The Effects of Storage Technology and Training on Post-Harvest Losses, Practices and Sales: Evidence from Small-Scale Farms in Tanzania*

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Abstract

We analyze the impact of a new storage technology and training on post-harvest losses (PHL), sales and the timing of sales, farmgate prices, maize quality and storage protection costs among small-scale maize farmers in rural Tanzania. The analysis is based on data collected by means of a randomized controlled trial (RCT) in which farmers were randomized into one of three groups: a control group and two treatment groups. Farmers in the first treatment group received training on post-harvest management practices, and farmers in the second treatment group were provided with hermetic (airtight) bags for storing maize, as well as the training administered to the first treatment group. Both interventions had a significant effect in reducing storage losses, and the intervention with hermetic bags improved the quality of maize grain, raised the likelihood of selling maize, increased the farmgate price of maize, enabled farmers to shift some of their sales to the lean season, and reduced the cost of storage protection. Both interventions are economically feasible.

JEL Classification: C93; Q18; Q16; D61

Keywords: food storage**,** randomized controlled trial; post-harvest losses; training; hermetic bags; cost-benefit analysis

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I. Introduction

Food insecurity, poor nutrition, hunger, and low incomes are chronic problems facing millions of poor smallholder farming households in Sub-Saharan Africa (SSA). Productivity growth in African agriculture has been stagnant over several decades. Several explanations for the weak performance of the sector have been proposed. These include credit constraints, failure to transfer new knowledge to the farm level, limited access to individual savings accounts, lack of information about input quality, uncertainty, and behavioral mechanisms (Bold et al., 2017; Brune et al., 2016; Duflo et al., 2011; Liu, 2013; Suri, 2011; Vandercasteelen et al., 2020). This literature has primarily focused on farmers' decisions prior to harvest, e.g. type of crop, type of seed, and decisions on irrigation and fertilizer.

However, it is increasingly recognized that reducing post-harvest losses (PHL) may offer a more cost-effective and environmentally sustainable way to promote food and nutrition safety than focusing solely on increased productivity (FAO and the World Bank, 2010). This is reflected, for example, in the Sustainable Development Goal (SDG) target 12.3, which calls for halving per capita global food waste at the retail and consumer levels and reducing food loss along production and supply chains (including post-harvest losses) by 2030. Estimates of PHL in African agriculture vary substantially (see e.g. Kaminski and Christensen, 2014; Ambler et. al., 2018), but losses appear to be considerable and costs non-negligible. Figures reported by the World Bank indicate that post-harvest physical grain losses in SSA range from 10 to 20 percent of the total grain production, at a value of USD 4 billion per year (World Bank, 2011). Survey evidence for Tanzania indicates that 10-20% of the harvest is lost during the post-harvest stage (Chegere, 2018). Farmers face new challenges too. For example, some of the traditional post-harvest practices used by East African maize farmers have become less effective due to climate change and new pests like the Larger Grain Borer (Gitonga et al., 2013; Ndegwa et al., 2016).[1] New PHL reduction technologies have been developed and promoted, but the adoption rate is low, especially among smallholder farmers (World Bank, 2011). FAO and the World Bank (2010) estimate that about half of the USD 940 billion needed for investment to eradicate hunger in SSA by 2050 should be geared toward the post-harvest sector including investments in cold and dry storage, rural roads, and rural and wholesale market facilities.

In this paper, we contribute to a small but growing literature that emphasizes the importance of post-harvest practices and management for the economic performance of agriculture (Sheahan and Barrett, 2017). Using a randomized controlled trial (RCT), we investigate whether a short training program, combined with a relatively simple and cheap storage method through the use of hermetic bags, can boost profitability in Tanzanian maize farming. We consider a reasonably broad range of outcome variables, including PHL, the timing of sales, farmgate price, maize quality and insecticides used to protect stored maize. Our data cover almost the entire period from when maize is harvested to just a month before the next harvesting season, enabling us to do a cost-benefit analysis based on the full benefits and costs incurred by the farmer in the post-harvest system. We estimate the discounted payback period of the training program on storage practices at four years and combining training with distribution of hermetic storage bags, the discounted payback period falls to two years. These estimates suggest that small-scale investments in storage methods can be quite profitable.

Our paper relates to the study by Basu and Wong (2015) where married or once-married female farmers in east Indonesia were offered free weather-sealed storage drums and storage sacks, or lean-season consumption loans that should be repaid after harvest, as part of the experiment. The authors consider the effects of these treatments on consumption, health and seasonal differences. Our study is complementary, in that we focus on the effects of training and better storage on farming decisions and outcomes following the harvest. We do not consider effects on consumption or income. Another important paper close to ours is that by Aggarwal et al. (2018), in which farmers in Western Kenya organized in Rotating Savings and Credit Associations (ROSCAs) were invited to join a three-armed RCT aimed at addressing the saving needs of farmers. The intervention underlying the study combined physical storage technology and mental accounting aspects (labeling) in a collective setting (group savings). As noted by Aggarwal et al. (2018), their intervention could have worked through many channels including safe-keeping, mental accounting, or peer-effects. Our paper is complementary in several ways. Our experiment is designed differently, to enable us to estimate the causal effects of training and an improved storage technology in a non-collective setting without mental accounting aspects. Our experiment involved no explicit references to storage as savings, and, unlike Aggerwal et al. (2018), we did not provide encouragement that the stored maize be used for later sale. These differences in the experimental design matter for the interpretation of the results: first, our findings shed light on the effects of improved storage technology and training without additional treatment; second, they apply for a setting in which farmers decide on storage, consumption and sales with no reference to collective group mechanisms, and with no requirement that the farmers move the maize out of their own homes.

The design of our field experiment is as follows. We began by randomly drawing 21 villages in the Kilosa district, in the Morogoro region. We randomly assigned the villages to two treatment groups – *training and bags* (six villages) and *training only* (six villages) – and the control group (nine villages). In the *training and bags* treatment group, 120 farmers in the six villages were trained on maize post-harvest handling and storage techniques. They were then provided with hermetic bags and trained on how to use them. Agronomists, specialized in maize production and post-harvest management, and with field experience in working with farmers, designed and conducted the training. In the *training only* treatment group, 120 farmers received the same training on maize harvesting and post-harvest handling, including the benefits of effective storage in reducing PHL and various technologies available to achieve them, but were not given hermetic bags. In both treatment groups, subjects were given the training manuals and a leaflet with verbal and pictorial explanations and illustrations about post-harvest technologies. The control group consisted of 180 farmers from nine control villages, who continued with business as usual. By comparing outcomes across the treatment and control groups, we can credibly estimate the causal effects of our interventions, i.e. the training and the storage bags. As the training provided to the farmers is reasonably generic, the results of the *training only* treatment may be more generalizable to other contexts than the results of the *training and bags* treatment.

The paper is organized as follows: Section II presents context, focusing on PHL; Section III presents the experimental design; Section IV describes the data; Section V describes the estimation strategy; Section VI presents the results; Section VII provides a cost-benefit analysis of the economic effectiveness of the interventions; and Section VIII contains the conclusion.

II. Storage and Post-Harvest Losses

Maize is the staple food crop in most of SSA. In Eastern and Southern Africa, production is highly seasonal, while consumption is relatively constant during the year (Gitonga et al., 2013). Gilbert et al. (2017) find average differences in monthly maize wholesale price between peak and trough of 30%.[2] Maize storage is therefore important for food security because it smooths the supply throughout the year. Burke et al. (2019) show that the share of small-scale farmers that "sell low and buy high" can be significantly reduced if credit constraints are relieved. In Tanzania, maize comprises more than 70 percent of total cereals production (Tanzanian National Bureau of Statistics, 2012) and contributes about 35 percent of the daily calorific intake. African Post-Harvest Losses Information System (APHLIS) (2019) estimates annual PHL for the region Morogoro during 2007-2012 to be around 18%.[3]

Polypropylene bags (sacks) are popular for storage among small-scale farmers in Tanzania, for several reasons: the sacks are cheap; portable in case of emergencies (e.g., floods, fires); make it easy to monitor quality; can be kept in the house after loading, serving as a protection against spillage and theft; take up less space in the room (as opposed to a large woven granary that fills a whole room, whether empty or full); and are always ready for marketing, in case of an emergency or for opportunistic sales (World Bank 2011; Ndegwa et al., 2016). However, there are also significant problems associated with the use of these sacks. Since the sacks do not provide protection against moisture and storage pests, farmers try to limit storage pest infestation using pesticides, insecticidal plants and ashes (Farrell and Schulten, 2002). These methods are not always economically effective and can impact the environment and human health negatively (Meikle et al., 2002; Kumari et al., 2012; FAO and WHO, 2016). Moreover, to avoid high losses due to lack of suitable grain storage structures and absence of storage management technologies, smallholders tend to sell their maize immediately after harvest. Consequently, because they sell when the market is flooded, prices are low. In addition, they may need to buy grain for consumption at a higher price just a few months after harvest, when their stock is exhausted (Gilbert et al., 2017).

