels kept for seeds is relatively constant across baseline and endline, despite lower yields in the endline season.

Figure 5: Fraction of farmers who sold, consumed, and kept any output at baseline



[32]Groundnuts are often given to others as payment-in-kind for labor during the growing season.

Figure 6: Mean fraction of output sold and kept at baseline



We analyze two outcomes relevant to understanding farmers' commercialization decisions. Figure 5 summarizes dummy variables equal to one if a farmer sold any output to the cooperative or another buyer, kept any output for home consumption or seeds, or gave any output away to others. We define corresponding variables using our endline data. The second outcome is the quantity of output allocated to the cooperative. Figure B.4 shows the distribution of output allocation to the cooperative at baseline and endline. The leftmost bar shows farmers who allocated zero output to the cooperative. The distribution is highly skewed at both baseline and endline. Given these two facts, we analyze the inverse hyperbolic sine transformation of output allocated to the cooperative.

We also face some attrition in these outcomes. The endline survey was conducted by phone in June 2020, and some farmers were unreachable after repeated attempts. We successfully surveyed 93% of the baseline sample, and attrition from the endline is not different by treatment status. Of the 7% who did not complete the endline survey, most were simply due to difficulty contacting the respondent by phone.

4.5 Climate data

To estimate the relationship between aflatoxin and growing season agro-climatic conditions, we use two sources of remotely-sensed data on precipitation and land surface temperature. For precipitation data, we rely on CHIRPS 2.0 daily rainfall estimates. For land surface temperature, we rely on the Copernicus LST10-DC dekadal land surface estimates. Both datasets have a 0.05° spatial resolution. We consider a "growing season" period defined by planting dates reported by farmers and the average time to harvest for the groundnut varieties common in our sample (90-110 days).

We define two village-level growing season variables: number of dry spells and average growing season daily max temperature. To define dry spells, we follow Bowen and Hagan (2015) who find that 3-day and 4-day dry spells are predictive of aflatoxin contamination. We calculate the cumulative number of dry spells experienced in each village during the growing season period. To define average growing season daily max temperature, we again follow Bowen and Hagan (2015) and take the max temperature for each dekadal temperature estimate, and then take the mean of these values over the growing season. To match villages to the spatial datasets, we take the mean value of all pixels within a 1 kilometer radius of the village midpoint.[33]

5 Empirical Strategy

For our outcomes of interest we estimate the following equation via OLS:

$$Y_{ijk} = \alpha + \beta_1 T_{jk} + \delta \mathbf{X}_{ijk} + \gamma_k + \epsilon_{ijk} \tag{1}$$

where T_{jk} is the treatment assignment of farmer i in village j in commune k, γ_k is a commune fixed effect, and standard errors ϵ_{ijk} are clustered at the village level.[34] We present results with and without baseline controls $\mathbf{X}_{ijk}$. Where appropriate, we also estimate the treatment effect on the treated via 2SLS where we instrument Aflasafe adoption by treatment status.[35].

We additionally estimate the following equation:

$$Y_{ijk} = \alpha + \beta_1 T_{jk} + \beta_2 (T_{jk} \times H_{ijk}) + \beta_3 H_{ijk} + \delta \mathbf{X}_{ijk} + \gamma_k + \epsilon_{ijk} \tag{2}$$

where H_{ijk} is a measure of heterogeneity. We consider spatial heterogeneity (by predicted aflatoxin risk), as well as heterogeneity across behavioral measures presented above in Table 1: risk aversion, patience, and reciprocity. We again cluster standard errors at the village level, and additionally bootstrap standard errors when we include the predicted aflatoxin risk dummy.

We prepared a pre-analysis plan (PAP) in the course of developing this project, which is registered with the AEA registry (AEARCTR-0006315).[36] We deviate from the PAP in three ways, which we describe here briefly and more fully below in Appendix A.1. First,

[33] We use the village midpoint because we only observe plot locations for 27 farmers in our dataset who were randomly selected for inclusion in the "audit" survey described above. The median distance from the plot to the village centerpoint is 0.97 km, motivating our use of a 1km radius. All results presented are robust to using a larger radius.

[34] We follow convention for cluster-randomized RCTs in clustering at the treatment assignment (village) level.

[35] Exclusion restriction: we assume that that treatment only affects outcomes through the uptake of Aflasafe, since Aflasafe was not available in previous years and other inputs were available and priced similarly in both groups.

[36] The PAP was presented publicly at the Northwestern University GPRL Pre-Analysis Plan Mini-Conference in May 2019, before we began any project activities in the field. This un-modified document was only submitted to the AEA registry in August 2020.

we implemented this project with a single treatment group, without offering any "partial" contracts as originally planned. Second, we randomized treatment assignment at the village level, to facilitate implementation and minimize potential spillovers. Third, we pre-specified several behavioral hypotheses which are infeasible to test due to insufficient variation in our elicited measurements.

Additionally, to address possibly non-random attrition in our measure of quality, we implement multiple strategies to test the robustness of our results. First, we implement Horowitz and Manski (2000) bounds which require no assumptions about the distribution of the missing data. Second, we implement a multiple-imputation procedure in which we predict the value of the missing outcomes using baseline farmer characteristics $\mathbf{X}_{ijk}$.

6 Results

In this section, we consider three main families of outcomes. First, we focus on individual barriers and test whether the intervention described in Section 3 increased farmers' adoption of Aflasafe, using both administrative and self-reported measures. Second, we discuss market-level barriers to quality upgrading along the value chain, and test whether the intervention impacted output aggregation by cooperatives. Third, we estimate intent-to-treat (ITT) and treatment-effect-on-the-treated (TOT) effects of our intervention on quality (aflatoxin standard compliance). Third, we estimate ITT and TOT effects on commercialization behavior (output sales to the cooperative). For each TOT regression, we present estimates in which we instrument for the administrative adoption measure in the main body of the text, and show comparable TOT estimates using self-reported adoption in Appendix B.

6.1 Individual barriers and technology adoption

We first present results on the adoption of Aflasafe. Table 2 demonstrates the treatment had a remarkably large effect on farmers' adoption decisions using either measure of adoption. The treatment effect when we use the admin data is 79-80 percentage points, whereas the treatment effect using the self-reported outcome is 59-61 percentage points. These effects are robust to the inclusion of commune or cooperative FE and additional baseline controls described above in Table 1.

It is worth taking a moment to discuss the magnitude of these results. Because the intervention mirrors a resource-providing contract, our adoption measure nests credit uptake by treated farmers. Existing work on credit expansion typically finds low rates of credit adoption, in the range of 17-31% (Angelucci et al., 2015; Crépon et al., 2015; Tarozzi et al., 2015; Chowdhury et al., 2020). Similarly, existing work on credit expansion typically finds small impacts on technology adoption and input use (Crépon et al., 2015; Tarozzi et al., 2015; Beaman et al., 2020) or even no effect at all (Chowdhury et al., 2020; Nakano and

Magezi, 2020).[37]

The bundled treatment additionally provided farmers ex-ante certainty about receiving training on proper use of the technology.[38] This is somewhat distinct from information interventions in the literature, which typically randomize the provision of information. Magnan et al. (2021) find information provision increases purchases of drying sheets for aflatoxin reduction by 9.7-14 percentage points. Training and farmer field days have been found to increase adoption of pest control practices and improved seeds by 12-15 percentage points (Emerick and Dar, 2020; Lerva, 2020). Information on international quality standards can similarly increase adoption of standards-compliant management practices in dragonfruit production (Park et al., 2021).

Finally, the treatment provided farmers with increased price premium certainty upon adoption and proper use of the technology. Results in the literature on the impact of a quality price premium are mixed. Hoffmann et al. (2022) find that a modest market premium for low-aflatoxin maize increases Aflasafe adoption by 75%, and Bold et al. (2022) find that offering a reliable market for quality maize increased adoption of post-harvest quality upgrading practices (proper drying, sorting, and winnowing) by 68-107%. By contrast, Magnan et al. (2021) find no significant effect of a low-aflatoxin price premium on the purchase of a low-cost technology (drying sheets) for groundnut farmers. Results on the impact of price certainty in general suggest a relatively small impact on farmer investment. Arouna et al. (2021) find that a contract with only price certainty is insufficient to increase agricultural investment, although it can increase productivity. Karlan et al. (2011) test the impacts of crop-price indemnification embedded in agricultural lending, and find modest impacts on high-risk agricultural investment and on the probability of sale to higher-return buyers.

Our setting differs in several important ways from these past studies. First, our treatment offers relatively small loans which are exclusively intended to finance adoption of the new technology. Second, the technology is not expected to increase yields.[39] Instead, by increasing quality, farmers may expect to earn a higher price for their output. The intervention offered treated farmers increased certainty that adoption would be profitable, conditional on quality certification. Profitability is an important element of agricultural technology adoption decisions (Michler et al., 2019). Third, farmers face non-pecuniary incentives to adopt the technology, since it can also have health impacts for farmers who consume some of the groundnuts they grow. Fourth, there may be important complementarities between the components of our bundled treatment which increase adoption rates beyond the additive effects we might expect from each component.

[37] Along the same lines, relaxing credit and risk constraints via grants and index insurance has a significant but relatively small effect on input investment (Karlan et al., 2014; Bulte et al., 2019).

[38] All farmers received in-person assistance to apply the technology. The difference between treatment and control is in the ex-ante promise of a field visit.

[39] In our data, there is no detectable effect of technology adoption on yields.

Table 2: Aflasafe adoption

	Admin Data Adoption			Self-Reported Adoption		
	(1)	(2)	(3)	(4)	(5)	(6)
Treated	0.79***	0.79***	0.78***	0.59***	0.61***	0.61***
	(0.06)	(0.06)	(0.06)	(0.07)	(0.06)	(0.06)
Observations	396	396	396	370	370	370
R^2	0.621	0.647	0.673	0.347	0.377	0.425
Control Mean Dep. Var	0.10	0.10	0.10	0.20	0.20	0.20
Commune FE	N	Y	Y	N	Y	Y
Baseline controls	N	N	Y	N	N	Y

Results in this table are from linear regressions of the adoption dummy on the treatment dummy. Admin Data Adoption is measured using distribution logs and extension agent field visit logs, provided by our partner cooperatives. Self-Reported Adoption was elicited in the endline survey. Standard errors (in parentheses) are clustered at the treatment assignment (village cluster) level. Baseline controls included are all variables shown above in Table 1.

