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ORIGINAL PAPER

The impact of hermetic storage bag supply and training on food security in Tanzania

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Abstract

Reduction of post-harvest loss (PHL) can play an important role in complementing efforts to address food security challenges. This paper used data from 390 small-scale maize farmers in Kilosa, Tanzania to analyse the impact of post-harvest management training and the supply of hermetic bags on food insecurity status in a framed field experiment setting with two treatments. In the first treatment group, farmers were trained on post-harvest management, and in the second treatment they were given the same training as the first treatment group and were, in addition, provided with hermetic bags for storing maize. Our estimations show that the interventions had an impact in reducing maize PHL and household food insecurity. The intervention combining training and supply of hermetic bags abated maize PHL by 53%, whereas the training intervention alone abated PHL by 26%. Further, the intervention combining training and supply of hermetic bags reduced the household food insecurity access scale (HFIAS) score by 30.9% while the training intervention alone reduced it by 10.8% relative to the control group. The two interventions also lowered the probability of treated households experiencing moderate or severe food insecurity, and increased the probability of households being food secure or mildly insecure relative to the control group. Notably, the intervention which combined training and supply of hermetic bags had a significantly larger impact compared to the one providing training only. These results imply that more investment should be done on interventions to reduce PHL to complement efforts to improve food security. They also point to possible affordable interventions to reduce maize PHL and the importance of supplying material support in addition to training to minimize PHL and improve food security in Tanzania.

JEL classification C93 · Q12 · Q16 · Q18

Keywords Post-harvest management · Training · Hermetic bags · Maize · Food security · Field experiment · Randomization inference

1 Introduction

One of the biggest challenges global societies have been facing in recent decades is the fight against hunger, food insecurity and malnutrition (FAO 2013; Hanjra et al. 2013; Pieters et al. 2013). The challenge is disproportionately higher in the developing world (Barrett 2002). Concerns over food insecurity in Sub Saharan Africa (SSA) are heightened by rapid population growth, reinforced by rising food prices due to growing consumer demand; increased weather variability and difficulty in adapting to climate change; persistently low agricultural productivity; and physical and economic post-harvest losses (Aulakh and Regmi 2013; Kaminski and Christiaensen 2014). Efforts to reduce challenges to food

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security and improve incomes of rural agricultural households can therefore focus on increasing productivity, improving marketing and mitigating post-harvest losses (PHL). Substantial effort and resources, such as the introduction and promotion of high-yield varieties of crops and the use of fertilizers, have been implemented to increase agricultural productivity over past decades. Despite being pertinent for improving incomes and ensuring food security, increasing the productivity of agriculture may not be sufficient. Challenges like limited land, limited water sources and increased weather variability due to climate change hinder the expansion of food production (Aulakh and Regmi 2013).

It is estimated that quantitative grain losses in Africa range from 10 to 20% of annual production and could be worth over US$4 billion per year (World Bank 2011). PHL reduces the food available for household consumption which directly impacts food security status. It also reduces the supply of food in markets relative to the demand and thus increases food prices especially during the lean season (Tefera et al. 2011; Basu and Wong 2015). PHL also lowers farmer's income by reducing the amount of food crop that could be sold by the farmer or by lowering the quality of grain and hence the market value of the food (Hodges and Stathers 2013). As a result of high market prices and low incomes, the purchasing power of the net-buyers is diminished and their access to food is compromised (Gabriel and Hundie 2006). The reduction of PHL can therefore potentially increase the food available for consumption and income from food sales at household and national level and thus improve food security status (FAO and World Bank 2010; Stathers et al. 2013; Sheahan and Barrett 2017).

Maize, the focus crop in this study, is the main staple food for most of SSA, including Tanzania. It is the basis for food security and is vital for the income of the majority of the people in Tanzania. The crop is also an important component of the diet in Tanzania, contributing about 34–36% of the daily caloric intake. Unfortunately, the levels of maize PHL in Tanzania are also high. According to ESRF (2013), between 2003 and 2007, PHL of maize in Tanzania was on average 15.5% of the total production of maize. Further, estimates from African Post Harvest Losses Information System (2020), which derives loss data from peer-reviewed literature, and contextual factors provided by local experts, show that maize PHL in Tanzania was around 18% in the period between 2008 and 2017. In Tanzania, maize is grown by about 60% of the households and comprises about 72% of total cereal production in the country (TNBS 2012). Thus, high PHL in maize imply that a significant amount of food in the country is lost, a notable amount of resources directed toward production is wasted, and households' livelihoods are affected substantially. So, by focusing on maize, we capture a large proportion of planted area, food production, and sources of household income.

The majority of maize production in Tanzania is conducted in small-scale agriculture. According to AGRA (2013), due to the difference in the extent of application of post-harvest management practices, the levels of PHL experienced may differ according to scale of production with small scale farmers experiencing higher levels compared to large scale farmers. Several techniques have therefore been introduced, tried and adopted to reduce PHL among small scale farmers in developing countries (Hodges et al. 2011; Tefera et al. 2011; Aggarwal et al. 2018). Previous studies have shown that there is a positive association between low levels of PHL and adoption of 'good' post-harvest management practices (Chegere 2018; Shee et al. 2019); and adoption of improved storage facilities (Gitonga et al. 2013; Costa 2014; Ndegwa et al. 2016). However, only a few studies have been able to establish the impact of adoption of PHL mitigation techniques on food security (see Bokusheva et al. 2012; Gitonga et al. 2013; Tesfaye and Tirivayi 2018). Despite being done in a rigorous way, the above studies are prone to potential bias from unobserved endogeneity because they did not employ experimental techniques in assessing the impact. Further, to the best of our knowledge no study has been done to assess the impact of training on post-harvest management and a combined effect of training and supply of improved storage on food security.

The main objective of this study was to analyse the impact of two interventions, 1. training on post-harvest management practices, and 2. the supply of hermetic bags bundled with training on post-harvest management practices, on household food security status in a framed field experiment setting. To achieve this objective, we had three specific objectives, the first examined the correlation between PHL and household food security, the second analysed the impact of the interventions on household food security and the third established whether the interventions impact household food security through reduction of PHL. Our study differs from the previous studies because it followed an experimental approach where the sample was randomly allocated into the two treatment groups and the control group. In addition, the intervention which supplied hermetic bags was also bundled with training on supporting post-harvest management practices. The paper contributes to different bodies of literature on the impacts of post-harvest management training, supply of improved storage technologies and food security in several ways. First, we used the Household Food Insecurity Access Scale (HFIAS), a comprehensive measure of food security which is created from nine different questions which capture various aspect of food access in a simple but rigorous way. Second, the study linked two techniques to reduce PHL, namely training on post-harvest management and supply of hermetic bags to food security. Third, the study employed a randomized control trial approach in a framed field experiment that minimizes bias due to unobserved endogeneity in a cross-sectional setting.