Improved storage technologies, mainly hermetic storage methods, have been developed in response to storage challenges. These include metal silos and hermetic bags. Metal silos are airtight and have proven to be effective in protecting the maize grains from both storage insects and rodent pests (FAO, 2008). Though metal silos could potentially reduce PHL and allow storage for a longer period, they are expensive and unaffordable to most small-scale farmers. Moreover, the metallic structure means that they permanently occupy space, whether they are used or not. The effectiveness of metal silos may also decrease when grain is removed because oxygen levels are likely to increase (Tefera et al, 2011; Ndegwa et al., 2016).

Hermetic storage bags offer a recently developed technology. These bags have two or more layers. The outer layer is the normal sack (polypropylene bag) and the inner layers are special plastic (high density polyethylene) linings, which are air-proof. At a cost of about USD 2 for a 100-kilogram (kg) bag they are cheap and they are easy to use. Storage pests are killed as they are deprived of oxygen inside the bags. Once some grains are off-loaded from the bag, the bags can easily be tightened again to keep them airtight and reduce the oxygen level to prevent insect pests from surviving. Hermetic bags can also substantially reduce the occurrence of aflatoxins contamination (Maina et al, 2016). The outcome of using hermetic bags is highly dependent on post-harvest handling practices before actual storing too. Adoption of recommended post-harvest handling practices reduces PHL (Chegere, 2018), and if combined with the usage of hermetic bags PHL can be reduced even more. Hermetic bags have recently been promoted by e.g. USAID in Kenya to reduce PHL (Aggarwal et al., 2018), but were unknown to all involved farmers at the time of our experiment.

III. Experimental design

Study area

The study was conducted in the Kilosa district in the Morogoro region in eastern Tanzania. According to the 2012 population census, the district had a population of 438,175. The district offers a variety of agro-ecological conditions for cultivation of different crops, such as maize, rice, millet, cassava, beans, bananas and cowpeas (Kajembe et al., 2013). Crop farming is the main economic activity for 55% of the households in the district (Tanzanian National Bureau of Statistics, 2012). Maize is the main food crop in Kilosa and, in a normal year, the district is a surplus producer of maize.

The Kilosa district receives an average annual rainfall of 800-1400 mm (Kajembe et al., 2013) distributed during two rain seasons, the short rains between November and January and the long rains between March and early June. Despite having two rain seasons, the pattern and amount of rainfall in the district allow for only one harvest of the main staples per cropping season. The climatic conditions of the Kilosa district are typical for maize production in SSA.

Despite efforts to increase production, the goals of improving food security, reducing rural poverty and ensuring environmental sustainability have been constrained by PHL. Results from the baseline survey show that PHL in maize are significantly correlated with household food insecurity and lead to income losses equivalent to a median monthly income of the sample households.

Sampling Framework and Data Collection

The sampling framework comprised households in villages which met two criteria: (1) Maize is the main crop produced by the villagers and (2) maize is the main staple food in the village. The selection of these villages was done after consulting the district administrative secretary and the district agricultural officer and then confirmed by respective village leaders and village agricultural officers. This selection was important to ensure that our interventions were targeted to the most relevant group of farmers. We used a two-stage sampling process to recruit participants in our survey. In the first stage, we randomly selected 21 villages from the list of villages that met the above criteria. In the second stage, we randomly selected 20 maize-farming households from each village from the household roster obtained from the village office. In total, the sample consisted of 420 households in 21 villages. A farmer who declined was replaced by another farmer in the same village by a random sampling procedure.

During April and May 2015, prior to the main baseline survey, we carried out consultations with village agriculture extension officers, conducted interviews with farmers and village leaders, and organized focus group discussions in two villages in the Kilosa district that were not included in the main survey. Farmers normally plant one crop of maize per year, most use propylene sacks for maize storage and none of the farmers were aware of the hermetic-bag-technology. We also conducted a pilot survey to test our questionnaire with 20 households in one village that was not included in the main survey.

We conducted the main baseline survey between the last week of June and mid-July in 2015. By the end of July 2015, we administered the implementation of the interventions, and in June 2016 we conducted a follow-up survey focusing on agricultural outcomes. The timeline of the field work is shown in Figure A1 in the Appendix.

Treatment and Control Groups

Our goal is to estimate the causal effects of post-harvest management training and hermetic storage bags on PHL and other agricultural outcomes. To achieve this goal, we implemented an RCT. We worked in collaboration with an agronomist in providing the training on post-harvest management practices and with two companies manufacturing hermetic bags to distribute the bags and explain their usage. During the baseline period, only 22 percent of the farmers reported ever having attended training on PHL, and none of them had ever used hermetic bags.

In order to minimize spill-over effects from treatment groups to the control group, we assigned treatments at the village level. We randomly assigned the villages to the two treatment groups –*training and bags* (six villages) and *training only* (six villages) – and the control group (nine villages). Figure A2 in the appendix shows the map of the study area and the distribution of villages according to experimental groups.

Training and bags treatment

In the *training and bags* treatment group, 120 farmers in six villages were given training on maize post-harvest handling and storage techniques and free access to the hermetic bags and training on how to use them. The training was designed by agronomists who are specialized in maize production and post-harvest management and have field experience in working with farmers. The content and material for the course were gathered from various sources, including maize harvesting and post-harvest management guidelines from the ministries and departments of agriculture in East Africa, consultation with NGOs working with maize farmers and dealing with PHL, scientific research, and field experience.[4] The topics covered included: time to harvest; requirements during the harvesting process; harvesting; drying; shelling; storage and storage structures; and losses due to poor storage. The subjects were given the training manuals and a leaflet with verbal and pictorial explanations and illustrations about post-harvest technologies. The training sessions lasted almost two hours. In each village, farmers were trained in either one or two groups depending on convenience. A separate training session focused on how to use the hermetic bags. Farmers were given a two-page leaflet, and had the chance to ask questions and seek clarification as much as they wished during and after the training session. Farmers were informed about possible adverse effects of not using the bags properly. For example, storing maize with high moisture content in the hermetic bags can cause fungal growth and rot all the grain in the bag; also, it was explained to the farmers that if a bag is perforated by rodents, it loses its air-proof quality.

When the training had been completed, each farmer received hermetic bags. In the baseline survey, we had asked farmers how many acres of land they had planted in maize during the prevailing season and how much maize they expected to harvest. We gave them the number of bags that would store about 60% of their expected harvest. This was done for two reasons. First, we assumed that farmers tend to be optimistic about the amount they can harvest, in which case the expected harvest in most cases would be higher than the actual harvest. We did not want the farmers to end up with excess bags, since that could contaminate our experiment if they try to sell or re-distribute bags that they did not need. Second, it is recommended that, once the grains are stored in hermetic plastic bags, the bag should remain sealed for at least six weeks to stop oxygen from entering the bag, which could revive the pests that were dying of suffocation. Thus, some of the maize, which would be used for food or sales within six weeks after storage, would not be stored in the hermetic bags.

Farmers were asked to use the hermetic bags solely for maize storage and not to give or lend them to other farmers. This was a precautionary measure to minimize the risk of contamination if bags were re-distributed to other farmers and potentially even ending up in neighboring villages. The farmers were specifically asked to inform their neighbors and relatives that they had an agreement with the researchers from the University of Dar es Salaam to use all the bags themselves, and that the researchers would be checking periodically to assess their use. In November and December 2015, random visits to about 50 percent of the farmers who received the bags were made at their homes to observe whether the bags were used and whether the farmers had any challenges in using them. Of the farmers visited, none had experienced any challenges in using the bags and everybody had used all the bags that had been given to them.[5]

Training only treatment

In the *training only* treatment group, 120 farmers received the same training on maize harvesting and post-harvest handling as administered to the *training and bags* group. However, farmers in this treatment group were not given hermetic bags. The same agronomist conducted the training on maize post-harvest management in all villages, both for the *training only* group and the *training and bags* group.