While we cannot fully address the mechanisms driving the treatment effect on adoption, we collected additional data which is suggestive of the importance of credit constraints and time consistency.[40] At baseline, after introducing farmers to Aflasafe and providing the conditions of their treatment assignment, we collected a non-binding measure of intention to purchase the product. Additionally, in the week before distribution began, we called farmers to inform them the product would soon be available and collect a second non-binding intention to adopt. Table B.2 demonstrates statistically significant treatment effects on these non-binding measures that are much smaller in magnitude than those we observe in the ultimate adoption decision. Control farmers were highly interested in the product at baseline and optimistic about their intent to adopt, with more than 90% indicating interest. At the time when distribution began, and farmers in the control group would need to pay cash to purchase the product, a majority of control group farmers remained optimistic about their ability and intention to purchase the product. The contract treatment seems to have allowed farmers to follow through with their intentions, rather than fundamentally shifting farmer interest in the technology.[41]

We may also learn more about mechanisms driving our effects by exploring heterogeneity in adoption. Ex ante, we anticipated heterogeneity in adoption decisions by farmer behavioral characteristics like reciprocity, patience, and risk aversion. We test for heterogeneity along these dimensions and report results in Table B.1. Our results have consistent sign across self-

[40]We did attempt to measure time inconsistency directly in our baseline survey, but we observe very little variation in the resulting measurement, with only 10% showing any evidence of time inconsistency in a non-incentivized hypothetical exercise.

[41]This interest in the product persists after our experiment. When contacted by phone after the conclusion of the experiment, 92% of farmers expressed an interest in using Aflasafe in the next season, without any information about credit access or other conditions of a potential contract. There is no statistically significant difference in this measure of intended adoption across treatment and control groups.

reported and admin data adoption measures, although we observe no statistically significant heterogeneity using the self-reported measure. Given the large average treatment effect and limited variation in some of our behavioral measures, it is perhaps unsurprising that we find only limited evidence of heterogeneity in this outcome along any dimension. Nevertheless, the sign of the interaction term between treatment and risk preferences in particular is consistent with our pre-specified hypothesis about the role of the contract (and the premium guarantee in particular) in affecting adoption decisions.

6.2 Market-level barriers and output sales

Next, we consider the impact of the intervention on market-level barriers to quality upgrading. Namely, we consider whether the intervention is sufficient to allow intermediaries (in our case, cooperatives) to aggregate farmers' higher-quality production. This is an important outcome for policy (Barrett, 2008; Fischer and Qaim, 2012), especially given the well-documented challenges cooperatives face aggregating farmer output (Bernard et al., 2008, 2015; Aflagah et al., 2022). If the intervention succeeds at this, cooperatives could plausibly offer our intervention at scale and induce widespread improvements in production quality and food safety. This outcome is also of academic interest. Given that the treatment represents a modification of the relational contract between farmers and cooperatives, it is useful to measure to what extent this change improves contract success by increasing output sales to the cooperative. In particular, given the high spot market prices in the season we study, the outcomes we observe here demonstrate the role of our intervention in improving informally-contracted relationships when the temptation to cheat is high.

Column 1 of Table 3 shows the effect of the contract offer on output sales to the cooperative at the extensive margin. The outcome is a dummy equal to one if the farmer reported any output sales to the cooperative at endline. On average, treatment increased the probability of selling any output to the cooperative by 12 percentage points. Given the low rate at which farmers decide to sell output to cooperatives, this represents a sizeable change in behavior at the extensive margin. Results analyzing the intensive margin of output allocation, shown in Table B.6, tell a similar story.[42]

How do these findings compare to the literature? Aflagah et al. (2022) find that in larger village cooperative groups, a cheap talk intervention of sharing ex-ante collective commercialization intentions increased the probability of sales to the cooperative by 1 percentage point (13%) per group member. At the median group size (24 members), their intervention increases collective commercialization by 24 percentage points. By comparison,

[42] One interpretation of this intensive-margin result is that treated farmers simply sold enough extra output to the cooperative to repay their credit for purchasing Aflasafe. However, the magnitude of the average treatment effect is roughly double that of the cost of Aflasafe. Indeed this increase in output aggregation is sufficient to cover all of a cooperative's marginal costs if they were additionally paying for aflatoxin testing. Combined with the premium buyers are willing to pay cooperatives for certified high-quality production, we estimate our partner cooperatives could at least break even if they scaled the intervention to all of their members and those members increased output sales to the cooperative by a similar margin.

our point estimate suggests a 12 percentage point (52%) increase in the probability of sales to the cooperative.

Table 3: Sold any output to coop, with behavioral heterogeneity

	(1)	(2)	(3)	(4)
Panel A: ITT estimates				
Treated	0.12**	0.04	0.00	0.15**
	(0.050)	(0.050)	(0.080)	(0.060)
Treated × Reciprocal		0.27***		
		(0.090)		
Treated × Patient			0.16*	
			(0.090)	
Treated × Risk loving				-0.10
				(0.090)
Reciprocal	-0.02	-0.17***	-0.03	-0.02
	(0.050)	(0.050)	(0.050)	(0.050)
Patient	0.00	-0.01	-0.08	0.00
	(0.050)	(0.050)	(0.070)	(0.050)
Risk loving	0.11**	0.11**	0.11*	0.17**
	(0.050)	(0.050)	(0.050)	(0.070)
Panel B: TOT estimates (admin data adoption)				
Adopted	0.15***	0.05	-0.01	0.18***
	(0.060)	(0.070)	(0.110)	(0.060)
Adopted × Reciprocal		0.31***		
		(0.110)		
Adopted × Patient			0.21*	
			(0.120)	
Adopted × Risk loving				-0.12
				(0.130)
Reciprocal	-0.03	-0.21***	-0.04	-0.03
	(0.050)	(0.070)	(0.050)	(0.050)
Patient	0.00	-0.01	-0.11	0.01
	(0.050)	(0.050)	(0.080)	(0.050)
Risk loving	0.10*	0.11**	0.10*	0.17**
	(0.050)	(0.050)	(0.050)	(0.090)
N	370	370	370	370
Control mean	0.230	0.230	0.230	0.230

This table shows results of regressions where the outcome variable is a dummy equal to one if the farmer reported selling any output to the cooperative. Panel A presents Intention-To-Treat results where the outcome is regressed on treatment status. Panel B presents 2SLS results where adoption (as measured in cooperative administrative data) is instrumented by treatment status. Column (2) additionally includes an interaction with a dummy equal to one if self-assessed intrinsic reciprocity is greater or equal to 0.6 on a standardized [0,1] scale, column (3) includes an interaction with a dummy equal to one for self-assessed patient farmers, and column (4) includes an interaction with a dummy equal to one if the farmer identified as extremely willing to take risks. In panel B, the 2SLS regressions additionally include treatment interacted with the cooperative dummy as a second instrument. All regressions include commune fixed effects to account for stratified randomization of treatment assignment. Standard errors are clustered at the treatment assignment (village) level. See Table B.5 for corresponding results using an additional measure of adoption and with additional baseline controls included.

6.2.1 Behavioral Mechanisms

Behavioral characteristics like reciprocity and patience can play important roles in the success of informal relationships (Leider et al., 2009; Finan and Schechter, 2012; Ligon and Schechter, 2012). Relationships between farmers and cooperatives are not purely commercial, as they also invoke a sense of collective action and solidarity among members. Understanding the behavioral mechanisms that drive increased collective commercialization could improve contract design or targeting. Table 3 shows that there is a significant and positive interaction between the treatment and a baseline measure of intrinsic reciprocity. The marginal effect of treatment is small or statistically indistinguishable from zero for low-reciprocity farmers. By comparison, for the most reciprocal farmers, the treatment increases output allocation to the cooperative by about 27 percentage points.

Patience is also a key component of improving collective commercialization. Farmers who sell output to traders typically get paid immediately, in cash. By comparison, sales via the cooperative often involve a delay receiving some or all of the proceeds from the sale. The new contract may require additional patience, as quality-contingent premium payments require farmers to wait for results from an aflatoxin test. Column (3) of Table 3 demonstrates that the treatment effect was indeed larger for more patient farmers, although the effect is imprecise. These farmers may have been more willing to wait for the potential rewards associated with allocating output to the cooperative. The wording of the patience elicitation question are also suggestive: we asked farmers how they assessed their willingness to give up something today in order to benefit in the future. Given that cooperatives may allocate access to new technologies and trials based on perceived reliability, it could be that the farmers we flag as more patient recognize this and respond accordingly.

By contrast, we fail to detect any evidence of heterogeneity by risk aversion. We observe a highly bimodal distribution of self-assessed risk aversion on an 11-point scale. This matches closely with earlier work by Charness and Viceisza (2016) in a similar context. We flag self-identified "risk-loving" farmers as those who responded that their willingness to take risks was 10 out of 10. Failure to detect an outcome could indicate a need to better adapt risk measurement methods to our precise context. Alternatively, it could indicate that risk aversion does not impact the decision to sell output to the cooperative. This seems less likely, given that farmers who choose to sell output elsewhere risk reduced access to future benefits from the cooperative.

6.3 Evidence on quality improvements and Aflasafe effectiveness

Finally, we present results on quality (aflatoxin contamination). Our study is among the first to explore the results of Aflasafe use under real world conditions which may deviate from tightly-controlled agronomic trials. We consider two outcomes: EU phytosanitary standard compliance[43] and a continuous measure of aflatoxin contamination.

Table 4 demonstrates the impact of the contract on phytosanitary compliance. We see that on average, the point estimate on standard compliance is positive but not statistically significant. This may seem a surprising departure from results in controlled agronomic studies (Bandyopadhyay et al., 2019; Senghor et al., 2020). Given that about 90% of farmers in the treated group purchased Aflasafe, agronomic results would suggest we should see no more than 10% of samples from that group showing any contamination levels. In practice, we observe that about 73% of samples from treated farmers complied with phytosanitary standards.

Several factors may help rationalize our results with the agronomic evidence. First, the samples we tested may not have come from farmers' treated fields. To simplify implementation and due to budget and Aflasafe availability constraints, our intervention offered farmers 10 kgs of Aflasafe, sufficient to treat one hectare. On average, farmers in our sample planted about 3.5 hectares, so the majority of the output in the treated group would not have been treated with Aflasafe. Second, due to production delays the distribution of Aflasafe happened later than originally planned. As a result, just 9% of farmers received and applied the product within the recommended 4-6 week window after planting. The median farmer applied the product nearly 9 weeks after planting.

However, given the significant spatial variation in aflatoxin levels among control farmers documented above in Section 4, this small average effect may disguise heterogeneous effects. Past research has demonstrated the potential for significant variation in contamination risk across space and time. In Ghana, Magnan et al. (2021) find substantial variation in aflatoxin levels: in their baseline season, contamination above EU standards exceeded 90 percent in both study regions, whereas one year later, on the same farms, they found contamination rates of 6 percent in one region and 10 in the other.

We use spatial data on agro-climatic conditions during the growing season to estimate each village's average risk of aflatoxin contamination in the absence of the treatment. In line with previous work by Bowen and Hagan (2015), we identify two key predictors of aflatoxin contamination: dry spell incidence and average max temperature during the growing season. Using these two predictors, we proceed to estimate climate-induced aflatoxin risk in three steps. First, we estimate the relationship between the natural log of observed aflatoxin levels in control villages and our agro-climatic variables using LASSO and a simpler quadratic specification.[44] Second, using this estimated relationship between temperature, precipitation, and contamination in control villages, we predict village-level aflatoxin contamination risk

[43] These are the strictest aflatoxin quality standards in the world, requiring total aflatoxin levels less than 4 p.p.b.