2 Post-harvest losses and storage technologies

Post-harvest loss (PHL) is defined as measurable quantitative or qualitative food loss from the time of harvest to the time the food reaches the end consumers (Hodges et al. 2011). PHL can be physical (spillage, shrinkage of grain size or deterioration of condition), nutritional (deterioration of mineral and vitamin content, loss of edibility and caloric value), monetary (i.e., decrease of sales value), or economic (i.e., inability to access certain markets) (FAO 1980; World Bank 2011; Aulakh and Regmi 2013). The levels of PHL for a particular crop vary at different stages of the post-harvest system. A typical post-harvest system in cereals comprises of interconnected activities such as harvesting, shelling, drying, storage, packaging, transportation, milling and marketing.

Production of maize in Africa is seasonal while its consumption over the year is relatively constant. Maize storage is therefore a crucial stage for food security by smoothing the supply throughout the year, as well as stabilizing prices which plummet during the peak supply season and surge during the lean season. Smallholder maize farmers in Africa have used traditional methods and structures such as woven, mud-plastered granaries and house roofs to store maize. However, the invasion of storage insect pests such as maize weevil, angoumois grain moth and the larger grain borer (LGB); and changes in climatic conditions favoring weevils and fungi survival have rendered traditional structures increasingly ineffective in ensuring proper and longer protection for stored maize (Tefera et al. 2011). In addition, most of the traditional structures were unportable, outdoor and difficult to monitor. The use of polypropylene bags (sacks) which are more portable during emergencies such as fire, can be kept indoors after loading, easier to monitor quality and take up less space in the room when empty have become more popular. These sacks however do not provide protection against moisture and storage pests. Therefore, farmers have to apply additional measures such as the use of pesticides, insecticidal plants and ashes to control storage pests (Farrell and Schulten 2002). The use of these storage pest control techniques may not be effective (Meikle et al. 2002) and may have negative impacts on the environment and human health (Kumari et al. 2012; FAO and WHO 2016).

In response to those storage challenges, hermetic storage methods such as metal silos and hermetic bags have been developed. Hermetic storage technologies are airtight and therefore prevent penetration of moisture and kill storage pests without pesticides by depriving them of oxygen. Metal silo technology has proven to be effective in protecting maize grain from both storage insects and rodent pests (FAO 2008). Despite their ability to reduce storage losses, metal silos are expensive and unaffordable to most small-scale farmers. In addition, the metallic structure means that they permanently occupy space even when they are empty and cannot be easily stored in the bedroom for close watch. The hermetic 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).

The hermetic storage bag is a recent technology addressing the challenges of metal silos to small-scale farmers. Hermetic bags have two or more layers of plastic bags. The outer layer is the normal sack (polypropylene bag) and the inner layers are special plastic (high density polyethylene) linings which can be sealed and are air proof. They cost about US$2 for a 100 kg bag, which is affordable and economically effective for small scale farmers (Chegere et al. in press). In addition, they are easier and friendlier to use and more portable. With hermetic bags, once some grains are off-loaded, the bag can easily be tightened again to keep it airtight and lower the oxygen level, a situation which is important for suffocating and killing insect pests.

3 Experimental design and methods

3.1 Study area and sample selection

The study was conducted in Kilosa district which is located in the Morogoro region found in eastern Tanzania. Due to a variance in the agro-ecological conditions, the district is suitable for production of different cereal and leguminous crops (Kajembe et al. 2013). The main economic activity for most of the households in the district is crop farming; and the main food crop cultivated is maize (TNBS 2012). Kilosa district has two rain seasons but, the pattern and amount of rainfall in the district allow for only one harvest of the main staples per year following the long rains between March and early June (Kajembe et al. 2013). The climatic conditions of Kilosa district and the level of maize production represent a typical maize producing area in Tanzania.

A two-stage sampling procedure was used to obtain respondents to the survey and participate in the experiment. The first stage involved a random selection of 21 villages from a list of villages in the District. In the second stage, 20 maize-farming households were randomly selected from each village using the household list from the village office. A selected household which declined to be part of the survey was replaced by another household in the same village by a random sampling procedure.

A baseline survey was conducted during June and July 2015, followed by the interventions. The timing targeted the maize harvesting period which starts early August. A recall period of 10 months was required for some of the questions during the baseline about the previous harvesting season (around August 2014). The baseline survey collected information on household's socioeconomic characteristics, food insecurity status, maize PHL and post-harvest management practices in the previous agricultural season. A follow-up survey was conducted in June 2016.

3.2 Experiment implementation

The two experimental interventions were implemented by the end of July 2015. The interventions were designed to ascertain the impact of post-harvest management training and the supply of hermetic bags storage technology on PHL and food security. The implementation of the interventions involved agronomists in providing post-harvest management training and was supported by two hermetic bag manufacturing companies in providing the user guides and more details about the bags. During the baseline period, none of the farmers in the study area had ever used hermetic bags and just over one fifth had obtained training on post-harvest management.

The interventions were assigned at the village level to minimize spill-overs from treatment groups to the control group. So, villages were randomly assigned to the two treatment groups – 'Training only' with six villages and 'Hermetic bags and training' with six villages. The remaining nine villages were assigned into the control group. Figure 1 shows a sketch map of the study area and the distribution of villages according to experimental groups.

In the 'Training only' treatment group, 120 farmers received the same training on maize post-harvest management. The training content and material were organized by agronomists who had field experience with farmers and were conversant with post-harvest management of cereals. The training materials were enriched with guidelines for harvesting and post-harvest management from the ministries and departments responsible for agriculture in East Africa, consultation with organizations working with farmers, researchers and scientific studies. The topics covered included harvest timing, requirements and processes; drying; shelling; storage and storage structures; and losses due to poor storage. Trained farmers were provided with 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. Training was conducted in Swahili, the national language of Tanzania which is spoken by more than 90% of the nationals, for everyone to understand.

In the 'Hermetic bags and training' treatment group, 120 farmers in six villages were provided the same training on maize post-harvest management as the first treatment group. In addition, they were provided hermetic bags and instructions on how to effectively use them. Farmers were also made aware of the possible adverse effects if the bags are not properly used; for example, if maize is stored in hermetic bags while having high moisture content it can cause fungal growth and rot all the grain in the bag. The hermetic bag will also lose its air-proof quality if perforated by rodents. During the training session farmers had the chance to ask questions and seek clarification as much as they wished. They were also given a two-page leaflet describing the use, the advantages and possible risks of hermetic bags.