Control

The control group consisted of 180 farmers from 9 villages, who continued with business as usual. The farmers in the control group were unlikely to be contaminated by the intervention. At the time of the intervention, the technology had not spread to the region and none of the farmers were aware of the technology during the pilot interviews. During the baseline survey, only two farmers had heard of it, after visiting relatives in another region where the technology was already available.

IV. Data and Descriptive Statistics

In the baseline survey we collected information on demographic and other socioeconomic characteristics, household food security and maize production practices from 420 households. We obtained recall data on PHL and post-harvest management practices in the previous agricultural season which had started in August 2014. Since the survey was carried out at the end of the maize farming season, the loss figures reported covered almost the entire post-harvest period for grain. In each household, we interviewed either the head of household or the spouse. In the follow-up survey, we interviewed 397 of the baseline households. We thus lost 23 households: twenty-two of these could not be induced to participate in the follow-up survey, resulting in an attrition rate of 5% which we consider quite low, and one household included in the baseline was dropped because it was an outlier, operating on a large scale.[6] We interviewed the same respondent in the follow-up survey as in the baseline. We drop seven households from the follow-up sample, as they could not provide essential information for our study. The estimation sample obtained from the follow-up survey thus consists of 390 respondents. For some variables that refer to the sales of maize (e.g. prices) we have fewer than 390 observations, since not all households sell maize.

The data obtained on PHL distinguish three stages: losses occurring between harvesting and storage (referred to as pre-storage losses in this study), losses occurring during storage until the time of consumption or sales (storage losses); and those occurring in the process of selling maize (marketing losses).[7] The information was self-reported and involved a recall period of about ten months. The farmers reported the loss at each stage in terms of kilograms (kg), number of buckets, or number of bags, depending on what they found easiest to estimate. All the quantities were converted into kg.[8] We asked the following questions to elicit data on losses:

(i) How much was the loss from the time you harvested to storage time (taking into account all losses during transporting, drying, shelling and winnowing)?

(ii) How much was the maize loss between the time you stored and the moment you used it for consumption or took it for sale?

(iii) How much was the loss at the marketing stage (taking into account all the stages from taking the grain from storage to weighing and transporting it)?

To minimize recall bias, the losses were assessed step-wise with indirect cross-checking questions for greater robustness. Enumerators were also trained and tested off the field and on the field during the pilot, to ensure effective collection of data. After the baseline data collection, the farmers were instructed to keep an account of the amount of maize they harvested, consumed and sold, at least at the end of each month, to be used in the follow-up.

Table 1 shows summary statistics for our estimation sample at the baseline. The majority of the heads of households are male (85%), their average age is 47 and their average years of education is 7.1. Households have on average 5.5 members and 3.0 active workers.[9] Mean annual income is USD 1,059, which translates to approximately USD 0.60 per person per day. The average value of the stock of assets is USD 4,341. The respondents have on average 19 years of experience with maize farming. The average land size is 2.6 hectares (ha), and the average land size devoted to maize farming is 1.7 ha. The maize harvest in 2014 averaged at 2.8 tons, or about 1.6t/ha. This is higher than the national average of 1.3 t/ha and above the district average of 0.98 t/ha in 2007, reported in the Tanzania Agricultural sample survey, 2007/08. Most of the households (90%) sold some of their maize from the 2014 harvest season. Two thirds of the amount harvested was sold on average, and 51% of that was sold within three months after harvesting. On average, farmers experienced a total of 12% PHL relative to the quantity harvested. Of the three stages, farmers experienced the most losses during storage, averaging 8% of the amount harvested. The main stated causes of storage losses were rodent attacks, insect infestations, moisture and rotting. Pre-storage losses were on average 3%, occurring mainly during shelling, drying and transporting to the homestead. Marketing losses were low, about 1%, as most farmers sell their maize to agents who collect them from their homes.

Table 1 also shows mean differences across treatment and control groups. In most cases these differences are small. This is entirely as expected, since treatment and control status was randomized across the households as part of the RCT. To investigate this issue further, for each variable we carry out a statistical test of the null hypothesis that the population mean difference is equal to zero. For these tests, we assume independence across but not within villages, and thus 'cluster' on village. Because the number of villages is relatively small, we use the wild cluster bootstrap approach proposed by Cameron et al. (2008). This approach is further discussed in the next section. We compare a total of 32 variables between the two treatment groups and the control group. Of the 96 comparisons, none is significantly different at the 1% level, and in only four cases is the difference significant at the 10% or 5% levels. In view of these results, we conclude that the randomization was successful.

V. Estimation of Average Treatment Effects

Because the treatments were randomly assigned at the village level, the impact of the interventions can be identified by simple mean comparisons across the groups. Using a simple regression framework, for each outcome, the estimation equation is:

$$Y_{iv} = \alpha + \gamma B_v + \delta T_v + X'_{iv}\beta + \varepsilon_{iv} \qquad (1)$$

where Y_{iv} is the outcome variable of interest for household i in village v, α is a constant, B_v is a dummy variable equal to 1 if the village received training on post-harvest management and hermetic bags for maize storage, T_v is a dummy variable equal to 1 if the village only received training on post-harvest management, and ε_{iv} is an error term which is uncorrelated with B_v and T_v since treatment was randomized. The coefficient γ measures the combined effect of post-harvest management training and hermetic maize storage bags on the outcome of interest. The effect of post-harvest management training only is measured by δ.

We consider a wide range of outcome variables. We first examine if PHL at the pre-storage and storage stages have been affected by the treatments. We then proceed by estimating the treatment effects on maize grain qualities. We investigate whether the training and the use of storage bags affected sales, and the timing of sales. We hypothesize that the farmers with bags shift some of their maize sales, since the bags enable them to store maize and sell later when prices are higher. We also investigate directly whether the price received by farmers is affected by our treatments. In the final part of the empirical analysis, we examine the effects of the training and storage bags on maize protection practices and post-harvest management practices more generally.

The issue of statistical inference has to be carefully considered in our case. We assume that the error terms are independent across but not within villages, and thus 'cluster the standard errors' at the village level. With a small number of clusters (21 in our case), the usual techniques for calculating cluster-robust standard errors based on asymptotic theory provide downward-biased standard errors. That is, when the number of clusters is small, the standard asymptotic tests tend to over-reject the null of no effect (Bertrand et al., 2004; Cameron et al., 2008). We therefore use the wild cluster bootstrap approach proposed by Cameron et al. (2008) for inference.[10] In the estimation results tables, we specifically report the p-values of tests of the null that the coefficient is 0, computed using the wild-bootstrap cluster-t procedure. We also use the randomization inference technique as outlined by Young (2019), which calculates p-values based on a distribution that is known regardless of sample size.[11] Given that our sample covers only 21 villages, concerns related to small sample size are clearly potentially warranted.

VI. Empirical Results

Impact on Post-harvest Losses

We first examine the quantitative impact of the interventions on PHL at two stages: between harvesting and storage (pre-storage) and during storage (storage losses). Results from specifications with, and without, socioeconomic controls are shown in Table 2. The results in columns [1] and [2] imply that the *training and bags* treatment had a negative but wholly statistically insignificant effect on pre-storage losses. Similarly, the *training only* treatment has a small negative effect but again this is not statistically significant. In contrast, the treatment effects on storage losses are highly statistically significant. The results in columns [3] and [4] imply that the *training and bags* intervention reduced storage losses by 6.1 percentage points, which implies a 76.8% reduction. This effect is statistically significant at the 1% level. The *training only* treatment reduced storage losses by 2.3 percentage points (29.5%). This effect is statistically significant at the 5% level. We test the null hypothesis that the *training and bags* treatment effect is equal to the *training only* effect. Results are shown at the bottom of Table 2. For storage losses, we reject equality of the effects at the 1% level. There is thus some evidence that the use of hermetic bags causes lower storage losses. As expected, because of the random assignment of villages to experimental groups, the estimated effects are virtually the same after the inclusion of socioeconomic controls. It can also be noted that the inclusion of socioeconomic controls affects the p-values to a very small extent, and that the p-values obtained by means of the wild bootstrap are very similar to those obtained by means of the randomization inference approach.