[44] Results are robust to a variety of alternative specifications, such as including temperature or dry season bins. Results are additionally robust to including or excluding baseline farmer characteristics, including lead farmer status and baseline aflatoxin awareness. We observe virtually no adoption of complementary practices for aflatoxin prevention at baseline, such as drying crops on a tarp (0%) or storing crops in hermetic bags (2%), so we do not include these variables in this step.

for all villages in our sample. Third, we generate a dummy variable for predicted "high-risk" villages where predicted average contamination exceeds EU phytosanitary standards. Columns (2) and (3) of Table 4 show that we find consistently that the treatment effect is statistically significant and large in magnitude in villages predicted to be at high risk of aflatoxin contamination, and indistinguishable from zero in low-risk villages.[45]

As discussed above in Section 4, statistical analysis of the continuous measure of quality is complicated by the fact that 49 percent of test results returned an aflatoxin level below the minimum level of detection of the testing equipment (2 parts per billion). We show results in Table B.4, but caution the reader that these results may not be robust to more sophisticated methods of addressing the censored nature of the outcome. Nevertheless, the story is quite similar to the binary measure which suffers no such problem. We are again unable to detect a significant average treatment effect, although the point estimate is negative (suggesting lower contamination levels among farmers in the treatment group). When we allow the effect to differ by predicted contamination risk, we again find that the contract had a large and significant impact on quality in high-risk villages.

How does this result compare to other studies of quality upgrading? Magnan et al. (2021) is the closest comparable study, in which they offer farmers a low-cost technology (a tarp for drying groundnuts) and a price premium for improved quality. They find treatment effects of technology provision on EU standard compliance of 40-46%, with similar but less precise effects of a price premium.[46] If we define an analogous outcome, we find treatment effects on EU standard compliance of 22-57%.[47]

More broadly, this finding demonstrates an avenue for smallholder farmers to comply with international standards and access lucrative export markets. Compliance with phytosanitary standards is often quite costly for farmers (Asfaw et al., 2009), and changing standards have played a significant role in stymieing past attempts to link smallholders to export markets (Ashraf et al., 2009). We find that using a relatively cheap new technology—Aflasafe—farmers

[45] We observe similar patterns when we simply interact treatment with spatial fixed effects at the cooperative or commune level. Endline survey data on farmer practices suggests that differences in this treatment effect are not driven by differences in farmer practices. Table C.2 shows that there are no detectable differences in endline adoption of improved drying practices or improved storage technologies. There is also no detectable heterogeneity in Aflasafe adoption by predicted risk, suggesting farmers did not adjust their adoption behavior in ex-ante anticipation of this risk. We also do not detect any significant relationship between climate-induced contamination risk and baseline aflatoxin awareness. When we consider sample attrition due to missing groundnut samples for aflatoxin testing, there is no differential attrition by predicted risk.

[46] Other work has focused on maize, another important crop in sub-Saharan Africa commonly affected by aflatoxin contamination. EU standards for aflatoxin in maize are slightly higher at 10ppb. Contamination risks may also differ from groundnuts. Providing farmers with training, hermetic storage bags, and drying tarps for maize has been found to increase EU standard compliance by 33-71% (Pretari et al., 2019; Bauchet et al., 2020).

[47] Macchiavello and Miquel-Florensa (2019) consider a very different setting—coffee cultivation—and find that a contract farming program induced upgrading along a variety of dimensions, with treatment effects of 2-25% depending on the outcome. Similarly, Park et al. (2021) find that information provision to farmers and intermediaries increased compliance with international pesticide standards for dragonfruit production by 20-68%. In a non-agricultural context, Atkin et al. (2017) find linking rug-producing firms to export markets increases quality by 26%.

Table 4: Phytosanitary standard compliance

	(1)	(2)	(3)
Panel A: ITT estimates			
Treated	0.08	-0.03	-0.08
	(0.050)	(0.070)	(0.060)
Treated × Pred. high risk (LASSO)		0.33***	
		(0.120)	
Treated × Pred. high risk (quadratic)			0.25*
			(0.130)
Pred. high risk (LASSO)		-0.34***	
		(0.080)	
Pred. high risk (quadratic)			-0.39***
			(0.080)
Panel B: TOT estimates (admin data adoption)			
Adopted	0.10	-0.05	-0.11
	(0.070)	(0.080)	(0.100)
Adopted × Pred. high risk (LASSO)		0.38***	
		(0.150)	
Adopted × Pred. high risk (quadratic)			0.33*
			(0.170)
Pred. high risk (LASSO)		-0.39***	
		(0.120)	
Pred. high risk (quadratic)			-0.39***
			(0.080)
N	328	328	328
Control mean	0.659	0.659	0.659

This table shows results of regressions where the outcome variable is a dummy equal to one if the groundnut sample complied with EU phytosanitary standards. Panel A presents Intention-To-Treat results where the outcome is regressed on treatment status. Panel B presents 2SLS results where adoption (as measured in cooperative administrative data) is instrumented by treatment status. Columns (2) and (3) include an interaction with a dummy equal to one if the village was predicted to be at high risk given agro-climatic conditions experienced during the growing season. See Appendix C for details. In panel B, the 2SLS regression additionally includes treatment interacted with the predicted high risk dummy as a second instrument. Standard errors are clustered at the treatment assignment (village) level and bootstrapped in columns (2) and (3). See Table B.3 for a longer table including an additional measure of adoption and estimates including additional baseline controls.

can significantly increase their likelihood of standards compliance when they otherwise would be at high risk of non-compliance. However, while necessary for export market access, standards compliance is not sufficient. Exporters are typically unwilling to work directly with small farmers. The second key to exporting is therefore output aggregation, which we discussed in Section 6.2 above.

6.3.1 Robustness to missing aflatoxin data

As discussed above in Section 4, we face non-trivial attrition in our quality measure, with only 83% of farmers providing a sample for testing. In follow-ups, we collected data which explains some of the attrition, namely that about 15% of our sample harvested either zero groundnuts (i.e., total crop failure) or harvested a quantity that falls below the median baseline quantity kept for seeds and home consumption. However, we also observe a differentially greater probability of attrition in the treatment group. As such, we implement two strategies to test the robustness of our quality findings to this non-random attrition.

Table 5: Phytosanitary standard compliance and robustness to sample attrition

	Main Spec	Horowitz & Manski		Multiple Imputation
		Upper	Lower	
Treated	-0.03	-0.22***	0.08	-0.07
	(0.070)	(0.070)	(0.060)	(0.060)
Treated ×	0.33***	0.24*	0.35***	0.31***
Pred. high risk (LASSO)	(0.120)	(0.140)	(0.100)	(0.090)
Pred. high risk (LASSO)	-0.34***	-0.26***	-0.34***	-0.18*
	(0.080)	(0.100)	(0.080)	(0.100)
N	328	396	396	396
Control mean	0.659	0.701	0.579	0.619

This table shows results of regressions where the outcome variable is a dummy equal to one if the groundnut sample complied with EU phytosanitary standards. Column 1 replicates the results shown in column 2 of Table 4. Columns 2 and 3 show the upper and lower Horowitz and Manski (2000) bounds which imposed no distributional assumptions on missing data. Column 4 shows multiply-imputed parameter estimates with 50 imputations, where missing test results are imputed using a linear regression with baseline controls. Standard errors are clustered at the treatment assignment (village) level and bootstrapped in columns 1-3.

Table 5 presents the results of these strategies. In columns 2 and 3, we show the upper and lower Horowitz and Manski (2000) bounds. More specifically, we estimate the upper bound by replacing missing values for treated farmers with the upper bound of the unconditional distribution and replacing missing values for control farmers with the lower bound of the unconditional distribution. The lower bound is analogous but uses the unconditional minimum for missing treated farmers and the unconditional maximum for control farmers. In column 4, we conduct a multiple imputation exercise where we first predict missing test result values using baseline farmer characteristics. We bootstrap the imputation exercise 50 times and report the average estimated parameters. These exercises should provide some reassurance that our findings on quality improvements in high-risk areas are not driven by missing data.

7 Follow-up: Learning and Adoption Two Years Later

Two years after the conclusion of the original study, our two partner cooperatives decided to make Aflasafe widely available to their members.[48] The cooperatives first held information sessions for village section presidents, in which representatives from the manufacturer and IITA described the problem of aflatoxin contamination and how Aflasafe could improve crop quality outcomes. Village section presidents were asked in turn to share information with their members.

Following these information sessions, farmers were invited to submit expressions of interest to the cooperative. This process functioned as it normally does for requesting seeds and fertilizer, but with the inclusion of Aflasafe in input packages. After receiving these expressions, the cooperatives decided how to allocate credit for Aflasafe in the same way they allocate credit for other inputs. Cooperative representatives state this is a function of perceived reliability and total credit available. Aflasafe was sold exclusively on credit. Cooperative representatives promised to send agents to train farmers when Aflasafe was distributed. Farmers were not promised a specific price premium for aflatoxin standard compliance, but may have harbored beliefs that a premium would be available. Thus, the conditions during the follow-up season partially matched the conditions of our bundled contracting treatment, but without a price premium guarantee.

In this section, we consider two outcomes from cooperative administrative data: did a farmer express interest in purchasing Aflasafe, and did they purchase it? The first outcome is purely dependent on farmers, and is not contingent on credit availability from the cooperative. The latter outcome is determined jointly by farmers' interest and cooperative staff. It is instructive to consider both outcomes, since past treatment status may have influenced cooperatives' perceptions of a given farmer's reliability or capability using Aflasafe. In practice, the two outcomes largely overlap.

7.1 Empirical Strategy

For our outcomes of interest in this section, we estimate the following equation via OLS:

$$Y_{ijk} = \alpha + \beta_1 T_{jk} + \beta_2 P_{ijk} + \beta_3 (T_{jk} \times P_{ijk}) + \beta_4 S_{jk} + \gamma_k + \epsilon_{ijk} \tag{3}$$

where T_{jk} is the treatment assignment of village j in commune k. In some columns we add P_{ijk}, a dummy equal to one if farmer i was sampled for inclusion in the previous study, and

[48] The COVID-19 crisis significantly constrained cooperatives, and the groundnut sector in general, during the year following the original study.

interact it with T_{jk}. We also sometimes include S_{jk}, a dummy equal to one if a village was sampled for inclusion in the original study. γ_k is a commune fixed effect, and standard errors ϵ_{ijk} are clustered at the village level.