At the end of the training session, each farmer was provided with the hermetic bags. During the baseline survey, farmers had been asked for the number of acres of land on which they had planted maize in that season and how much of maize they expected to harvest. They were then given the number of bags that would store about 60% of their expected harvest. This was done intentionally for three reasons. First, farmers tend to overestimate the amount they perceive can be harvested from their farms, thus the predicted harvest would in most cases be larger compared to the realized harvest. Second, not all maize should be stored in the hermetic bags. It is recommended that, maize that will be used within six weeks after harvest should not be stored in hermetic bags. The bags need to be sealed and grain to be stored for at least this period of time to reduce the oxygen in the bag. If air can get into the bag and circulate, the pests that were dying of suffocation can revive back to life. Third, this was a technique to discourage farmers ending up with excess bags. A random visit to about 50% of the farmers who received the hermetic bags was made at their homes in November and December 2015, to observe whether the bags were used and whether the farmers had any challenges in using them. None of the farmers visited had experienced any challenges in using the bags and all of them used the bags supplied to them.

The control group continued with business as usual and this consisted of 180 farmers from nine villages. Contamination by the intervention to the farmers in the control group was unlikely because at the time of the intervention, the hermetic bags were not accessible in the region and only two of the farmers were aware of the technology after visiting relatives in another region where the technology was first introduced during the baseline.

3.3 Data

The data used for analysis in this study was obtained in two separate rounds of household surveys. The baseline data was collected between June and July 2015 and the follow-up survey was conducted in June 2016. In the baseline, the questionnaire was administered to the heads of households or their spouses in case the two were not available, then any other adult involved in household decisions was interviewed. The follow up survey interviewed the same person in the household who was a respondent in the baseline survey. Information on some of the socioeconomic variables (sex, age and education of the head of household, household size

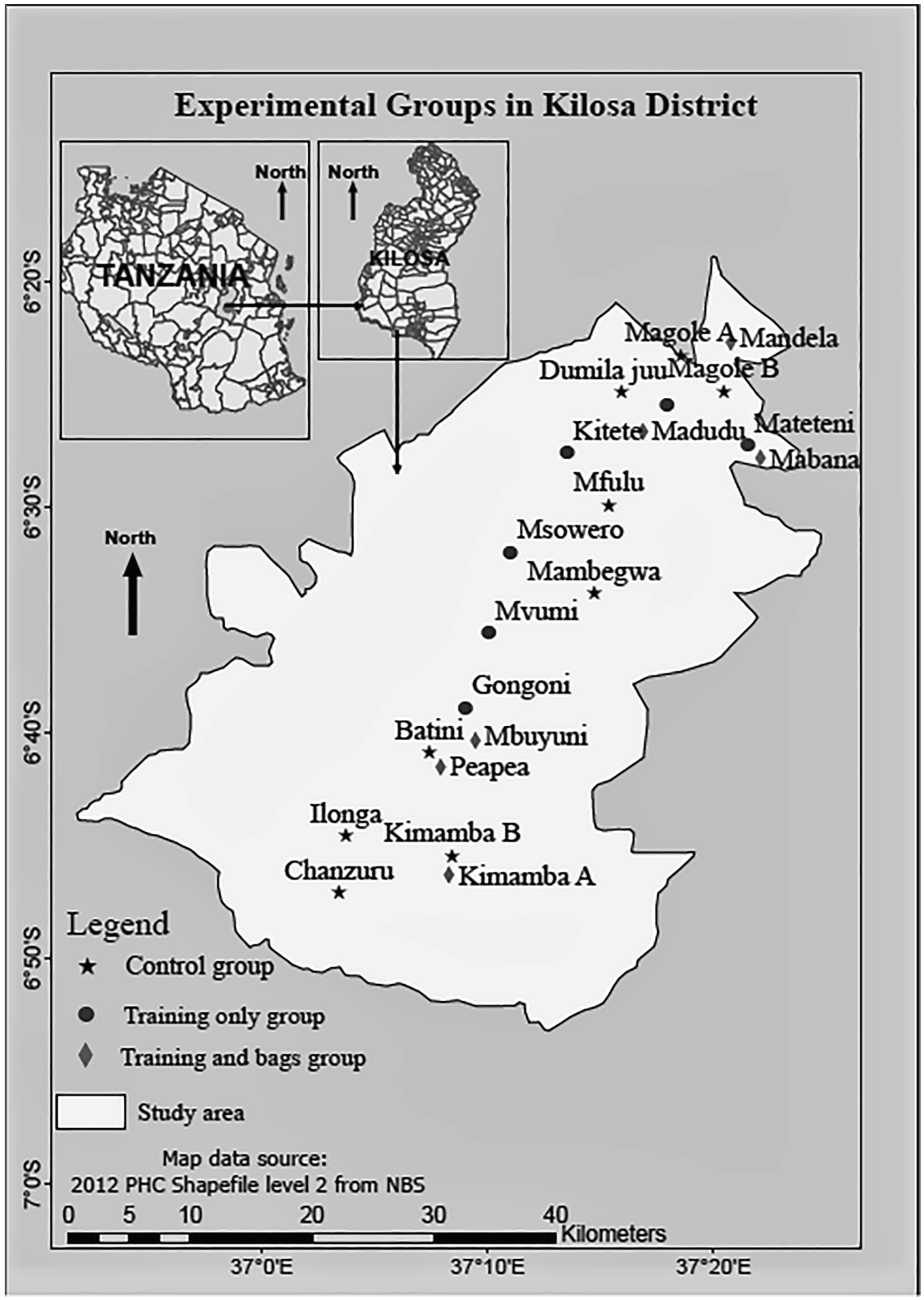

Fig. 1 A map of Kilosa district in Tanzania showing the distribution of villages according to experimental groups

and value of assets owned) was not collected in the follow up survey. This was because the variables were not expected to significantly change in just one year. The baseline involved 420 households. However, the follow-up survey could not obtain and re-interview 22 households. Further, one outlier household which operated at a larger scale not representative of small-scale farmers was dropped from the analysis. This reduced the sample to 397 households, and after dropping observations which missed information on key variables, the working sample was further reduced to 390.