Impact on maize grain quality, sales and price

Physical quality of the grain is important for maize marketing as well as for consumption. Farmers were asked if the size, shape, aroma, taste and color of the maize grain were maintained after being stored. They responded whether they greatly agree =4, agree=3, disagree=2, or greatly disagree=1 with the statement. The farmers were also asked to compare the degree of maize infestation and rotting before and after storage, to which they responded that it remained the same=1, increased=2 or increased greatly=3. We asked farmers to state the amount of maize harvested, the amount sold, and the amount sold within three months after harvesting. We use these data to investigate whether the treatments have affected the timing of sales for the farmers who sold maize. We furthermore asked these farmers to state the highest and the lowest price of maize they obtained in their transactions. We estimate the effects of the interventions on the above qualitative outcomes, the timing of sales, and on maize prices obtained (highest, lowest, and the average of the two).[12]

Columns [1]-[4] of Table 3 show that both *training and bags* and *training only* treatments have positive effects on the physical characteristics of the stored maize grain. However, only the effects of *training and bags* on size and shape of maize, and maize aroma, are statistically significant, at 1% and 10%, respectively. Hence, there is some evidence that the use of hermetic bags, combined with training, improves the qualitative characteristics of the maize grain. The *training only* treatment is statistically insignificant in all cases. We also find that the *training and bags* treatment causes statistically significantly lower degrees of pest infestation and rotting of maize compared to the control and the *training only* groups (columns [5] and [6] of Table 3; equality of treatment effects can be rejected at the 5% level). Given the large number of characteristics that we use to proxy for quality, we construct a composite index of quality using a principal component analysis of the dependent variables in columns [1]-[6]. The effect of *training and bags* treatment on the composite quality index is positive and significant at the 5% level (Table 3, Column [7]).

Next we investigate whether better storage technology and know-how affect sales patterns. Columns [1]-[5] in Table 4 show estimates of treatment effects on the amount of maize sold, and the timing of sales. The effects of the treatments on amounts sold (measured in kg; with all observations, including those with zero sales, included) are statistically insignificant (column [1]). Next, we break down sales into two periods: an “early” period, within three months after harvesting; and a “late” period, which is later than three months after harvesting. We find that the *training and bags* treatment affects sales in the early period negatively (column [2]) and sales in the late period positively (column [3]). These differences are economically quite significant, but not statistically significant. Once we focus more closely on the *shift* in sales from the early to the late period, we are getting closer to statistical significance. In column [4], the dependent variable is the difference between late and early sales. We find that the *training and bags* treatment results in a shift of 389 kg of maize sold from the early to the late period.

The effect is not quite statistically significant, however (the p-values associated with the test of the null of no effect are 0.16 (wild-cluster bootstrap) and 0.12 (randomization inference), respectively). An alternative way of investigating whether the interventions cause a shift in sales to the later period is to consider the share of sold maize that is sold early. The effect of *training and bags* treatment is estimated at -0.12, and it is statistically significant at the 10% level (column [5]). Overall, while the statistical significance is clearly marginal, these results indicate that the *training and bags* treatment shifts some of the maize sales to the later period, when prices are higher. [13] A similar result was documented for Kenyan farmers by Aggarwal et al. (2018).

Estimated treatment effects on prices are shown in Table 4, columns [6]-[8]. The results in column [6] indicate that the highest price per ton of maize obtained by households assigned *training and bags* treatment was USD 21.5 higher than for households in the control group. This effect, which is statistically significant at the 5% level, is equivalent to 8.8% of the sample average of the highest price obtained. The *training only* treatment effect is estimated at USD 10.4, but is not statistically significant. Column [7] shows that there are no significant treatment effects on the lowest maize price obtained by the households. These results are consistent with the notion that bags enable farmers to store maize longer and sell when prices are high. Column [8] shows results referring to the average of the highest and lowest price obtained ('min-max average'). These results indicate that the min-max average price for households in *training and bags* and *training only* treatments is USD 12.66 and USD 5.62 higher per ton, respectively, compared to those in the control group. The effect is statistically significant at 10% for the *training and bags* intervention but insignificant for the *training only* intervention. Based on separate regressions (see appendix, Table A1), we find a negative and highly statistically significant conditional association between price and a variable measuring the percentage of maize sold within three months of harvest. Our composite index of maize quality (see above) is positively associated with highest price obtained (and with the min-max average) but the relationship is not statistically significant. The results thus suggest that opportunistic sales play a more significant role than maize quality on price.

Impact on maize protectants use and cost of protection

One of the advantages of using hermetic bags is that it kills pests by depriving them of oxygen. This means less of a need to use insecticides, which reduces cost and lowers the probability of negative health effects caused by pesticide residues. Column [1] of Table 5 shows that the proportion of farmers who used at least one technique of protection, such as chemical protectants, ashes, plants, herbs, rat traps or rat poison, to protect their stored crops was significantly lower for those who received the hermetic bags compared to the control group. Different storage methods require different types of protections. A significantly lower proportion of farmers in the *training and bags* treatment group used chemical protectants, compared to the other groups (column [2]); on the other hand, a significantly higher proportion of those in the *training and bags* treatment group used rat traps and poison compared to those in the control group (column [3]). The latter result is intuitive because an attack by rodents on the hermetic bags will perforate them and render them useless as airtight storage.

To gauge the economic effects of the changes in protection practices associated with bag usage, we regress the total cost of protecting stored maize on the treatment and control variables. The results are shown in Table 5, column [4]. Farmers in the *training and bags* treatment group spent USD 2.6 less to protect a ton of stored maize, compared to those in the control group. There are no significant differences between the *training only* treatment and the control group with respect to protection practices or protection costs.

Post-harvest Management Practices

Table 6 presents the estimated effects of the interventions on five post-harvest management practices that were covered in the training: harvest at maturity; spreading maize after harvesting; sorting maize after harvesting; number of days maize was dried; and whether maize storage was cleaned and disinfected. The results show that, although farmers in the treatment groups to a greater extent adopted 'desirable' post-harvest management practices, compared to those in the control group, the differences are not statistically significant. Using a principal component analysis of the five post-harvest management practices, we compute a composite index of post-harvest management practices. The treatment effects on the composite index of post-harvest management practices are statistically insignificant (Table 6, column [6]). There is thus no strong evidence that the treatments affected post-harvest management practices.

VII. Economic Effectiveness of the Interventions

We have found a number of channels through which the interventions affect profitability, e.g. through reduced PHL, increased market price of maize, and lower protection costs. In this section we assess the economic effectiveness of training and the use of hermetic bags. Our calculations are based on the point estimates of the relevant treatment effects, and we make no distinction between effects that are statistically significant and insignificant. Table 7 shows the calculation of the total value gained by a hypothetical average farmer in the *training only* group, compared to the average farmer in the control group. Evaluated at the average level of maize harvested among farmers in the *training only* treatment group (1,887 kg), the training reduces PHL by 10.85 kg at the pre-storage stage and by 44.34 kg at the storage stage. Assuming a price of USD 0.2 per kg of maize, these loss reductions are valued at USD 2.17 and USD 8.87, respectively. In addition, the training has a positive effect on the price (see Table 4). As already noted, we do not have a good measure of the average maize price obtained by farmers. Using the simple average of the highest and lowest price reported (i.e. our 'min-max average'; see Table 4, column [8]) as a crude proxy for the average price, and evaluating the *training only* treatment effect on price at the average amount sold in the market (1,385 kg), the price effect of training implies a gain of USD 7.56. Adjusted for the proportion of farmers who sell maize, this figure is equal to USD 5.74. So, in total, the farmer who received the *training only* treatment gains USD 16.78 compared to the case if she were in the control group.

In addition, farmers incurred more costs to adopt 'good' post-harvest management practices. We take these costs into account too, and present them in Table 8. We collected information from farmers on the labor hours and expenditures required to adopt each of the practices. We converted the labor hours into monetary terms by multiplying by the labor cost per hour in the study area.[14] We obtain the total monetary costs of adoption of post-harvest management practices per ton of maize. We then multiply this cost by the average amount of maize harvested or stored, depending on the stage at which the practice is done, and then multiply by the relevant treatment effects. This yields the cost of adoption of each practice by a treated farmer relative to one in the control group.[15] In total, the hypothetical average farmer incurs USD 6.73 more in costs for adoption compared to a farmer in the control group.