7.2 Direct and Indirect Effects

First, we turn to the direct effects of past assignment to the contract treatment. Table 6 shows the effects of treatment assignment on interest and purchase decisions. In the first two columns, we restrict the sample to past study participants. It is worth noting first that average adoption among farmers in previously-treated villages is significantly lower than the adoption we observed in the original experiment. Patterns of technology adoption and disadoption are common in the literature (Suri, 2011; Nourani, 2019), and perhaps are particularly unsurprising in a context like ours where farmers must learn about the effectiveness of a technology in reducing a contamination which is costly to observe and for which contamination risk is stochastic. The lingering effects of the COVID-19 crisis may have also reduced farmer willingness to experiment. Despite this substantially lower adoption, we nevertheless find that among past study participants, treated farmers are 160% more likely to be interested in purchasing Aflasafe and 180% more likely to actually purchase it in 2021.

Table 6: Aflasafe adoption in 2021

	Participants		Study Villages		All Villages	
	(1)	(2)	(3)	(4)	(5)	(6)
	Int.	Bought	Int.	Bought	Int.	Bought
Treated Village in 2019	0.08^{**}	0.09^{**}	0.01	0.02	-0.01	0.00
	(0.03)	(0.04)	(0.02)	(0.02)	(0.03)	(0.02)
Participant in 2019			-0.03	-0.01	-0.03	-0.01
			(0.02)	(0.02)	(0.02)	(0.02)
Treated Village in 2019 × Participated in 2019			0.07^{*}	0.07^{*}	0.08^{**}	0.08^{**}
			(0.04)	(0.04)	(0.04)	(0.04)
Study Village in 2019					-0.02	-0.02
					(0.02)	(0.02)
Observations	392	392	1335	1335	4466	4466
R^2	0.098	0.095	0.062	0.040	0.083	0.086
Excluded Group Mean Dep. Var	0.05	0.05	0.09	0.07	0.12	0.11

Results in this table are from linear regressions of dummies equal to one if a farmer expressed interest in, or actually purchased, Aflasafe in 2021. Odd columns report stated interest in purchasing Aflasafe, as reported to cooperatives, and even columns report actual purchases. These outcomes are measured using cooperative administrative data. The first two columns restrict only to past study participants. The third and fourth columns expand the sample to include non-participants in study villages. The fifth and sixth columns include all cooperative members. Standard errors (in parentheses) are clustered at the treatment assignment (village) level. All regressions include commune fixed effects.

We can additionally test for the presence of within-village spillovers in 2021 adoption decisions. In addition to the randomly-assigned 2019 treatment status of villages, we additionally exploit the random selection of study participants from the larger pool of cooperative members. As we expand the sample to include non-participants from study villages in the third and fourth columns, we see that the increase in purchases is driven almost entirely by past participants themselves, with little evidence of within-village spillovers to non-participants.

Finally, we can also exploit the random selection of villages for inclusion in the original study. In the fifth and sixth columns of Table 6, we find little evidence of information effects distinct from past treatment. Farmers in non-treated study villages received information about Aflasafe, but with few actual adopters in 2019. Additionally, somewhat in contrast to Treurniet (2021), we find no evidence that participation status in the 2019 study, separately from treatment status, has any impact on adoption two years later. Thus, it appears that information alone in 2019 was insufficient to increase adoption in 2021. This is despite evidence that farmers in this group were more aware of aflatoxins in general.[49]

7.3 Experiment Participants

If we restrict the sample to past participants, for whom we collected baseline characteristics in 2019, we can also learn more who benefits the most from past experience. Mirroring analyses in previous sections, we consider several dimensions of heterogeneity according to behavioral characteristics like risk and reciprocity.

In Table 7, we observe significant heterogeneity in follow-up adoption along two behavioral dimensions: reciprocity and risk aversion. Consistent with our results on adoption in 2019 (see Table B.1), we find that the treatment effect is larger among highly-reciprocal farmers, but the effect is not statistically significant. It may be that reciprocity continues to play a role, or simply that past experience is higher among these farmers leading to higher adoption in the current season. Similarly, we see in 2019 that highly risk-loving farmers are less affected by the treatment, and more likely to adopt in absence of the treatment. This pattern carries through to 2021, which again may be driven either by a increased likelihood of past experience or ongoing increased appetite for risky agricultural investments.

8 Concluding Remarks

In this paper, we present new evidence that a simple contracting arrangement can induce improvements in crop quality via the adoption of a new technology. Farmers who adopt this technology in areas where quality would otherwise be low produce significantly higher-quality groundnuts. The contracting arrangement improves commercial outcomes at cooperatives,

[49]Results from a phone survey conducted in May and June 2020 with study participants and a random sample of non-participants, available upon request.

with treatment effects concentrated among farmers who are more reciprocal and patient. The contract increases technology adoption two years after the study, but there is significant disadoption by previously treated farmers. These findings have important implications for contract design, particularly in environments with low enforcement capabilities and where contracts involve using previously-unknown technologies or techniques.

Our work suggests several avenues for further research. In particular, although the bundled contract was highly effective at increasing Aflasafe adoption and did improve quality in high-risk areas, implementation of a comprehensive contract is costly. Many buyers are unwilling to commit to a fixed premium up front. Could a simpler resource-providing contract without price guarantees provide similar benefits? This could be particularly relevant given the repeated game nature of the interaction between farmers and cooperatves. Producers may not need guarantees of training or price rewards as their experience with the technology increases and they learn about potential market rewards to quality upgrading. Our follow-up results suggest the price premium guarantee may play an important role in determining farmers' decisions to invest in quality upgrading, in line with Hoffmann et al. (2022).

Additionally, our finding that the contract induced changes in commercialization decisions by producers merits further study. Given the well-documented difficulties cooperatives face in effectively aggregating output (Aflagah et al., 2019), our results suggest an avenue for improving cooperative performance by focusing on supporting higher-quality production. Future work could delve further into the behavioral heterogeneity we observe, to better understand how factors like reciprocity and reputation impact producer decisions.

Table 7: Adoption of Aflasafe two years after original study, with behavioral heterogeneity

	(1)	(2)	(3)	(4)
Panel A: Interested in Purchasing Aflasafe				
Treated	0.10***	0.08**	0.03	0.14***
	(0.030)	(0.040)	(0.060)	(0.040)
Treated × Reciprocal		0.06		
		(0.070)		
Treated × Patient			0.10	
			(0.070)	
Treated × Risk-loving				-0.17***
				(0.050)
Reciprocal	-0.03	-0.06*	-0.03	-0.03
	(0.040)	(0.030)	(0.040)	(0.040)
Patient	-0.03	-0.03	-0.08**	-0.02
	(0.040)	(0.040)	(0.030)	(0.040)
Risk-loving	-0.01	-0.01	-0.01	0.08*
	(0.030)	(0.030)	(0.030)	(0.040)
N	392	392	392	392
Control mean	0.046	0.046	0.046	0.046
Panel B: Purchased Aflasafe				
Treated	0.11***	0.08**	0.03	0.15***
	(0.030)	(0.040)	(0.060)	(0.040)
Treated × Reciprocal		0.08		
		(0.070)		
Treated × Patient			0.10	
			(0.070)	
Treated × Risk-loving				-0.17***
				(0.050)
Reciprocal	-0.04	-0.08***	-0.04	-0.04
	(0.040)	(0.020)	(0.040)	(0.040)
Patient	-0.03	-0.03	-0.09**	-0.03
	(0.040)	(0.040)	(0.030)	(0.040)
Risk-loving	-0.01	-0.01	-0.01	0.09*
	(0.030)	(0.030)	(0.030)	(0.040)
N	392	392	392	392
Control mean	0.041	0.041	0.041	0.041

This table shows results of regressions where the outcome variables are shown at the top of each panel. Panel A presents Intention-To-Treat results where the outcome is a dummy equal to one if a farmer indicated binding interest in purchasing Aflasafe from the cooperative. Panel B presents Intention-To-Treat results where the outcome is a dummy equal to one if a farmer purchased Aflasafe from the cooperative. Column (2) additionally includes an interaction with a dummy equal to one if self-assessed intrinsic reciprocity is greater or equal to 6 on a 10 point scale, column (3) includes an interaction with a dummy equal to one for self-assessed patient farmers, and column (4) includes an interaction with a dummy equal to one if the farmer identified as extremely willing to take risks. All regressions include commune fixed effects to account for stratified randomization of treatment assignment. Standard errors are clustered at the treatment assignment (village) level.

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A Additional detail on design and experimental context

A.1 Pre-Specified Analysis

In the interest of transparency, we describe here several ways in which our analysis deviates from the pre-specified analysis, and why. We feel these changes are justified given the deviations in design and implementation from the PAP, but readers are invited to draw their own conclusions and judge our results accordingly.

First, the PAP covered a planned larger trial, featuring multiple treatment groups with both partial and full contracts. After writing this PAP and preparing to launch the project in the field, we decided to simplify the design to include a single treatment group covering the "full contract" described in the PAP. We reasoned this would allow us to demonstrate an upper bound on the treatment effects we might expect from partial contracts, as well as establishing working relationships with our implementation partners. We planned to implement the full design discussed in the PAP in the second year of the project, but this second phase has been delayed due to COVID-19.

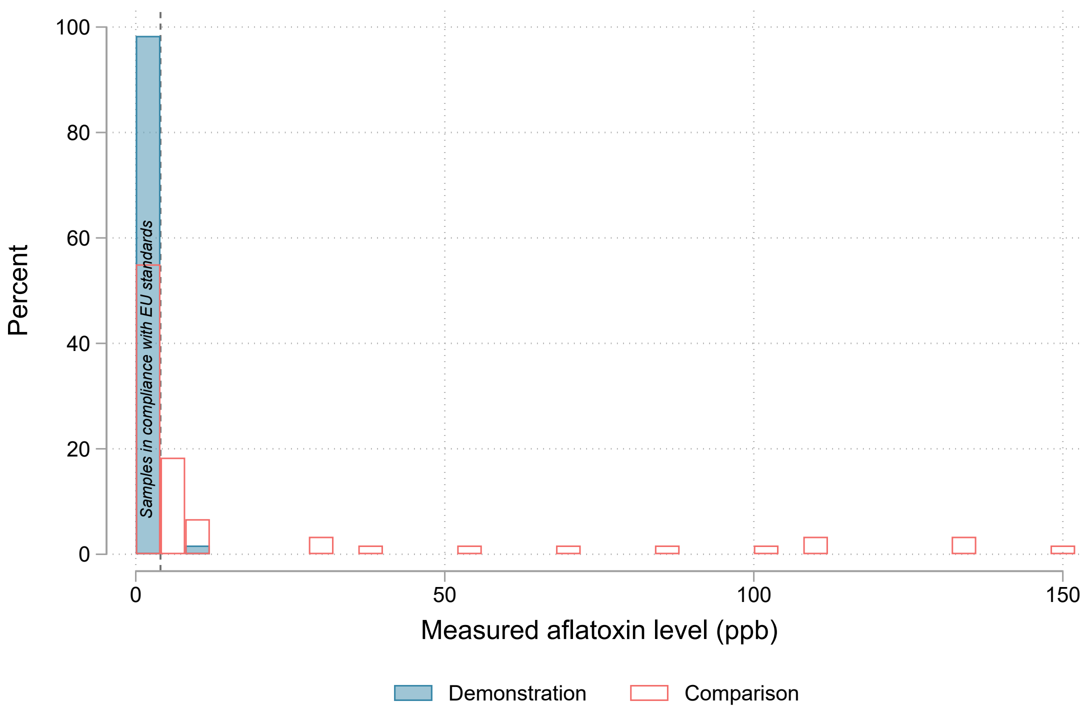
Second, the PAP hinged on an individually-randomized trial. Upon finalizing our partnerships with two groundnut cooperatives, we learned more about the village-centered way they organize their existing field activities, including distribution of seeds and other inputs on credit. We decided that following this model in our project would significantly facilitate project implementation. More importantly, following this model allowed us to test an intervention which is feasible for our partner cooperatives to implement themselves within their existing model. Additionally, a cluster-randomized trial minimizes the potential for spillovers because both aflatoxin contamination and any potential effects of Aflasafe can impact neighboring fields.