The third version of the HFIAS questionnaire was used to measure household food insecurity status (see Coates et al. 2007). This was the main outcome variable in the study. HFIAS is designed to capture food access and it does not capture other aspects of food security such as caloric or nutritional status, nor diet diversity. The questionnaire was developed by the U.S. Agency for International Development Bureau for Global Health, through the Food and Nutrition Technical Assistance Project for measurement of household food access. The HFIAS measure of food access is a relatively simple, but methodologically rigorous, indicator of the access component of household food insecurity, compared to other measures such as income and caloric adequacy which are technically difficult, data-intensive, and costly to collect. The HFIAS questionnaire consists of nine 'yes or no' occurrence questions, representing a generally increasing level of severity of food insecurity, and nine 'frequency-of-occurrence' questions. The respondent is first asked whether the condition occurred at all in the past four weeks. If the respondent answers 'yes' to an occurrence question, a frequency-of-occurrence question, scored 1–3, is asked to determine whether the condition happened 1 = rarely (once or twice), 2 = sometimes (three to ten times) or 3 = often (more than ten times) in the past four weeks. The questions range from inquiring about the respondents' *perceptions* of food vulnerability or stress (e.g., did you worry that your household would not have enough food?) to the respondents' *behavioral responses* to insecurity (e.g., did you or any household member have to eat fewer meals in a day because there was not enough food?). The questions address the situation of all household members without distinguishing adults from children (Coates et al. 2007).

From responses to the nine questions, a Household Food Insecurity Access Scale score (HFIAS score) for the household is constructed. If the response to the question on occurrence is 'No', that response is assigned a score of 0; if the response is 'Yes' (and therefore the respondent proceeded to answer the frequency-of-occurrence question) that response is given a score between 1 and 3 according to the frequency. Then the total HFIAS score for each household is calculated by adding the scores from all nine questions. Thus, the most possible food-secure household would receive a score of 0 on the food insecurity scale and the most possible food-insecure household would receive a score of 27. HFIAS has been used in empirical studies such as Hasan et al. (2018). Then the Household Food Insecurity Access Prevalence (HFIAP) indicator which categorizes households into four levels of household food insecurity access: food secure, and mild, moderately and severely food insecure was also constructed as described by (Coates et al. 2007) and applied in other studies like Tuholske et al. (2020). As households respond affirmatively to more severe conditions and/or experience those conditions more frequently they are increasingly categorized as food insecure. It is recommended that HFIAP be reported in addition to, rather than instead of the average HFIAS score because the average HFIAS score is a continuous variable, thus more sensitive to capturing smaller increments of changes over time than the HFIAP indicator (Coates et al. 2007).

PHL was measured using self-reported information by farmers from the harvesting season after the intervention. To ensure that losses are measured with minimal errors, PHL information was collected at three stages: between harvesting and storage, during storage, and during marketing. The interview asked the following specific questions:

(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 loss between the time you stored the maize and the moment you used it for consumption or took it for sale? (for those who stored maize)?*
(iii) *How much was the loss at the marketing stage (for those who sold maize, taking into account all the stages from taking the maize from storage, weighing and transporting it)?*

Farmers responded to the questions by stating losses at each stage in terms of quantities – in kilograms, buckets or bags. All the quantities were then converted into kilograms. Then, PHL was measured as the ratio of the amount of maize lost in all three stages to the total amount of maize harvested. Nonetheless, the technique used may have suffered some drawbacks such as subjectivity and recall bias which are well discussed in Chegere (2018). To minimize these biases, indirect cross-checking questions were used. Enumerators were also trained and tested off the field and on the field during the pilot, to ensure effective collection of data.

Information on socio economic variables, namely sex, age and years of schooling of the head of household, household size, value of assets owned by the household and distance to the nearest market, were collected. In addition, information was obtained on maize farming, experience with maize production, area of land used for agriculture and for maize production, amount of maize harvested and amount stored, and amount of maize stored per capita. Household size was measured in terms of the number of family members living and sharing meals together. Years of schooling was measured the number of years it would take to reach the highest level of education by the head of household. Value of assets was measured by summing the total value of selected major assets owned by the household if they were to be sold to the market. Time to the nearest market is a proxy for the distance to the nearest market and was measured by time (in minutes) taken to walk to the nearest market. Maize farming experience was measured in terms of number of years the household has been producing maize as a major food or cash crop. Area of land for agriculture was measured as the total area of land cultivated in the previous year. Area of land for maize was measured as the total area of land cultivated in the previous year. Amount of maize harvested was measured as the total weight of maize harvested from plots owned by the household after shelling. Amount stored was measure as the amount that was kept in stores and not consumed or sold immediately after shelling. Amount of maize stored per capita was measured as amount of maize stored divided by number of adult equivalents.

3.4 Estimation strategy

We first analysed the correlation between post-harvest losses and food insecurity using the baseline information. The outcome variables were the HFIAS score, which takes the value of a whole number between 0 and 27, and the HFIAP which is a categorical variable with four categories. We controlled for other factors that might also affect household food security, such as agricultural land area, which can proxy for the total amount of food produced by the household; amount of maize stored for food, which captures the consumption plan; and socioeconomic variables such as wealth (measured by value of assets owned by the household), and household size which affect households' food decisions. We cannot claim causality in this case because of the possible endogeneity problem due to omitted variables, such as household consumption pattern, which affect both post-harvest losses and the household food situation. Because of the count data nature of the outcome variable, we estimated a negative binomial model of the following equation:

$$Food\ Insecurity_h = \alpha_0 + \alpha_1 PHL_h + \alpha_2 SC_h + \alpha_3 FarmFoodBehvr_h + \alpha_4 Village_h + \varepsilon_h \quad (1)$$

where $Food\ Insecurity_h$ is the measure of food insecurity by either HFIAS score or HFIAP categories for household h; PHL_h is the total maize post-harvest losses experienced by the household as a percentage of the amount of maize harvested; SC_h is a vector of socioeconomic characteristics; $FarmFoodBehvr_h$ is a vector of farming and food storage behavior of the household; $Village_h$ is a vector of dummies for the villages; ε_h is the error term; and h is the index for household. The same relationship will be estimated for post-intervention values to assess the mechanism of the impacts, if any.

In the second stage, we performed our main estimation which aims to analyse the impact of the interventions, 'Hermetic bags and training' and 'Training only', on PHL and household food insecurity status. The interventions were introduced at village level but the unit of analysis was a household. We estimated the following equation using different econometric variables depending on the nature of the outcome variable:

$$Outcome_{hv} = \alpha_0 + \alpha_1 BAGS_v + \alpha_2 TRAIN_v + \alpha_3 SC_{hv} + \alpha_4 FarmFoodBehvr_{hv} + \varepsilon_{hv} \quad (2)$$

where $Outcome_{hv}$ is the measure of PHL or household food insecurity by either HFIAS score or HFIAP categories for household h in village v. $BAGS_v$ is a dummy variable equal to 1 if the village received hermetic bags and training on post-harvest management treatment. $TRAIN_v$ is a dummy variable equal to 1 if the village received training on post-harvest management only treatment. SC_{hv} is a vector of socioeconomic characteristics for household h in village v. $FarmFoodBehvr_{hv}$ is a vector of farming and food storage behavior for household h in village v. ε_{hv} is the error term. We used the OLS method to estimate the equation when PHL is the outcome variable, negative binomial model when HFIAS score equation and the ordered probit model for the HFIAP categories equation. The estimations were done both with and without the household level socioeconomic and farming and food storage behavior controls. While controls are not necessary when one has a successful randomisation, including them in the estimation improves efficiency if they predict variance in the dependent variable (Mutz and Pemantle 2012).