The estimated total net benefit of the *training only* treatment is thus USD 10.05 (USD 16.78 minus 6.73) in one season. The total cost of providing training for 120 farmers was USD 4,000, which is equivalent to USD 33.33 per farmer.[16] Assuming that the discount rate is 12%, and that the net benefits during that period are constant (USD 10.05) in every season, then, with the initial investment of USD 33.33, the discounted payback period is approximately four years. [17,18] Several caveats are in order, however. First, recall that maize prices are likely measured with error (see note 12), which suggests that the estimated price effects in the present study should be interpreted with caution. As noted above, the estimated price effect contributes USD 5.74 to the overall *training only* treatment effect, i.e. slightly more than half of the estimated effect. If the true price effect were in fact zero – a conservative scenario worth considering in our case, since the price data is unlikely of high quality – the total net benefit would decrease to USD 4.31, and the associated discounted payback period would be approximately 23 years. This can be considered a lower bound of the benefits of the intervention. Second, it is worth recalling at this point that several of the *training only* treatment effects are statistically insignificant, so the confidence interval associated with estimates above is likely quite wide. Third, we have not considered the spillover effects of the training to other people in the village, and we assume that training can be administered to twenty people per village, but in reality, more can be covered at a very small additional cost. It should be clear from these points that our effect estimates are crude, and only indicative of the magnitude of the true treatment effect.

Next, we conduct a similar analysis for the economic effectiveness of the *training and bags* treatment. Table 9 shows the calculation of the total value gained through this treatment. Evaluated at the average level of maize harvested amongst farmers in the *training and bags* treatment group (1,925 kg), the training reduces PHL by 7.32 kg at the pre-storage stage and by 116.8 kg at the storage stage. Assuming a price of USD 0.2 per kg of maize, these loss reductions are valued at USD 1.46 and USD 23.37, respectively. Evaluated at the average amount sold in the market (1,347 kg), the *training and bags* treatment effect on price (again using the results for the 'min-max average'; see Table 4) implies an additional gain of USD 17.11. Adjusted for the proportion of farmers who sell maize in the market (0.875), the value of the price effect is USD 14.97. The *training and bags* treatment also implies a reduction in the cost of protection of stored maize of 2.6 USD per ton. Evaluated at the average amount of maize stored (1,780 kg) for farmers in the *treatment and bags* group, this implies an additional gain from the treatment of USD 4.63. In total, the farmer who received the *training and bags* treatment gains USD 44.43 compared to the case if they had been in the control group.

The monetary costs of adoption of post-harvest management practices per ton of maize are presented in Table 10. The adoption cost for the average farmer in the *training and bags* group is USD 7.23 higher than for the control group. Therefore, the net benefit of the *training and bags* treatment is USD 37.2 (44.43 minus 7.23), for one season.

Again, the total cost of providing the post-harvest management training for 120 farmers was USD 4,000, which is equivalent to USD 33.33 per farmer. On average, a farmer in the *training and bags* treatment group received 12 hermetic bags, at total cost USD 24 (each bag costs USD 2). The total initial investment is thus USD 57.33 (33.33+24). Assuming that the net benefits during are constant at USD 37.2 per season, then, with the initial investment of USD 57.33, the discounted payback period for this intervention is slightly less than two years. In a conservative scenario, where the intervention has no effect on maize prices, the total net benefit reduces to USD 22.23 (USD 37.2 minus price effect of 14.97), implying a discounted payback period of slightly more than 3 years. These calculations imply that if the hermetic bags last for at least three seasons, they are profitable even if there is no positive effect on prices. The caveats discussed above, in relation to our estimates of the economic effectiveness of the *training only* treatment, apply for the *training and bags* intervention too, of course.

VIII. Conclusions

Agriculture in SSA employs two-thirds of the labour force and generates about one-third of gross domestic product (GDP) growth. According to the World Development Report (World Bank, 2008), GDP growth originating in agriculture is about four times more effective in reducing poverty than GDP growth originating outside agriculture. For this reason, policies that increase net revenues in agriculture can have a substantial impact on food security and poverty reduction. Reducing PHL and improving storage possibilities are potential low-cost options to achieve those objectives.

We have carried out an RCT experiment where Tanzanian maize farmers received training in post-harvest management and were equipped with hermetic bags. Analyzing the data from this experiment, we find that both interventions had a significant impact on PHL. A combination of both interventions led to a reduction in PHL of more than 70% or almost 7 percentage points. In addition, quality increased, and, compared to the control group, the *training and bags* group got a significantly higher price for their maize. Hence, bags and training increase income, which in turn could facilitate the financing of purchases of modern agricultural inputs, potentially leading to additional increases (Adjognon et al., 2017). It should be noted that some of the outcomes that we have studied depend on market mechanisms. The effects on, for example, prices could be quite different if training and hermetic bags were widely adopted, due to general equilibrium effects.

Our results confirm that the main mechanism driving these results is reduced storage losses. In both interventions, a greater proportion of farmers perceived that the physical characteristics of their maize grain were maintained during storage. We find that a significantly higher proportion of farmers who received hermetic bags invested more in controlling rodents, but they significantly reduced the net cost of storage protection. We observe that higher proportions of farmers in the treatment groups adopted post-harvest loss-mitigating practices, compared to those in the control group. This adoption, plus the use of the hermetic bag itself, may explain the success of the intervention.

Our analysis of the economic effectiveness of the interventions shows that the training is beneficial, if the effects of the training last beyond four years. There are reasons to believe that the effects can last longer. First, the more farmers use the adopted techniques, the more they become familiar with them, and thus can implement them at a lower cost. Second, through social networks, more farmers might adopt due to learning from early adopters about the suitability, profitability, and methods of using the new technology, as documented in literature on technology adoption (Maertens and Barrett, 2013; Magnan et al., 2015).

The results in our study thus indicate non-negligible returns to training and considerable returns to training and physical capital (hermetic bags) combined. Our study relates to a much larger literature on the relative importance of physical and human capital for economic development. Bigsten et al. (2000) report far higher returns on physical than human capital in Africa's manufacturing sector, and remark that this finding is consistent with high (shadow) costs of capital. A similar argument can be made in our context. Since the purchase cost of a hermetic bag is relatively modest, other capital cost components must be substantial. In our setting, the farmers have poor access to the market for new technology and new knowledge. If the obstacles for technology and knowledge diffusion can be mitigated or removed, the gains can thus be substantial.

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TABLE 1: *Baseline Summary Statistics and Randomization Tests*

	ALL			1-CONTROL		2-TRAINING		3-TRAIN+BAGS		[1 - 2]	[1 - 3]	[2 - 3]
Variable	Obs	Mean	Stdv	Mean	Stdv	Mean	Stdv	Mean	Stdv	Diff	Diff	Diff
Socioeconomic characteristics												
Sex	390	0.85	0.35	0.84	0.37	0.87	0.34	0.87	0.34	-0.04	-0.03	0.00
Age	390	46.89	12.08	48.54	11.54	46.53	11.41	44.74	13.18	2.01	3.79**	1.79
Years of schooling	390	7.06	2.82	7.13	3.10	6.67	2.60	7.32	2.53	0.46	-0.19	-0.65*
Number of active workers	390	3.04	1.58	3.06	1.67	3.13	1.72	2.93	1.28	-0.07	0.13	0.20
Household size	390	5.47	2.08	5.65	2.19	5.50	2.18	5.15	1.76	0.15	0.50*	0.35
Yearly Income (USD)	390	1059	1287	1065	1124	1027	1627	1081	1153	38	-16	-54
Value of assets (USD)	390	4341	7078	4787	7412	4475	6853	3534	6760	312	1254	941
Maize farming practices												
Maize experience (Years)	390	19.03	12.21	19.81	12.67	17.87	11.21	18.95	12.44	1.94	0.87	-1.08
Got PH training before	390	0.22	0.42	0.19	0.39	0.24	0.43	0.25	0.43	-0.05	-0.06	-0.01
Area of Land for agric (ha)	390	2.62	2.25	2.66	2.49	2.56	2.31	2.62	1.76	0.10	0.05	-0.06
Area of Land for maize (ha)	390	1.67	1.45	1.74	1.70	1.67	1.35	1.57	1.11	0.07	0.17	0.09
Number of maize plots	390	1.36	0.74	1.34	0.63	1.33	0.89	1.44	0.72	0.00	-0.10	-0.10
Amount harvested (kg)	388	2818	2781	2874	2928	2831	3131	2721	2148	43	154	111
Amount of maize stored (kg)	387	2659	2609	2748	2839	2629	2795	2550	2008	119	199	80
Sold maize (yes=1)	388	0.90	0.30	0.88	0.33	0.91	0.29	0.93	0.26	-0.03	-0.05	-0.02
Amount sold (kg)	349	1882	2244	1936	2436	1851	2469	1834	1691	85	102	17
kg sold within 3 months after harv.	349	958	1068	986	1115	1009	1261	870	766	-23	116	138
Average price per ton (USD)	348	179.1	43.30	177.7	44.47	180.5	49.28	179.9	35.17	-2.81	-2.23	0.57
Weather at harvest (Sunny=1)	387	0.81	0.39	0.80	0.40	0.87	0.34	0.78	0.41	-0.07	0.02	0.09
Harvest at maturity (yes=1)	388	0.19	0.39	0.18	0.39	0.20	0.40	0.19	0.39	-0.01	0.00	0.01
Proper immediate handling (yes=1)	390	0.29	0.46	0.31	0.46	0.30	0.46	0.26	0.44	0.02	0.05	0.04
Maize sorted (yes=1)	388	0.52	0.50	0.51	0.50	0.54	0.50	0.50	0.50	-0.03	0.01	0.04
Number of days maize dried	390	4.65	10.29	4.89	10.13	4.57	10.37	4.37	10.53	0.31	0.52	0.21
Store disinfected (yes=1)	387	0.45	0.50	0.46	0.50	0.44	0.50	0.45	0.50	0.02	0.01	-0.01
Used any means to protect (yes=1)	387	0.80	0.40	0.76	0.43	0.79	0.41	0.86	0.34	-0.02	-0.10**	-0.08
Used chemical protectants	387	0.61	0.49	0.60	0.49	0.61	0.49	0.61	0.49	0.00	-0.01	-0.01
Used traps and poisons	387	0.17	0.38	0.18	0.38	0.19	0.39	0.15	0.36	-0.01	0.02	0.03
Protections costs per ton (USD)	387	4.89	3.88	4.71	3.94	5.06	4.31	4.98	3.35	-0.35	-0.28	0.08
Post-Harvest Losses												
Pre-storage losses	388	0.03	0.02	0.03	0.02	0.03	0.02	0.03	0.03	0.00	0.00	0.00
Storage losses	388	0.08	0.06	0.08	0.06	0.08	0.05	0.07	0.05	0.01	0.01	0.00
Marketing losses	388	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
Total Losses	388	0.12	0.07	0.12	0.07	0.12	0.06	0.12	0.07	0.01	0.01	0.00