Finally, we modify our empirical strategy given that the trial as implemented included only one treatment and was randomized at the village level. In particular, we are unable to implement our planned strategy for low variation in aflatoxin levels among non-treated farmers, which was to exclude villages with sufficiently low levels of aflatoxin among control farmers. Instead, we test for spatial heterogeneity by interacting treatment status with spatial dummies at cooperative and commune levels. We also pre-specified a number of behavioral mechanisms we would test. Some of these hypotheses are redundant given the simplified treatment. Some are also fruitless to test because our baseline measurements were unable to capture sufficient variation. We discuss some of the issues with baseline measurement above in Section 4.[50]

B Additional tables and figures

[50] Due to the pilot nature of this project, we tested a variety of measurement techniques for behavioral variables of interest. This will allow us to improve our measurement for the larger-scale project and test behavioral mechanisms more effectively.

Figure B.1: Distribution of test results from IITA agronomic trials in 2019



Note: this figure shows aflatoxin test results from agronomic trials conducted elsewhere in Senegal during the same season we study. Demonstration plots were treated with Aflasafe, whereas comparison plots were not treated.

B.1 More on baseline and endline data

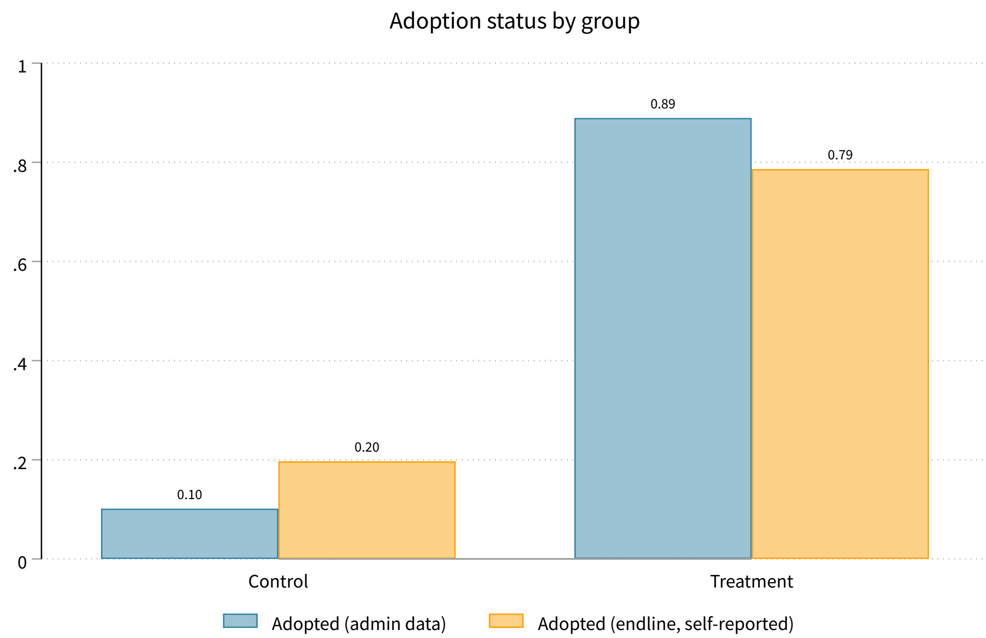
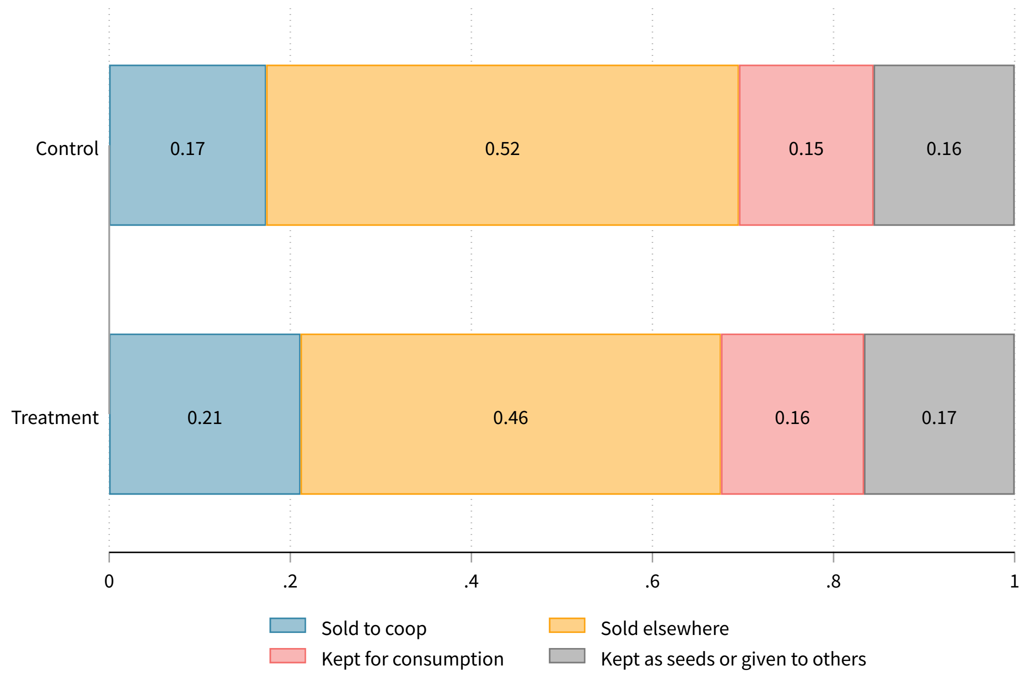


Figure B.2: Aflasafe adoption

(a) Baseline



(b) Endline

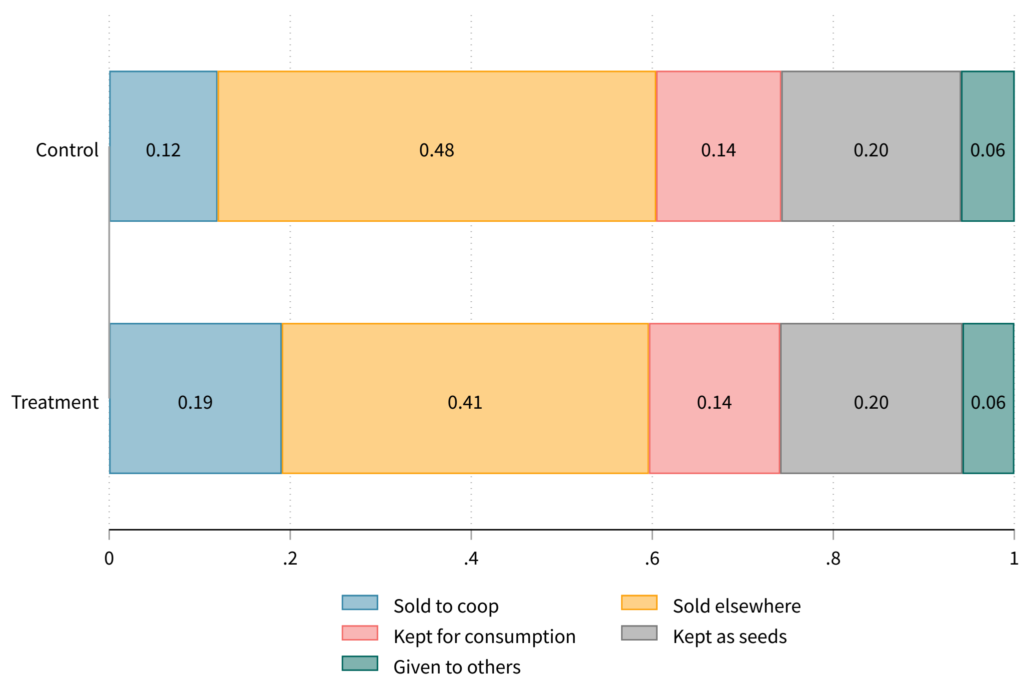
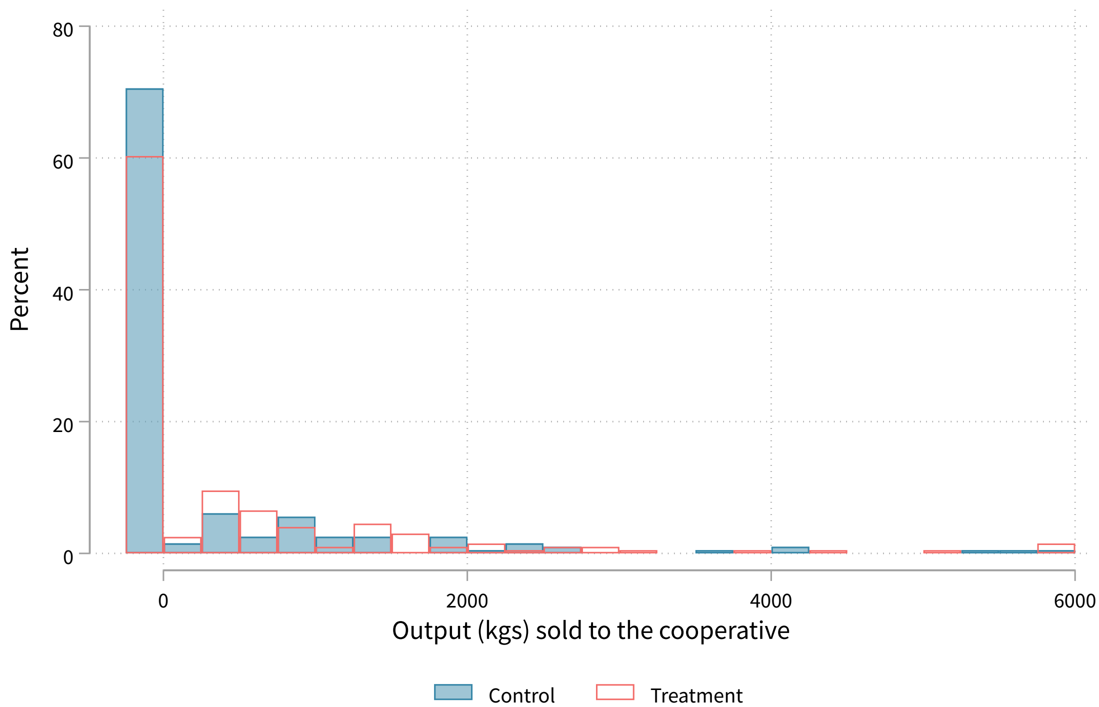