Due to a small number of clusters (21 villages), the estimations may suffer from wrong statistical inference. The usual techniques for calculating cluster-robust standard errors based on asymptotic theory generates downward-biased standard errors, thus the tests will tend to over-reject the null hypothesis of no effect (Bertrand et al. 2004; Cameron et al. 2008). We used the wild cluster bootstrap standard errors for making inferences as suggested by Cameron et al. (2008). The STATA command 'boottest' is used, 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. Further, for more robustness check of the statistical inferences, randomisation inference method is performed. Using the STATA command 'randmcmd' developed by Alwyn Young, this method calculates p-values that take into account any variations in framed field experiment data arising from the random assignment of treatments (detailed discussion can be found in Young (2019)).

Finally, we examined the pathway to the hypothesized impact by analyzing the effect of the interventions on PHL. Taking the advantage of the Randomized Controlled Trial (RCT) setting, we estimated an OLS model similar to the previous one but now with the outcome variable being PHL as a proportion of total harvest. All estimates were done using STATA software, version 16.

4 Results

4.1 Baseline summary statistics and test for balance across treatment groups

Table 1 reports definitions and descriptive statistics for selected variables measured at the baseline (conducted in June and July 2015) for the 390 households. It also presents the test

Table 1 Baseline summary statistics and randomisation tests

Variable	All			1-Contol		2-Training		3-Training+Bags		[1–2]	[1–3]	[2–3]
	Obs	Mean	Stdv	Mean	Stdv	Mean	Stdv	Mean	Stdv	Diff	Diff	Diff
Socioeconomic characteristics												
Sex of head of hh (male = 1)	390	0.85	0.35	0.84	0.37	0.87	0.34	0.87	0.34	−0.04	−0.03	0.00
Age of head of hh (years)	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 of head of hh	390	7.06	2.82	7.13	3.10	6.67	2.60	7.32	2.53	0.46	−0.19	−0.65
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
Log value of assets (USD)	390	7.61	1.27	7.72	1.29	7.63	1.29	7.41	1.22	0.09	0.31	0.22
Time to the nearest market (minutes)	390	42.93	58.58	41.24	53.97	44.56	76.97	43.94	43.26	−3.31	−2.69	0.62
Maize farming practices												
Maize farming 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
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
Log amount harvested (kg)	388	7.59	0.87	7.60	0.89	7.54	0.90	7.62	0.80	0.07	−0.02	−0.09
Log amount of maize stored (kg)	387	7.53	0.87	7.55	0.90	7.46	0.91	7.56	0.79	0.09	−0.01	−0.09
Maize stored for food per capita (kgs/adult equivalent)	387	170.65	133.19	169.00	143.32	176.95	134.08	167.09	116.20	−7.95	1.91	9.86
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
Log amount sold (kg)	349	7.06	1.01	7.11	0.97	6.88	1.19	7.15	0.87	0.22	−0.05	−0.27
Post-harvest losses												
Pre-storage losses (proportion)	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 (proportion)	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 (proportion)	388	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
Post-harvest losses (%)	388	11.93	6.88	12.42	7.08	11.59	6.42	11.51	7.03	.084	0.92	0.08
Got post-harvest training before(yes = 1)	390	0.22	0.42	0.19	0.39	0.24	0.43	0.25	0.43	−0.05	−0.06	−0.01
Food Security												
HFIAS score	397	6.36	5.06	6.45	4.98	6.16	4.92	6.44	5.35	0.29	−0.01	−0.28

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

results for balance across treatment groups. Some variables missed a few observations because of no responses, misreporting or wrong entries. There was no variable with more than three missing observations and thus we did not expect our estimations to be affected.

At the baseline, the average HFIAS score from sampled households was 6.41 (sd = 5.05). Households experienced on average about 12% loss of their maize. Farmers self-reported the PHL figures occurring at three stages: Pre-storage losses, Storage losses and Marketing losses. On average most of the losses occurred during storage (about 8% of the total harvest), consistent with findings by Abass et al. (2014). Storage losses were mainly caused by insect infestations, rodents and rotting of grain as a result of moisture. Pre-storage losses and Marketing losses were at 3% and 1% of the total amount of maize harvested, respectively. A majority of the households (85%) were male-headed. The heads of households were on average 47 years old with seven years of schooling. Primary school education in Tanzania is seven years, so on average the heads of households have just completed primary education. The average household size was 5.5, which is large compared to the national average of 4.7 according to the 2012 census. The stock of assets possessed by a household was valued at US$ 4341 (antilog of 7.6) on average. Households are distanced far from the nearest major crop-market; on average, householders take 42 min to walk to the market.

On average the households had 19 years of experience in maize production. In the agricultural season preceding the baseline survey, households cultivated, on average, 2.6 ha of land for agriculture, of which, 64% (1.67 ha) were cultivated with maize, indicating the importance of maize in the study population. On average, farmers harvested a total amount of 2.82 t grain and stored on average 2.66 t, implying that most maize is stored first before sales start.

We compared 21 variables in three pairs, between the two treatment groups and the control group. Of the 63 comparisons made, none was significantly different at the 1% level of significance, one (age of head of household) was different at 5% level and one (household size) at 10% level; which assures that the randomisation was successful in terms of homogeneity among the treatment and control groups.

Table 2 shows the summary statistics for some of the variables in the follow-up survey after the interventions. Comparing with the baseline season, the agricultural season during the follow-up survey was not so good to farmers in all treatment groups; poor rains being the reason according to farmers. Less land was cultivated for all crops and for maize, on average, 2.18 ha and 1.43 ha respectively, compared to 2.62 ha and 1.67 ha in the baseline respectively. The amount of maize harvested, stored, and sold was also lower during the follow-up compare to the baseline. We observed that the proportion of farmers who sold maize was also lower. This indicates that in a not so good season, farmers will trade what they would sell for their own consumption. The level of PHL in the follow-up survey was lower compared to the baseline, attributed to lower losses in the treated groups. The HFIAS score between the two surveys was similar (mean of 6.36 during the baseline and 6.56 during the follow-up). The control group actually experienced a higher food insecurity score in the follow-up survey which could sum up to the low maize season and the importance of maize to the study area.

4.2 Post-harvest losses and household food insecurity status across experimental group

The interventions on training and the supply of hermetic bags aimed to impart knowledge and introduce a relatively new technology to reduce PHL. Figure 2 shows that at the baseline, the levels of PHL were similar for all experimental groups. After the interventions, the levels of PHL were lower for the groups that received the intervention treatments compared to the control group. Notably the level of PHL was the lowest among farmers who received both the training and the hermetic bags.