Note: The randomization tests are based on wild-cluster bootstrap-t p-values. *** p<0.01, ** p<0.05, * p<0.1.

TABLE 2: *Impact on Post-harvest Losses*[a]

	[1]	[2]	[3]	[4]
VARIABLES	Pre-storage losses		Storage losses	
Mean of Dep. Variable	0.026	0.026	0.061	0.061
Training and bags	-0.00391	-0.00384	-0.0609***	-0.0607***
	(0.5656)	(0.5846)	(0.0000)	(0.0000)
	[0.53132]	[0.55729]	[0.00085]	[0.0009]
Training only	-0.00564	-0.00575	-0.0233**	-0.0235**
	(0.3734)	(0.3193)	(0.0250)	(0.0260)
	[0.37824]	[0.32729]	[0.02559]	[.02759]
Sex		-0.00996**		0.00793
		(0.0140)		(0.3473)
Age		-0.000185		-6.17e-05
		(0.2833)		(0.8629)
Years of schooling		0.000143		0.000694
		(0.8438)		(0.5546)
No. of active workers		0.000379		0.00364
		(0.7708)		(0.3423)
Wealth (USD)		3.10e-07		-2.46e-07
		(0.2202)		(0.6547)
Maize farming experience (years)		-0.000226		-0.000244
		(0.2082)		(0.7117)
Got PH Training before		-0.00411		-0.0128
		(0.2643)		(0.1552)
(Training and bags) - (Training only)	0.00173	0.00191	-0.0376***	-0.0372***
	(0.8198)	(0.8168)	(0.0010)	(0.0010)
Observations	390	390	390	390
R-squared	0.006	0.040	0.102	0.114

Note: A constant is included in all regressions. Wild-cluster bootstrap-t p-values in parentheses. Randomization inference p-values in brackets (for treatment variables only). *** p<0.01, ** p<0.05, * p<0.1.

[a] Losses are expressed as a proportion of all maize harvested.

TABLE 3: *Impact on the qualitative characteristics of stored maize grain*

	[1]	[2]	[3]	[4]	[5]	[6]	[7]
VARIABLES	Size and shape	Aroma	Taste	Color	Pest infestation	Rotting	Quality Index Using PCA
Mean of dept. variable	3.45	3.41	3.43	3.51	1.29	1.24	0.00
Training and bags	0.494***	0.453*	0.410	0.332	-0.311***	-0.235***	1.279**
	(0.0070)	(0.0681)	(0.1241)	(0.1131)	(0.0030)	(0.0050)	(0.0290)
	[0.01883]	[0.06978]	[0.12573]	[0.12672]	[0.00385]	[0.00485]	[0.03681]
Training only	0.226	0.202	0.220	0.173	-0.152	-0.0836	0.607
	(0.2272)	(0.3744)	(0.3584)	(0.3694)	(0.1211)	(0.2783)	(0.2503)
	[0.26635]	[0.43218]	[0.40421]	[0.40721]	[0.15246]	[0.3163]	[0.3133]
Sex	-0.177	-0.0871	-0.0652	-0.102	0.0527	0.0138	-0.287
	(0.1802)	(0.4645)	(0.6006)	(0.3393)	(0.5045)	(0.8719)	(0.2993)
Age	-0.00467	-0.00595	-0.00400	-2.30e-05	-0.00280	-0.00145	-0.00589
	(0.2983)	(0.3013)	(0.3594)	(0.9980)	(0.2913)	(0.6346)	(0.5986)
Years of schooling	-0.0124	0.00804	-5.84e-05	0.00253	-0.0222*	-0.00719	0.0161
	(0.5235)	(0.6106)	(0.9970)	(0.8749)	(0.0871)	(0.4955)	(0.7007)
No. of active workers	-0.0104	-0.0410	-0.0257	-0.0139	0.0344	0.00687	-0.0764
	(0.7367)	(0.1251)	(0.3153)	(0.6517)	(0.1522)	(0.7267)	(0.2633)
Wealth (USD)	8.28e-06	4.39e-06	1.83e-06	1.07e-06	3.13e-06	4.62e-06	4.57e-06
	(0.1221)	(0.4685)	(0.7508)	(0.8428)	(0.4214)	(0.3063)	(0.6847)
Years of experience	0.00514	0.00789	0.00493	0.00371	-0.00136	-0.000570	0.0136
	(0.2833)	(0.1712)	(0.3544)	(0.2753)	(0.6867)	(0.8128)	(0.2513)
Got PH Training before	-0.0384	0.0384	0.0484	0.136*	-0.00903	-0.0518	0.144
	(0.7147)	(0.6386)	(0.4995)	(0.0831)	(0.8579)	(0.3493)	(0.4044)
(Training & bags) - (Training only)	0.268**	0.251*	0.190	0.159	-0.159**	-0.1514**	0.672*
	(0.0310)	(0.0821)	(0.3023)	(0.2883)	(0.0300)	(0.0300)	(0.0581)
Observations	390	390	390	390	390	390	390
R-squared	0.084	0.073	0.060	0.051	0.075	0.041	0.097

Note: A constant is included in all regressions. Wild-cluster bootstrap-t p-values in parentheses. Randomization inference p-values in brackets (for treatment variables only). *** p<0.01, ** p<0.05, * p<0.1.