Figure B.3: Output allocation

(a) Baseline



(b) Endline

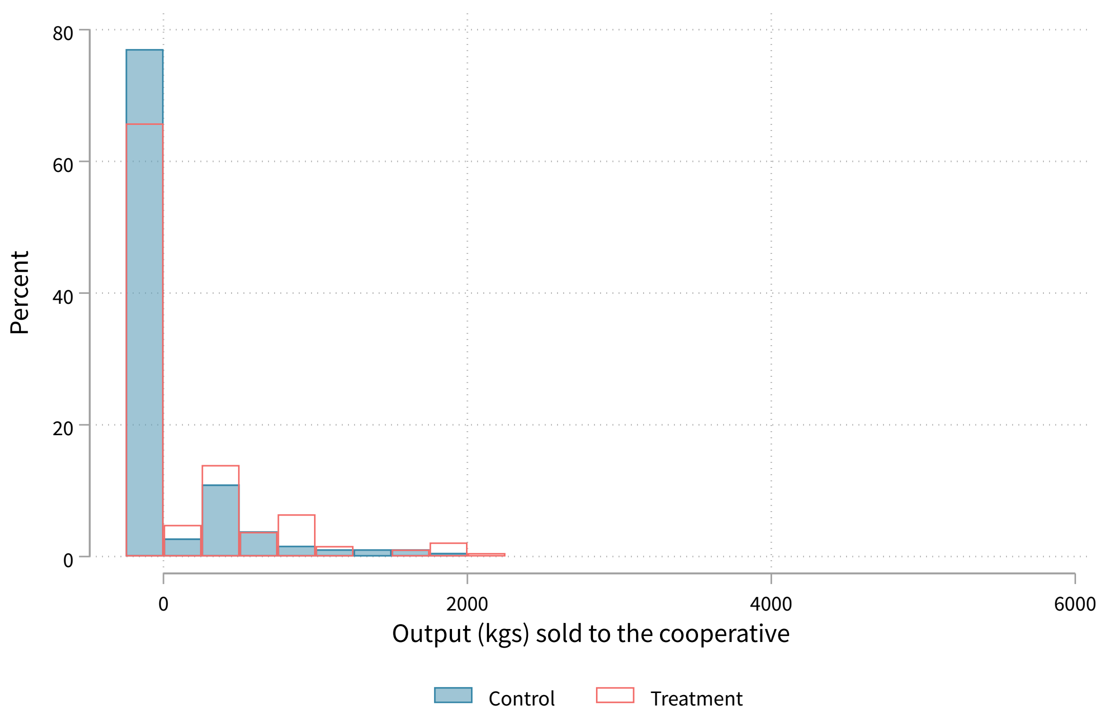
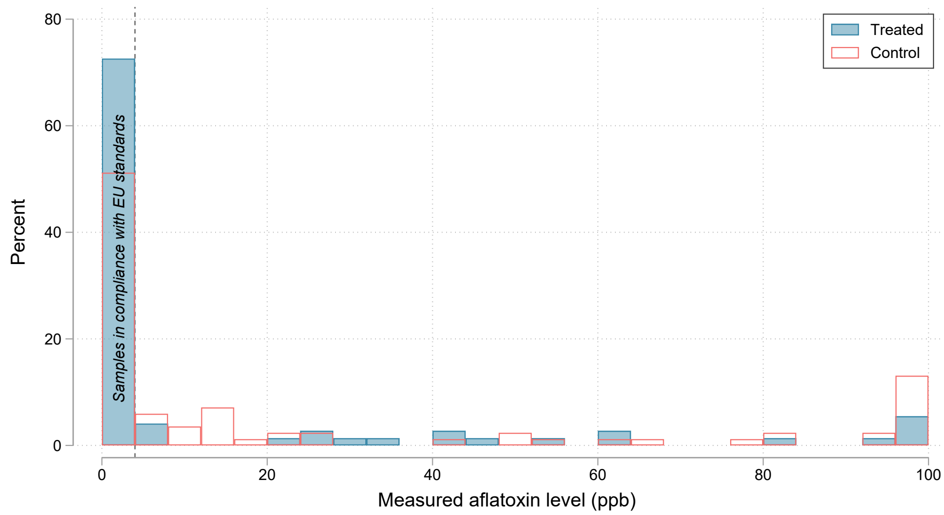


Figure B.4: Output allocation to the cooperative (kgs)

(a) Northern cooperative



(b) Southern cooperative

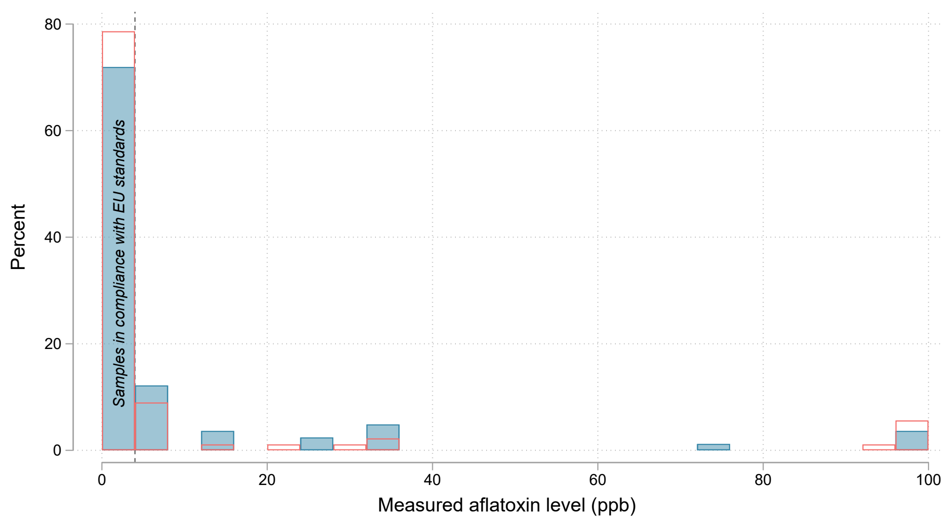


Figure B.5: Post-harvest aflatoxin levels

B.2 Additional results tables

Table B.1: Adoption of Aflasafe, with behavioral heterogeneity

	(1)	(2)	(3)	(4)
Panel A: ITT estimates (admin data adoption)				
Treated	0.79***	0.75***	0.74***	0.83***
	(0.060)	(0.070)	(0.090)	(0.060)
Treated × Reciprocal		0.13*		
		(0.070)		
Treated × Patient			0.06	
			(0.070)	
Treated × Risk-loving				-0.16*
				(0.090)
Reciprocal	0.06**	-0.01	0.05*	0.06**
	(0.030)	(0.040)	(0.030)	(0.030)
Patient	-0.03	-0.03	-0.06	-0.02
	(0.030)	(0.030)	(0.050)	(0.030)
Risk-loving	0.06*	0.06*	0.06*	0.15**
	(0.030)	(0.030)	(0.030)	(0.060)
N	396	396	396	396
Control mean	0.102	0.102	0.102	0.102
Panel B: ITT estimates (self-reported adoption)				
Treated	0.60***	0.57***	0.59***	0.64***
	(0.060)	(0.070)	(0.100)	(0.070)
Treated × Reciprocal		0.12		
		(0.080)		
Treated × Patient			0.01	
			(0.090)	
Treated × Risk-loving				-0.15
				(0.110)
Reciprocal	0.01	-0.06	0.01	0.01
	(0.040)	(0.060)	(0.040)	(0.040)
Patient	-0.05	-0.05	-0.06	-0.04
	(0.040)	(0.040)	(0.070)	(0.040)
Risk-loving	0.04	0.04	0.04	0.12*
	(0.060)	(0.060)	(0.060)	(0.060)
N	370	370	370	370
Control mean	0.197	0.197	0.197	0.197

This table shows results of regressions where the outcome variable is a dummy equal to one if the farmer adopted Aflasafe according to admin and self-reported measures.. Panel A presents Intention-To-Treat results where the outcome is regressed on treatment status. Panel B presents 2SLS results where adoption (as measured in cooperative administrative data) is instrumented by treatment status. Column (2) additionally includes an interaction with a dummy equal to one if self-assessed intrinsic reciprocity is greater or equal to 0.6 on a standardized [0,1] scale, column (3) includes an interaction with a dummy equal to one for self-assessed patient farmers, and column (4) includes an interaction with a dummy equal to one if the farmer identified as extremely willing to take risks. In panel B, the 2SLS regressions additionally include treatment interacted with the cooperative dummy as a second instrument. All regressions include commune fixed effects to account for stratified randomization of treatment assignment. Standard errors are clustered at the treatment assignment (village) level.

Table B.2: Aflasafe non-binding intent to adopt

	Baseline			Pre-Distribution		
	(1)	(2)	(3)	(4)	(5)	(6)
Treated	0.07***	0.07***	0.06***	0.20***	0.22***	0.20***
	(0.02)	(0.02)	(0.02)	(0.05)	(0.04)	(0.05)
Observations	396	396	396	396	396	396
R^2	0.024	0.090	0.198	0.060	0.082	0.124
Control Mean Dep. Var	0.91	0.91	0.91	0.68	0.68	0.68
Commune FE	N	Y	Y	N	Y	Y
Baseline controls	N	N	Y	N	N	Y

Results in this table are from linear regressions of the intention to adopt dummies on the treatment dummy. Baseline intent to adopt was elicited immediately after farmers were informed about Aflasafe and their treatment assignment. Pre-Distribution intent to adopt was elicited by phone when Aflasafe distribution began. Standard errors (in parentheses) are clustered at the treatment assignment (village cluster) level. Baseline controls included are all variables shown above in Table 1.