The food insecurity status of the households was measured using HFIAS score and HFIAP. Table 2 shows that households in the 'Hermetic bags and training' treatment group had low average food insecurity scores (mean = 5.22, sd = 4.34); households in the 'Training' treatment group had relatively higher food insecurity scores (mean = 6.56, sd = 4.65) and the 'Control' group had the highest average food insecurity scores (mean = 7.44, sd = 5.68). The households were categorized into four groups of HFIAP according to the occurrence and frequency of different food insecurity conditions. The 'Control' group had a higher proportion of severe food insecure households compared to the 'Hermetic bags and training' and the 'Training only' groups. The 'Hermetic bags and training' had a higher proportion of food secure households compared to other groups (Fig. 3). Average scores for occurrence questions indicate that farmers experienced mostly anxiety and uncertainty about food supply and insufficient quality (eating limited varieties of foods, inability to eat preferred foods or eating some foods they did not really want to eat). Severe conditions related to insufficient food intake and its physical consequence such as skipping meals, going a whole day and night without eating, going to sleep at night hungry or having no food of any kind to eat were less common (Fig. 4).

4.3 Econometric results

4.3.1 Correlations between PHL and household food insecurity at baseline

We start our estimations with the analysis of the correlation between PHL and food insecurity using the baseline information. We estimated a negative binomial model with the HFIAS

Table 2 Follow up summary statistics

	All			1-Contol		2-Training		3-Training+Bags		[1–2]	[1–3]	[2–3]
Variable	Obs	Mean	Stdv	Mean	Stdv	Mean	Stdv	Mean	Stdv	Diff	Diff	Diff
Area of land for agric (ha)	390	2.18	1.71	2.17	1.66	2.01	1.71	2.35	1.76	0.15	−0.18	−0.34
Area of land for maize (ha)	390	1.43	1.24	1.43	1.22	1.47	1.45	1.39	1.03	−0.03	0.03	0.07
Log amount harvested (kg)	390	7.2	0.87	7.22	0.92	7.16	0.83	7.23	0.82	0.06	0	−0.07
Log amount of maize stored (kg)	390	7.12	0.88	7.12	0.94	7.09	0.84	7.14	0.84	0.03	−0.01	−0.04
Maize stored for food per capita (kgs/adult equivalent)	390	143.76	119.84	146.69	133.08	154.27	132.44	129.17	78.24	−7.57	17.52	25.1
Sold maize (yes = 1)	390	0.79	0.4	0.76	0.42	0.75	0.42	0.87	0.33	0	−0.11*	−0.11*
Log amount sold (kg)	310	6.74	1.03	6.86	0.99	6.58	1.13	6.72	0.98	0.28	0.14	−0.13
Post-harvest losses (%)	390	9.16	8.88	11.81	9.8	8.87	9.2	5.4	4.88	2.93**	6.4***	3.47***
HFIAS score	390	6.56	5.12	7.44	5.69	6.56	4.65	5.22	4.34	0.87	2.22**	1.34

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

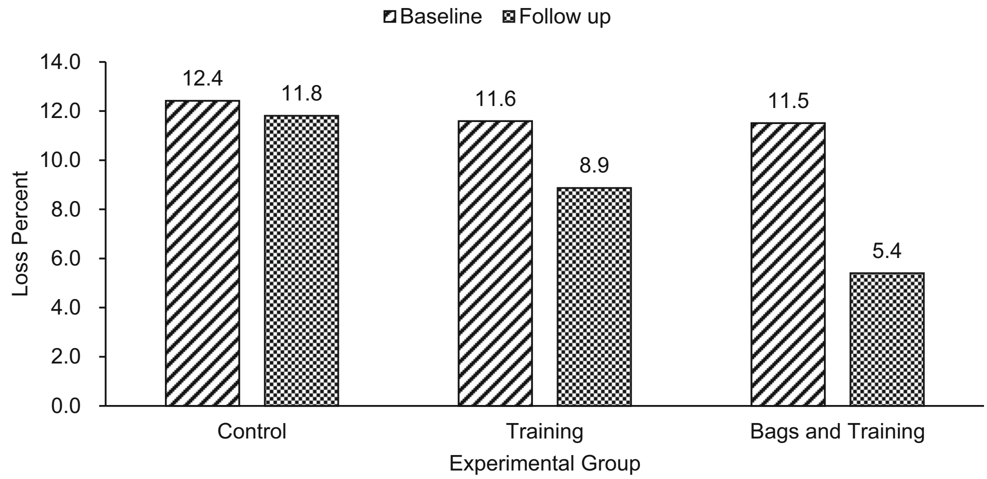

Fig. 2 Maize post-harvest losses at baseline and follow-up surveys across experimental groups in Tanzania

score as an outcome variable and an ordered probit model with HFIAP categories as the outcome variable. The marginal effects after the estimation of these models are reported in Table 3.

Table 3 shows that maize PHL had a positive and statistically significant correlation with household's food insecurity. A percentage point increase in PHL in maize was associated with an increase of the HFIAS score by 0.12 (column 1 of Table 3). PHL was also correlated with higher probability of experiencing moderate or severe food insecurity (columns 4 and 5 of Table 3), and lower probability of experiencing mild food insecurity or being food secure (columns 2 and 3 of Table 3). This implies that more maize PHL was associated with poor food security status of the households. Other factors, such as the amount of maize stored for food purposes per capita and amount of maize harvested which are indicators of food availability showed statistically significant negative correlation with food insecurity as expected. Household's wealth measured as the logarithm of value of assets had a statistically significant negative correlation with food insecurity as expected. Wealth increases affordability hence food accessibility, similar to the finding by Snapp and Fisher (2015).

4.3.2 Impact of hermetic bag supply and training on PHL and household food insecurity

We then explain the findings from the randomized experiment which aimed to assess the causal effect of the 'Hermetic bags and training' and 'Training only' treatments on PHL and household food insecurity status. We conceptualized that PHL reduces the amount of maize available for consumption and sale. We therefore hypothesized that training on post-harvest management and the supply of hermetic bags will lead to lower PHL and thus improve the food security status of the household. The impact of the two interventions on PHL, HFIAS score and HFIAP are reported in Tables 4 and 5.