TABLE 4: *Impact on sales patterns and price*

VARIABLES	[1] Amount sold (kg)	[2] Amount sold (kg) within 3 months of harvest	[3] Amount sold (kg) later than 3 months after harvest	[4] Amount sold late minus amount sold early (kg)	[5] Share of sales sold within 3 months	[6] Highest price obtained per ton (USD)	[7] Lowest price obtained per ton (USD)	[8] min-max average price per ton (USD)
Mean of dept. variable	1,165	478	687	209	0.41	243.3	200.3	221.8
Training and bags	-56.3	-222.7	166.4	389.1	-0.120*	21.50**	3.83	12.66*
	(0.859)	(0.218)	(0.439)	(0.161)	(0.056)	(0.018)	(0.569)	(0.079)
	[0.860]	[0.216]	[0.485]	[0.117]	[0.053]	[0.019]	[0.586]	[0.080]
Training only	-152.4	-47.1	-105.3	-58.2	(0.012	10.40	0.84	5.62
	(0.657)	(0.841)	(0.536)	(0.694)	0.863)	(0.132)	(0.910)	(0.398)
	[0.647]	[0.845]	[0.539]	[0.713]	[0.859]	[0.157]	[0.911]	[0.389]
Sex	560.8***	278.6**	282.2**	3.7	0.049	5.96	3.17	4.56
	(0.008)	(0.019)	(0.027)	(0.970)	(0.453)	(0.507)	(0.726)	(0.582)
Age	-8.0	-0.9	-7.1	-6.2	0.000	-0.432	-0.445	-0.438
	(0.456)	(0.909)	(0.280)	(0.400)	(0.948)	(0.201)	(0.309)	(0.210)
Years of schooling	46.2	44.9**	1.2	-43.7	-0.006	0.897	0.701	0.799
	(0.166)	(0.047)	(0.962)	(0.143)	(0.507)	(0.403)	(0.448)	(0.388)
No. of active workers	-117.3***	-45.9**	-71.4**	-25.5	0.004	1.512	-0.295	0.609
	(0.006)	(0.039)	(0.023)	(0.464)	(0.812)	(0.192)	(0.881)	(0.655)
Wealth (USD)	0.038	0.009	0.029**	0.020	0.000	0.001*	0.000	0.001
	(0.016)**	(0.201)	(0.022)	(0.143)	(0.188)	(0.073)	(0.591)	(0.183)
Years of experience	3.11	-2.46	5.57	8.03	-0.001	-0.215	0.127	-0.044
	(0.833)	(0.894)	(0.343)	(0.368)	(0.564)	(0.522)	(0.749)	(0.904)
Got PH Training before	-258.3	-229.7**	-28.6	201.1	-0.096***	8.752	18.721**	13.736**
	(0.231)	(0.036)	(0.885)	(0.363)	(0.008)	(0.126)	(0.011)	(0.011)
(Training and bags) – (Training only)	96.1	-175.6	271.7	447.2	-0.132*	11.10	2.98	7.04
	(0.777)	(0.301)	(0.271)	(0.082)	(0.067)	(0.176)	(0.692)	(0.316)
Observations	390	390	390	390	310	310	310	310
R-squared	0.052	0.051	0.045	0.038	0.046	0.106	0.050	0.086

Note: A constant is included in all regressions. Wild-cluster bootstrap-t p-values in parentheses. Randomization inference p-values in brackets (for treatment variables only). *** p<0.01, ** p<0.05, * p<0.1. For the regressions modeling amounts sold (col. [1]-4]), observations of zero sales are included. The results in col. [5]-[8] are based on the subsample of farmers selling maize, hence the number of observations for these regressions is lower than for the main sample.

TABLE 5: *Impact on maize protectants use and cost of protection*

VARIABLES	[1] Protected stored maize (YES=1)	[2] Used chemical protectants (YES=1)	[3] Used rat traps and poison (YES=1)	[4] Cost of protection (Per 1 Ton) Mean=4.53
Training and bags	-0.173*	-0.359***	0.110**	-2.595**
	(0.0681)	(0.0070)	(0.0340)	(0.0300)
	[0.07877]	[0.00385]	[0.09076]	[0.04381]
Training only	-0.0415	0.0183	0.00172	0.904
	(0.6537)	(0.8759)	(0.9900)	(0.5546)
	[0.64797]	[0.88573]	[0.98763]	[0.55106]
Sex	0.0863	0.0864*	0.0209	2.342***
	(0.1321)	(0.0911)	(0.6837)	(0.0060)
Age	0.000259	-0.00326	-0.000521	-0.0651**
	(0.8378)	(0.1471)	(0.8669)	(0.0150)
Years of schooling	0.00712	3.84e-05	0.00805	-0.0619
	(0.4855)	(0.9980)	(0.4064)	(0.6456)
No. of active workers	0.00718	0.00440	0.0117	-0.286
	(0.6176)	(0.7808)	(0.4264)	(0.2573)
Wealth (USD)	-8.23e-07	1.10e-06	2.33e-06	0.000306***
	(0.8438)	(0.8619)	(0.5375)	(0.0020)
Years of experience	0.00249	0.00309	-0.000984	0.0487
	(0.2342)	(0.2432)	(0.7247)	(0.1271)
Got PH Training before	0.0121	-0.0116	0.0198	-1.230
	(0.7858)	(0.8599)	(0.7197)	(0.1712)
(Training and bags) -	-0.1315	-0.3773***	0.1083	3.499**
(Training only)	(0.1862)	(0.0010)	(0.2663)	(0.0210)
Observations	390	390	390	390
R-squared	0.042	0.114	0.028	0.138

Note: A constant is included in all regressions. Wild-cluster bootstrap-t p-values in parentheses. Randomization inference p-values in brackets (for treatment variables only). *** p<0.01, ** p<0.05, * p<0.1.

TABLE 6: *Effect of interventions on post-harvest management practices*

VARIABLES	[1] Harvested immediately when matured (Yes=1)	[2] Maize spread after harvest (Yes=1)	[3] Maize sorted (yes=1)	[4] Number of days maize dried	[5] Store disinfected (yes=1)	[6] Post-harvest management practices index
Training and bags	0.0644	0.146*	0.134	1.263	0.0214	0.309
	(0.4705)	(0.0581)	(0.1682)	(0.2573)	(0.7838)	(0.2392)
	[0.46539]	[0.0508]	[0.16469]	[0.24361]	[0.81604]	[0.23761]
Training only	0.0584	0.111*	0.156	1.318	0.00361	0.300
	(0.5075)	(0.0781)	(0.1151)	(0.2432)	(0.9630)	(0.2583)
	[0.47414]	[0.08353]	[0.12449]	[0.22439]	[0.97264]	[0.22539]
Sex	0.0140	-0.00820	0.00784	-0.361	0.0554	-0.0127
	(0.7137)	(0.9149)	(0.9099)	(0.8168)	(0.3884)	(0.9520)
Age	0.00427*	0.00207	0.00229	0.0309	0.00256	0.0121
	(0.0871)	(0.4765)	(0.3564)	(0.3714)	(0.4054)	(0.1211)
Years of schooling	0.00598	-0.00184	0.000327	0.0432	0.000194	0.0153
	(0.5596)	(0.8599)	(0.9750)	(0.7207)	(0.9830)	(0.6056)
No. of active workers	0.00124	0.000119	0.0167	0.102	-0.0163	0.0149
	(0.9269)	(0.9980)	(0.2813)	(0.7728)	(0.3504)	(0.8138)
Wealth (USD)	-5.62e-07	9.47e-07	-3.65e-06	-4.21e-05	1.31e-05***	-4.94e-06
	(0.8509)	(0.8428)	(0.4384)	(0.4044)	(0.0020)	(0.6346)
Years of experience	-0.00156	-0.00118	-0.000357	0.00238	0.00117	-0.00257
	(0.4795)	(0.6947)	(0.8799)	(0.9449)	(0.6406)	(0.7137)
Got PH Training	0.0151	0.0233	0.0138	0.958	0.00426	0.146
	(0.7508)	(0.7247)	(0.7928)	(0.4915)	(0.9359)	(0.4354)
(Training & bags) -	0.0060	0.035	-0.022	-0.055	0.01779	0.009
(Training only)	(0.9439)	(0.4314)	(0.8108)	(0.9710)	(0.8188)	(0.9670)
Observations	390	390	390	390	390	390
R-squared	0.016	0.018	0.030	0.021	0.052	0.025

Note: A constant is included in all regressions. Wild-cluster bootstrap-t p-values in parentheses. Randomization inference p-values in brackets (for treatment variables only). *** p<0.01, ** p<0.05, * p<0.1.