Table B.3: Phytosanitary standard compliance

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: ITT estimates						
Treated	0.08	0.08	-0.03	-0.03	-0.08	-0.06
	(0.050)	(0.050)	(0.070)	(0.080)	(0.060)	(0.080)
Treated × Pred. high risk (LASSO)			0.33***	0.32**		
			(0.120)	(0.130)		
Treated × Pred. high risk (quadratic)					0.25*	0.24*
					(0.130)	(0.140)
Pred. high risk (LASSO)			-0.34***	-0.19		
			(0.080)	(0.130)		
Pred. high risk (quadratic)					-0.39***	-0.32***
					(0.080)	(0.120)
Baseline controls	N	Y	N	Y	N	Y
N	328	328	328	328	328	328
Panel B: TOT estimates (admin data adoption)						
Adopted	0.10	0.10*	-0.05	-0.04	-0.11	-0.09
	(0.070)	(0.060)	(0.080)	(0.090)	(0.100)	(0.090)
Adopted × Pred. high risk (LASSO)			0.38***	0.38***		
			(0.150)	(0.120)		
Adopted × Pred. high risk (quadratic)					0.33*	0.31*
					(0.170)	(0.170)
Pred. high risk (LASSO)			-0.34***	-0.19		
			(0.080)	(0.130)		
Pred. high risk (quadratic)					-0.39***	-0.32***
					(0.080)	(0.120)
Baseline controls	N	Y	N	Y	N	Y
N	328	328	328	328	328	328
Panel C: TOT estimates (self-reported adoption)						
Adopted	0.14	0.14*	-0.11	-0.14	-0.10	-0.09
	(0.080)	(0.070)	(0.300)	(0.230)	(0.110)	(0.110)
Adopted × Pred. high risk (LASSO)			0.72	0.84		
			(1.420)	(0.630)		
Adopted × Pred. high risk (quadratic)					0.39	0.40
					(0.250)	(0.280)
Pred. high risk (LASSO)			-0.34***	-0.19		
			(0.080)	(0.130)		
Pred. high risk (quadratic)					-0.39***	-0.32***
					(0.080)	(0.120)
Baseline controls	N	Y	N	Y	N	Y
N	307	307	307	307	307	307
Control mean	0.659	0.659	0.659	0.659	0.659	0.659

This table shows results of regressions where the outcome variable is a dummy equal to one if the groundnut sample complied with EU phytosanitary standards. Panel A presents Intention-To-Treat results where the outcome is regressed on treatment status. Panel B presents 2SLS results where adoption (as measured in cooperative administrative data) is instrumented by treatment status. Panel C presents 2SLS results where adoption (as reported in the endline survey) is instrumented by treatment status. Columns (3) and (4) additionally include an interaction with the cooperative dummy. Columns (5) and (6) include an interaction with a dummy equal to one if the village was predicted to be at high risk given agro-climatic conditions experienced during the growing season. See Appendix C for details. In panels B and C, the 2SLS regressions additionally include treatment interacted with the cooperative dummy or the predicted high risk dummy as a second instrument. Standard errors are clustered at the treatment assignment (village) level and bootstrapped in columns (3)-(6). Baseline controls included are all variables shown above in Table 1

Table B.4: Natural log of measured aflatoxin contamination levels

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: ITT estimates						
Treated	-0.21	-0.18	0.22	0.19	0.31	0.27
	(0.200)	(0.170)	(0.200)	(0.200)	(0.210)	(0.240)
Treated ×			-1.24***	-1.21***		
Pred. high risk (LASSO)			(0.380)	(0.460)		
Treated ×					-0.87*	-0.82*
Pred. high risk (quadratic)					(0.500)	(0.490)
Pred. high risk (LASSO)			1.40***	1.10***		
			(0.280)	(0.400)		
Pred. high risk (quadratic)					1.22***	0.88**
					(0.400)	(0.430)
Baseline controls	N	Y	N	Y	N	Y
N	328	328	328	328	328	328
Panel B: TOT estimates (admin data adoption)						
Adopted	-0.27	-0.23	0.29	0.25	0.43	0.38
	(0.240)	(0.200)	(0.280)	(0.300)	(0.300)	(1.650)
Adopted ×			-1.44***	-1.41**		
Pred. high risk (LASSO)			(0.460)	(0.550)		
Adopted ×					-1.14*	-1.09
Pred. high risk (quadratic)					(0.590)	(1.740)
Pred. high risk (LASSO)			1.40***	1.10***		
			(0.280)	(0.400)		
Pred. high risk (quadratic)					1.22***	0.88**
					(0.400)	(0.430)
Baseline controls	N	Y	N	Y	N	Y
N	328	328	328	328	328	328
Panel C: TOT estimates (self-reported adoption)						
Adopted	-0.34	-0.30	0.30	0.29	0.57	0.57
	(0.330)	(0.260)	(0.310)	(0.400)	(0.370)	(0.520)
Adopted ×			-1.82**	-1.87**		
Pred. high risk (LASSO)			(0.750)	(0.890)		
Adopted ×					-1.67*	-1.71
Pred. high risk (quadratic)					(0.870)	(1.240)
Pred. high risk (LASSO)			1.40***	1.10***		
			(0.280)	(0.400)		
Pred. high risk (quadratic)					1.22***	0.88**
					(0.400)	(0.430)
Baseline controls	N	Y	N	Y	N	Y
N	307	307	307	307	307	307
Control mean	1.304	1.304	1.304	1.304	1.304	1.304

This table shows results of regressions where the outcome variable is the natural log of the measured aflatoxin contamination (in parts per billion) in the tested groundnut sample. Panel A presents Intention-To-Treat results where the outcome is regressed on treatment status. Panel B presents 2SLS results where adoption (as measured in cooperative administrative data) is instrumented by treatment status. Panel C presents 2SLS results where adoption (as reported in the endline survey) is instrumented by treatment status. Columns (3) and (4) additionally include an interaction with the cooperative dummy. Columns (5) and (6) include an interaction with a dummy equal to one if the village was predicted to be at high risk given agro-climatic conditions experienced during the growing season. See Appendix C for details. In panels B and C, the 2SLS regressions additionally include treatment interacted with the cooperative dummy or the predicted high risk dummy as a second instrument. Standard errors are clustered at the treatment assignment (village) level and bootstrapped in columns (3)-(6). Baseline controls included are all variables shown above in Table 1

Table B.5: Sold any output to coop, with behavioral heterogeneity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: ITT estimates								
Treated	0.12**	0.09*	0.04	0.01	0.00	-0.05	0.15**	0.12**
	(0.050)	(0.050)	(0.050)	(0.050)	(0.080)	(0.090)	(0.060)	(0.050)
Treated × Reciprocal			0.27***	0.27***				
			(0.090)	(0.090)				
Treated × Patient					0.16*	0.18*		
					(0.090)	(0.100)		
Treated × Risk loving							-0.10	-0.10
							(0.090)	(0.090)
Reciprocal	-0.02	0.01	-0.17***	-0.13**	-0.03	0.01	-0.02	0.01
	(0.050)	(0.060)	(0.050)	(0.050)	(0.050)	(0.060)	(0.050)	(0.060)
Patient	0.00	-0.03	-0.01	-0.04	-0.08	-0.12	0.00	-0.03
	(0.050)	(0.060)	(0.050)	(0.060)	(0.070)	(0.080)	(0.050)	(0.060)
Risk loving	0.11**	0.11*	0.11**	0.10*	0.11*	0.10*	0.17**	0.16**
	(0.050)	(0.060)	(0.050)	(0.060)	(0.050)	(0.060)	(0.070)	(0.070)
Panel B: TOT estimates (admin data adoption)								
Adopted	0.15***	0.12**	0.05	0.01	-0.01	-0.07	0.18***	0.14**
	(0.060)	(0.050)	(0.070)	(0.070)	(0.110)	(0.110)	(0.060)	(0.060)
Adopted × Reciprocal			0.31***	0.31***				
			(0.110)	(0.110)				
Adopted × Patient					0.21*	0.23*		
					(0.120)	(0.120)		
Adopted × Risk loving							-0.12	-0.11
							(0.130)	(0.120)
Reciprocal	-0.03	0.01	-0.21***	-0.17**	-0.04	0.00	-0.03	0.01
	(0.050)	(0.050)	(0.070)	(0.070)	(0.050)	(0.050)	(0.050)	(0.050)
Patient	0.00	-0.03	-0.01	-0.03	-0.11	-0.15*	0.01	-0.02
	(0.050)	(0.050)	(0.050)	(0.050)	(0.080)	(0.090)	(0.050)	(0.050)
Risk loving	0.10*	0.10*	0.11**	0.10*	0.10*	0.09	0.17**	0.16*
	(0.050)	(0.050)	(0.050)	(0.050)	(0.050)	(0.060)	(0.090)	(0.080)
Panel C: TOT estimates (self-reported adoption)								
Adopted	0.20**	0.15**	0.06	0.01	-0.02	-0.09	0.23***	0.18**
	(0.080)	(0.070)	(0.090)	(0.090)	(0.140)	(0.150)	(0.090)	(0.080)
Adopted × Reciprocal			0.39***	0.38***				
			(0.140)	(0.140)				
Adopted × Patient					0.28*	0.30*		
					(0.150)	(0.160)		
Adopted × Risk loving							-0.15	-0.15
							(0.180)	(0.170)
Reciprocal	-0.02	0.01	-0.23***	-0.19**	-0.03	0.00	-0.02	0.01
	(0.050)	(0.050)	(0.080)	(0.080)	(0.050)	(0.050)	(0.050)	(0.050)
Patient	0.01	-0.02	-0.01	-0.04	-0.14	-0.18*	0.01	-0.02
	(0.050)	(0.060)	(0.050)	(0.050)	(0.100)	(0.100)	(0.050)	(0.050)
Risk loving	0.11**	0.10*	0.10*	0.09	0.11**	0.10*	0.19*	0.18*
	(0.050)	(0.060)	(0.050)	(0.060)	(0.050)	(0.060)	(0.110)	(0.100)
Baseline controls	N	Y	N	Y	N	Y	N	Y
N	370	370	370	370	370	370	370	370
Control mean	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230

This table shows results of regressions where the outcome variable is a dummy equal to one if the farmer reported selling any output to the cooperative. Panel A presents Intention-To-Treat results where the outcome is regressed on treatment status. Panel B presents 2SLS results where adoption (as measured in cooperative administrative data) is instrumented by treatment status. Panel C presents 2SLS results where adoption (as reported in the endline survey) is instrumented by treatment status. Columns (3) and (4) additionally include an interaction with a dummy equal to one if self-assessed intrinsic reciprocity is greater or equal to 0.6 on a standardized [0,1] scale, columns (5) and (6) include an interaction with a dummy equal to one for self-assessed patient farmers, and columns (7) and (8) include an interaction with a dummy equal to one if the farmer identified as extremely willing to take risks. In panels B and C, the 2SLS regressions additionally include treatment interacted with the cooperative dummy as a second instrument. Standard errors are clustered at the treatment assignment (village) level. Baseline controls included are all variables shown above in Table 1