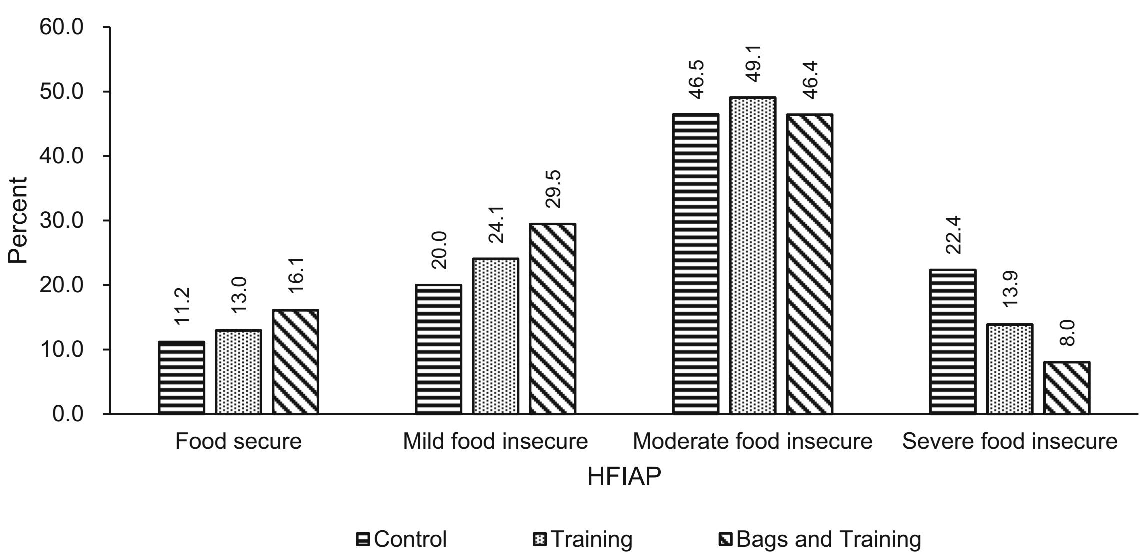

Fig. 3 Household food insecurity access prevalence across experimental groups in Tanzania

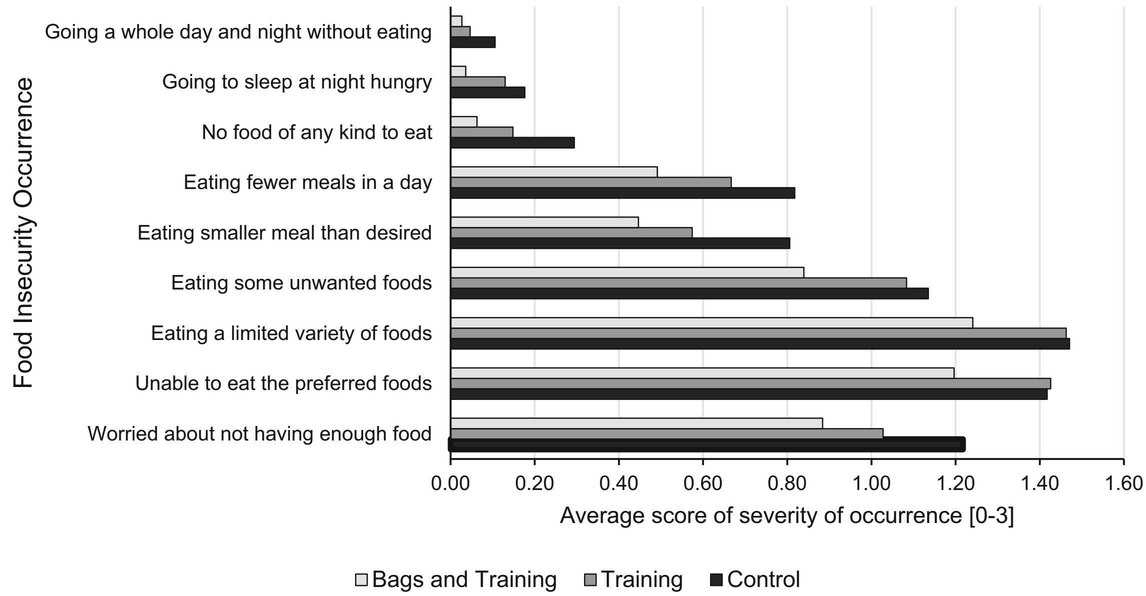

Fig. 4 The average scores on the items of the household food insecurity access scale for sampled households in Kilosa district, Tanzania

Table 4 reports the results of the estimated models without control variables and Table 5 with controls to improve the efficiency of estimations. Column [1] of Table 4 shows that 'Hermetic bags and training' and 'Training only' treatments had significant impacts on PHL, reducing losses by 6.4 and 2.9 percentage points respectively. The 'Hermetic bags and training' treatment had a statistically significantly greater impact on PHL compared to the 'Training only' treatment. The results on the positive effect of using hermetic bags on PHL reduction is consistent with Ndegwa et al. (2016). Similarly, the study by Shee et al. (2019) showed that farmers trained on PHL management are likely to experience lower PHL.

Column [2] of Table 4 presents the marginal effects of the two treatments on HFIAS scores estimated using the negative binomial model. The 'Hermetic bags and training' treatment had a negative and significant effect on HFIAS score. Compared to the control group, households which received the 'Hermetic bags and training' intervention had on average a 2.3 lower HFIAS score. The 'Training only' intervention on the other hand had a negative but statistically insignificant impact. Columns [3] to [6] of Table 4 show the marginal probabilities after ordered probit estimation of the interventions on HFIAP categories. The 'Hermetic bags and training' intervention had a positive and significant impact on the probability of a household being food secure or mildly food insecure and negative and significant impact on the probability of being moderately or severely food insecure. The 'Training only' intervention had similar directional effects, but the impacts were not statistically significant. Compared to the control group, households in the 'Hermetic bags and training' group had a 8.9% and 6.8% higher probability of being food secure and mildly food insecure respectively; and 5.6% and 10.1% lower probability of being moderately and severely food insecure respectively. The impact of the 'Hermetic bags and training' treatment on food insecurity was also statistically significantly greater than the 'Training only' treatment.

Inclusion of control variables improve the efficiency of estimates, so in Table 5 we report the results of similar estimations as in Table 4 but with control variables included. When socioeconomic controls are included, the effect of the 'Hermetic bags and training' treatment remained characteristically similar; while the effect of 'Training only' treatment, which was insignificant, turned to be significant and almost of similar magnitude as without controls. Similar to our results are those in the study by Feder et al. (2004) which found positive effects of training to farmers on pest management and Shee et al. (2019) who found that farmers who received training on PHL management were less likely to suffer perceived levels of PHL at key stages of maize and sweet potato value chains. The positive impact of hermetic bag supply on household food security status obtained in our study is consistent with the studies by Gitonga et al. (2013) and Tesfaye and Tirivayi (2018) which found similar relationships. The significances of the marginal effect of the intervention dummies remained stable after testing using wild cluster bootstrap standard errors and randomisation inference. We also found that other variables such as area of land under agriculture and household's wealth had statistically significant negative associations with food insecurity, as expected. Household size was positively correlated with food insecurity while male-headed households are less likely to be food insecure compared to female-headed households.