TABLE 7: *The marginal value gained by a hypothetical average farmer in the 'training only' treatment*

	kg			Treatment effect	Amount abated	Value gained($)
Amount harvested	1887	x	Marginal pre-storage loss abated	0.00575	= 10.85	= 2.17
Amount harvested	1887	x	Marginal storage loss abated	0.0235	= 44.34	= 8.87
Amount sold	1385	x	Gain from selling at higher price	0.0056		= 7.56
Total value gained	=		2.17+8.87+82/108*7.56			**= 16.78**

TABLE 8: *The marginal cost of adoption by a hypothetical average farmer in the 'training only' treatment*

	[1]	[2]	[3]	[4]	[5]	[6]
	Labour hours per ton	Monetary cost per ton (USD)	Total Monetary cost per ton (USD) =0.5*[1]+[2]	Amount for average farmer(ton)	Treatment effect	Cost of adoption =[3]*[4]*[5]
Harvest at maturity	8.12		4.06	1.886	0.058	0.44
Proper immediate handling		6.33	6.33	1.886	0.111	1.33
Sorting maize	5.11		2.56	1.886	0.156	0.75
Drying an extra day	3.36		1.68	1.886	1.318	4.18
Disinfect store facility	2.10	4.26	5.31	1.793	0.0036	0.03
					Total	**6.73**

TABLE 9: *The marginal value gained by a hypothetical average farmer in the 'training and bags' treatment*

	kg					**Amount abated**		**Value saved**
Amount harvested	1925	x	Marginal pre-storage loss abated	0.0038	=	7.32	=	1.46
Amount stored	1925	x	Marginal pre-storage loss abated	0.0607	=	116.8	=	23.37
Amount stored	1780	x	Gain from not using insecticides	0.0026			=	4.63
Amount sold	1347	x	Gain from selling at higher price	0.0127			=	17.11
Total value gained	=		1.46+23.37+4.63+98/112x17.11				**=**	**44.43**

TABLE 10: *The marginal cost of adoption by a hypothetical average farmer in the 'training and bags' treatment*

	[1]	[2]	[3]	[4]	[5]	[6]
	Labour hours per ton	Monetary cost per ton (USD)	Total Monetary cost per ton (USD) =0.5*[1]+[2]	Amount for average farmer(ton)	Treatment effect	Cost of adoption =[3]*[4]*[5]
Harvest at maturity	8.12		4.06	1.925	0.0644	0.50
Proper immediate handling		6.33	6.33	1.925	0.146	1.79
Sorting maize	5.11		2.56	1.925	0.134	0.66
Drying an extra day	3.36		1.68	1.925	1.263	4.08
Disinfect store facility	2.10	4.26	5.31	1.78	0.0214	0.20
					Total	**7.23**

Appendix

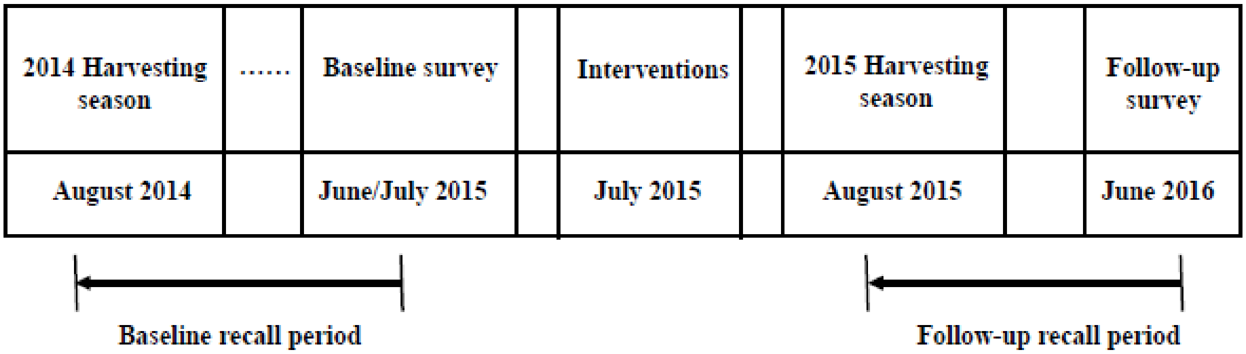

Figure A1: Timeline of field events

Figure A2:

Map of the study area showing the distribution of villages according to experimental groups

TABLE A1: *Effect of maize quality and opportunistic selling on maize price*

VARIABLES	[1] Highest maize price obtained per ton	[2] Lowest maize price obtained per ton	[3] min-max average price obtained per ton
Quality Index	1.45	-0.30	0.58
	(0.357)	(0.834)	(0.688)
Share sold within 3 months	-56.02	-42.33	-49.17
	(0.000)***	(0.000)***	(0.000)***
Sex	9.57	5.16	7.36
	(0.239)	(0.504)	(0.329)
Age	-0.55	-0.45	-0.50
	(0.081)*	(0.290)	(0.140)
Years of schooling	0.41	0.39	0.40
	(0.686)	(0.667)	(0.637)
No. of active workers	1.88	-0.12	0.88
	(0.126)	(0.945)	(0.398)
Wealth (USD) / 1000	0.670	0.053	0.00
	(0.283)	(0.904)	(0.446)
Years of experience	-0.26	0.07	-0.10
	(0.333)	(0.852)	(0.683)
Got PH Training Before	3.77	14.90	9.33
	(0.438)	(0.022)**	(0.048)**
Observations	310	310	310
R-squared	0.287	0.164	0.281

Note: A constant is included in all regressions. Wild cluster bootstrap-t p-values in parentheses.
*** p<0.001, ** p<0.05, * p<0.1.

NOTES

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[1] The Larger Grain Borer (*Prostephanus Trancatus*) spread from Central America to Africa in the late 1970s and has become one of the most destructive pests affecting stored maize (Boxall, 2002).

[2] Differences in farmgate prices (which we have used in this study) are likely to be less than whole sale price differences. The figure is also an average for the country which means it could be lower for maize surplus areas like our study area.

[3] The African Post-Harvest Losses Information System, APHLIS, was created within the framework of the project 'Postharvest Losses Database for Food Balance Sheet Operations', initiated and financed by the European Commission's Joint Research Centre, led by the national natural resources experts.

[4] Alliance for a Green Revolution in Africa (AGRA) and the NAFAKA project are the NGOs that were consulted. They work closely with maize farmers. Consultation was also done with researchers at Sokoine University of Agriculture in Morogoro, Tanzania.

[5] As pointed out by an anonymous reviewer this approach may also have served as a commitment device mechanism, i.e., if selling early is related to a self-control problem our instructions may have encouraged more and longer storage. It may also have reduced "social depreciation", when neighbors and relatives ask for maize from those who managed to store longer (Basu and Wong, 2015). These two factors may have induced larger and longer savings for bag farmers, and if so, would imply higher PHL. Hence, our estimates may in this respect be underestimates of the PHL reduction associated with bag storage as compared to traditional storage, holding storage time and other farmer decisions constant. It should also be noted that the bags provided would only store about 60% of the farmers' expected harvest, and the commitment device referred only to the use of the bags. The remaining 40% of the harvest may not have been much affected by the

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commitment device, in which case the overall effect on quantity stored would be small or even non-existent.

[6] The attrition rates were 3.9%, 7.6% and 5% for the control group, the *training only* treatment group, and the *training and bags* group, respectively.

[7] It is useful to disaggregate the losses since there are different drivers and mechanisms for mitigation for different stages of losses (Chegere, 2018).

[8] In each village, we explored the weights of maize when put in different vessels used by farmers in carrying maize. We also probed whether farmers knew how much maize weighs when put in those vessels. In most cases, their responses were the same as our measurements.

[9] We define active workers as household members aged 15 to 64 years without health or physical impediment to working.

[10] We used the Stata code "boottest", which computes the standard errors using the wild-bootstrap cluster-t procedure after OLS estimation and reports the p-values of tests of the null that the coefficient estimate is 0.

[11] We thank an associate editor and an anonymous reviewer for this suggestion. We use the command "randmcmd", developed and discussed by Young (2019).

[12] We made no attempt to obtain data that would enable us to compute that average maize prices faced by farmers over a longer time period. Obtaining data on the highest and lowest prices proved feasible, but clearly these data do not form a good basis for the calculation of average prices.

[13] The price would vary year by year, but on average during the lean season, the price of 100 kg bag of maize will be around USD 22 and during the harvest season around USD 18 based on information collected from farmers and the Focus group discussions with traders.

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[14] We calculated the average labor cost per hour in the study area from different farm activities; it is about USD 0.50 per hour.

[15] Multiplying by the marginal effect captures the difference in adoption rates between the treated group and the control group.

[16] The costs take into account trainers' fees, transport and other logistics to organize the training sessions.

[17] IFAD (2016) argues that the discount rate for rural financing of agricultural projects is between 5-12%. We pick the highest rate, i.e. 12%, for our calculations. It should be noted that we abstract from the economic discounting of selling late as distinct from early; the bias from not discounting revenues over a few months is likely negligible.

[18] Discounted payback period is the time period that it takes for the initial cost of a project to equal the discounted value of expected cash flows. Calculations of the discounted payback period rely on the same formula as the Net Present Value: $NPV = \sum_{t=1}^{T}(B_t/(1+r)^t) - C_0$ where B_t is the net flow of benefits at time t and C_0 is the initial cost at time zero, *r* is the discount rate, and T is the number of time periods.