Table B.6: Quantity sold to coop, with behavioral heterogeneity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: ITT estimates								
Treated	0.85**	0.64*	0.27	0.08	0.04	-0.27	1.04**	0.81**
	(0.340)	(0.320)	(0.360)	(0.370)	(0.600)	(0.620)	(0.390)	(0.380)
Treated × Reciprocal			1.86***	1.79***				
			(0.600)	(0.610)				
Treated × Patient					1.02	1.14		
					(0.650)	(0.690)		
Treated × Risk-loving							-0.73	-0.69
							(0.650)	(0.620)
Reciprocal	-0.14	0.11	-1.13***	-0.85**	-0.16	0.08	-0.14	0.09
	(0.370)	(0.410)	(0.350)	(0.380)	(0.370)	(0.410)	(0.370)	(0.410)
Patient	-0.04	-0.26	-0.10	-0.31	-0.56	-0.83	0.00	-0.23
	(0.350)	(0.390)	(0.350)	(0.380)	(0.490)	(0.530)	(0.340)	(0.380)
Risk-loving	0.83**	0.76*	0.83**	0.74*	0.80**	0.72*	1.24**	1.15**
	(0.380)	(0.400)	(0.370)	(0.390)	(0.390)	(0.400)	(0.480)	(0.490)
Panel B: TOT estimates (admin data adoption)								
Adopted	1.08***	0.81**	0.34	0.09	0.01	-0.42	1.26***	0.99**
	(0.400)	(0.380)	(0.470)	(0.470)	(0.770)	(0.790)	(0.450)	(0.430)
Adopted × Reciprocal			2.11***	2.06***				
			(0.740)	(0.730)				
Adopted × Patient					1.32	1.50*		
					(0.810)	(0.860)		
Adopted × Risk-loving							-0.84	-0.82
							(0.890)	(0.800)
Reciprocal	-0.19	0.06	-1.39***	-1.10**	-0.23	0.03	-0.20	0.06
	(0.360)	(0.380)	(0.470)	(0.480)	(0.360)	(0.380)	(0.350)	(0.380)
Patient	0.01	-0.22	-0.08	-0.28	-0.71	-1.01*	0.03	-0.20
	(0.340)	(0.370)	(0.320)	(0.360)	(0.560)	(0.590)	(0.330)	(0.360)
Risk-loving	0.75**	0.70*	0.77**	0.71*	0.73*	0.66*	1.25**	1.18**
	(0.380)	(0.380)	(0.370)	(0.380)	(0.390)	(0.390)	(0.610)	(0.580)
Panel C: TOT estimates (self-reported adoption)								
Adopted	1.41**	1.05**	0.45	0.10	-0.02	-0.52	1.62***	1.26**
	(0.550)	(0.500)	(0.640)	(0.620)	(1.010)	(1.070)	(0.590)	(0.540)
Adopted × Reciprocal			2.65***	2.57***				
			(0.930)	(0.920)				
Adopted × Patient					1.78	1.93*		
					(1.090)	(1.150)		
Adopted × Risk-loving							-1.05	-1.07
							(1.280)	(1.140)
Reciprocal	-0.15	0.07	-1.54***	-1.26**	-0.20	0.02	-0.12	0.11
	(0.360)	(0.380)	(0.580)	(0.560)	(0.360)	(0.380)	(0.360)	(0.380)
Patient	0.03	-0.20	-0.08	-0.30	-0.92	-1.21*	0.04	-0.19
	(0.350)	(0.380)	(0.340)	(0.370)	(0.660)	(0.710)	(0.340)	(0.370)
Risk-loving	0.78**	0.72*	0.72*	0.66*	0.77**	0.70*	1.36*	1.31*
	(0.380)	(0.380)	(0.380)	(0.390)	(0.380)	(0.390)	(0.770)	(0.700)
Baseline controls	N	Y	N	Y	N	Y	N	Y
N	370	370	370	370	370	370	370	370
Control mean	1.583	1.583	1.583	1.583	1.583	1.583	1.583	1.583

This table shows results of regressions where the outcome variable is the inverse hyperbolic sine transformation of groundnut output (in kgs) sold to the cooperative.. Panel A presents Intention-To-Treat results where the outcome is regressed on treatment status. Panel B presents 2SLS results where adoption (as measured in cooperative administrative data) is instrumented by treatment status. Panel C presents 2SLS results where adoption (as reported in the endline survey) is instrumented by treatment status. Columns (3) and (4) additionally include an interaction with a continuous measure of reciprocity bounded in [0,1], columns (5) and (6) include an interaction with a dummy equal to one for self-assessed patient farmers, and columns (7) and (8) include an interaction with a dummy equal to one if the farmer identified as extremely willing to take risks. In panels B and C, the 2SLS regressions additionally include treatment interacted with the cooperative dummy as a second instrument. Standard errors are clustered at the treatment assignment (village) level. Baseline controls included are all variables shown above in Table 1

C Agro-climatic conditions and aflatoxin contamination

Table C.1: Agro-climatic predictors of aflatoxin contamination

	(1)	(2)	(3)
3-day dry spells	1.01		1.34**
	(0.68)		(0.56)
(3-day dry spells)^2	-0.01		-0.02**
	(0.01)		(0.01)
Max temperature		-5.09**	-6.45***
		(2.08)	(2.11)
(Max temperature)^2		0.06**	0.07***
		(0.02)	(0.02)
Observations	173	173	173
R^2	0.133	0.147	0.165

Results in this table are from linear regressions of the observed aflatoxin level (log-transformed) among control farmers on agro-climatic variables. 3-day dry spells is the number of 3-day dry spells observed during the growing season. Max temperature is the mean value of the max temperature observed in dekadal observations over the growing season. All regressions include commune fixed effects. Standard errors (in parentheses) are clustered at the village level.

Table C.2: Post-harvest practices at endline

	(1) Dried on ground	(2) Used standard storage
Treated=1	0.00	0.01
	(.)	(0.01)
Northern cooperative	-0.03	-0.05
	(0.03)	(0.03)
Treated=1 × Northern cooperative	0.01	-0.02
	(0.01)	(0.02)
Observations	353	353
R^2	0.031	0.020

Results in this table are from linear regressions of self-reported post-harvest practices at endline on the treatment dummy and the cooperative dummy. Dried on ground is a dummy equal to one if the farmer dried his groundnuts directly on the ground, as opposed to a tarp or concrete pad. Used standard storage is a dummy equal to one if the farmer reported using standard single-layer plastic bags to store harvested groundnuts. All regressions include commune fixed effects. Standard errors (in parentheses) are clustered at the village level.

D Baseline details

D.1 Aflasafe script

The following is the script that was presented to farmers in Wolof, translated to English, at the end of the baseline survey:

Now, we would like to talk about aflatoxin and a new product called Aflasafe. Aflatoxin is produced by a fungus that comes from the soil and grows on groundnuts, maize, and other crops. When crops are not dried well, or not stored in dry conditions, this can cause aflatoxin to increase and spread within your stored crops. Aflatoxin has many negative health effects, especially for pregnant women and young children, and can cause liver cancer when consumed in large amounts over time.

Aflasafe is a new product developed to fight aflatoxin. It is a biological product, not chemical, and uses a non-toxigenic fungus to compete against the toxic fungus which produces aflatoxin on crops. It was originally developed by scientists in America and Nigeria, and customized for use in Senegal. It has been tested here for more than five years, and this year is now launching for sale in the market. If you use Aflasafe correctly, it has been shown to reduce aflatoxin levels in crops by 80-100%. It can also help protect your crops during storage.

Aflasafe is not a substitute for correctly drying and storing your groundnuts. But when used together with these good practices, it can make your groundnuts safer to eat. Buyers and exporters are also interested in buying groundnuts without aflatoxin. Aflasafe is designed to be applied in your field, about 6 weeks after planting, just after the last weeding before the flowering. Aflasafe is distributed as a blue coating on sterilized sorghum seeds which will not grow. To apply Aflasafe, you walk around your fields and broadcast the same way as fertilizer but a small amount of seeds evenly. To treat one hectare of groundnuts, you would need to use 10 kg of Aflasafe. The market price of 10 kgs is 10000 CFA.

Here is a video with more information about Aflasafe: **video link (Wolof)**

In partnership with the cooperative, we are making 10 kgs of Aflasafe available for you to purchase. To purchase the Aflasafe, you would visit the cooperative's magasin to pick it up. The Aflasafe will be available from the magasin before the end of July. You should call to confirm it is available before traveling to pick it up. In addition, we will offer a free service to test your production and certify it if it is low in aflatoxin. We will offer this in your normal collection point with the cooperative.

Treated farmers

We have a coupon here that allows you to receive 10 kgs of Aflasafe this month, and pay 10000 CFA in kind when you bring your groundnuts to the buying center. You do not decide now if you want the Aflasafe, but you will need to decide and pick it up at the magasin before September 1. The cooperative will distribute Aflasafe only to those who bring their coupon to the supply shop at the collection point, so make sure to bring this with you.

In addition, the cooperative will send an animateur to your field to help answer any questions you may have about how to properly apply Aflasafe, including the correct time to apply it. They will also verify for the cooperative that you applied Aflasafe to your field.

If your groundnuts pass the low-aflatoxin test and receive quality certification, the buyers at the center will pay you a guaranteed bonus of 40 CFA/kg over the price the cooperative normally pays. If you treat your field with Aflasafe, it is important that you keep those treated groundnuts separate from any others. If you mix them together with untreated groundnuts, it will affect the results of the aflatoxin test.

Do you plan to accept this contract and pick up your Aflasafe from the cooperative?

Control farmers

We have a coupon here that allows you to purchase 10 kgs of Aflasafe from the cooperative supply shop for 10000 CFA. You do not need to decide now if you want the Aflasafe, but you will need to decide and purchase it at the magasin before September 1. The cooperative will distribute Aflasafe only to those who bring their coupon to the supply shop at the collection point, so make sure to bring this with you.

The cooperative may send an animateur to visit your field to verify if you used Aflasafe.

If your groundnuts pass the low-aflatoxin test and receive quality certification, there may be buyers available who will pay more than the normal cooperative price. If you treat your field with Aflasafe, it is important that you keep those treated groundnuts separate from any others. If you mix them together with untreated groundnuts, it will affect the results of the aflatoxin test.

Do you plan to purchase the Aflasafe from the cooperative?

D.2 Behavioral variable measurement

Reciprocity

We define reciprocity as the mean response to the following three questions, for which the answer options were (Always willing / Sometimes willing / Never willing).

- When someone does me a favor, I am willing to return it
- How willing are you to punish someone who treats you unfairly, even if there may be costs for you?
- How willing are you to punish someone who treats others unfairly, even if there may be costs to you?

Patience

We define patience if a respondent responded “Yes, always” or “Yes, sometimes” to the following question:

- In comparison to others, are you a person who is generally willing to give up something today in order to benefit from that in the future?

Risk

Following Charness and Viceisza (2016), we elicited risk aversion using an 11-point scale:

- Please tell me, in general, how willing or unwilling you are to take risks, using a scale from 0 to 10, where 0 means you are "completely unwilling to take risks" and 10 means you are "very willing to take risks." You can also use any number between 0 and 10 to indicate where you fall on the scale, using 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10