Table 3 Baseline correlation between maize post-harvest losses and food insecurity in Tanzania

	[1]	[2]	[3]	[4]	[5]
Variable (units)	Household Food Insecurity Access Scale	Household Food Insecurity Access Prevalence			
		Secure	Mild	Moderate	Severe
	Negative Binomial marginal effects	Ordered probit marginal probabilities			
Post-harvest losses (%)	0.120***	−0.00428**	−0.00340**	0.00178**	0.00591**
	(0.0424)	(0.00167)	(0.00148)	(0.000807)	(0.00234)
Sex of head of hh [male = 1]	0.225	−0.0131	−0.0104	0.00543	0.0180
	(0.650)	(0.0332)	(0.0266)	(0.0140)	(0.0458)
Age of Head of hh [years]	−0.0682**	0.00172*	0.00137*	−0.000715**	−0.00237*
	(0.0284)	(0.000943)	(0.000731)	(0.000362)	(0.00131)
Years of schooling of head of hh	−0.151	0.00485	0.00384	−0.00201	−0.00668
	(0.131)	(0.00579)	(0.00455)	(0.00239)	(0.00795)
Household size	0.303*	−0.0105	−0.00830*	0.00435*	0.0144
	(0.182)	(0.00670)	(0.00494)	(0.00247)	(0.00917)
Log value of assets	−0.822***	0.0274***	0.0218***	−0.0114**	−0.0378***
	(0.231)	(0.00834)	(0.00779)	(0.00450)	(0.0116)
Maize farming experience (years)	0.0455*	−0.00123	−0.000977	0.000511	0.00170
	(0.0237)	(0.00103)	(0.000782)	(0.000407)	(0.00141)
Area of agricultural land cultivated (ha)	−0.228	0.00439	0.00348	−0.00182	−0.00605
	(0.164)	(0.00482)	(0.00374)	(0.00194)	(0.00662)
Time to the nearest market (minutes)	−0.00250	0.00016	0.00013	−0.00007	−0.00022
	(0.00341)	(0.000155)	(0.000115)	(0.00006)	(0.00021)
Log amount harvested (kg)	−0.629	0.0386**	0.0306**	−0.0160***	−0.0532**
	(0.461)	(0.0167)	(0.0123)	(0.00588)	(0.0231)
Maize stored for food per capita (kg/adult equivalent)	−0.00737***	0.00022***	0.00018***	−0.00009***	−0.00031***
	(0.00201)	(0.00007)	(0.00006)	(0.00003)	(0.00010)
Village dummies	YES	YES	YES	YES	YES
Observations	387	387	387	387	387
Pseudo R-squared	0.06	0.11	0.11	0.11	0.11

Clustered robust standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

The square brackets, [], on top of the table, number the columns with results for easier reference in the text

4.3.3 Correlations between PHL and household food insecurity after interventions

In subsection 4.3.2 we showed that PHL had a positive and statistically significant correlation with household's food insecurity. In this section we test whether this relationship still holds after the interventions with the post-intervention HFIAS score and HFIAP categories as the outcome variables and post-intervention PHL as the main explanatory variable. The marginal effects after the estimations are reported in Table 6.

Table 6 shows that the positive association between maize PHL and household's food insecurity still holds significantly after the interventions. PHL was positively correlated with HFIAS score and the probability of experiencing moderate or severe food insecurity, and negatively correlated with the probability of experiencing mild food insecurity or being food secure. This finding sums the conceptualized mechanism of the effect that the interventions will lead to lower PHL and in turn improve the food security status of the household. We also found that the amount of maize stored for food purposes per capita, amount of maize harvested, area of land under agriculture and household's wealth had statistically significant negative correlations with food insecurity, as expected. Household size is positively associated with food insecurity whereas male-headed households are less likely to be food insecure compared to female-headed households.

5 Discussion

In this study we found that PHL in maize has a positive and significant correlation with food insecurity status of the

Table 4 The impact of the hermetic bag and training interventions on food insecurity and post-harvest losses in Tanzania (without controls)

Variable (units)	[1] Post-Harvest Losses	[2] Household Food Insecurity Access Scale	[3] Household Food Insecurity Access Prevalence	[4]	[5]	[6]
			Secure	Mild	Moderate	Severe
	OLS marginal effects	Negative Binomial marginal effects	Ordered probit marginal probabilities			
Hermetic bags and training	−6.408***	−2.322**	0.0887*	0.0685***	−0.0562***	−0.101***
	(1.047)	(1.060)	(0.0478)	(0.0212)	(0.0189)	(0.0318)
	[0.0000]	[0.0180]				
	{0.0009}	{0.0578}				
Training only	−2.938***	−0.822	0.0440	0.0340	−0.0279	−0.0501
	(1.106)	(0.748)	(0.0341)	(0.0214)	(0.0180)	(0.0317)
	[0.0220]	[0.2853]				
	{0.0326}	{0.3393}				
(Hermetic bags and training) - (Training only) +	−3.47***	−1.50**	0.0447	0.0345	−0.0283	−0.0509
	((0.0026))	((0.0320))	((0.142))	((0.1410))	((0.1466))	((0.1424))
Observations	390	390	390	390	390	390
R-squared	0.091	0.006	0.011	0.011	0.011	0.011

Clustered robust standard errors in parentheses. Wild-cluster bootstrap-t p-values in square brackets. Randomisation Inference p-values in curly brackets

+ *p*-values for the test of equality between the marginal effects of the two interventions are shown in double parentheses. The *p*-values are obtained from respective statistical test for each estimated model, F-statistic for OLS, z-statistic for negative binomial and chi-2 for ordered probit models

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$, assigned according to the p-values obtained using clustered standard errors

The square brackets, [], on top of the table, number the columns with results for easier reference in the text

household at the baseline. This means that the more the household experiences losses in maize after harvesting, the more likely that their food security status will be poor. Being the staple food in the study area, losses in maize directly compromise household food security since they reduce the amount of food available for consumption in households. Additionally, PHL reduces the amount of maize that could be sold and generate income that could in turn be used to purchase food thus affecting household food security status. The correlation is big enough to draw attention to the importance of mitigating PHL. This makes it worthwhile to investigate whether and to what extent mitigation strategies can improve food security status.

The results of the randomized controlled trial show that the two interventions 'Hermetic bags and training' and 'Training only' were effective in reducing PHL. We found that the intervention combining the supply of hermetic bags and training reduced maize losses by 6.4 percentage points while the intervention providing post-harvest management training only reduced losses by 2.9 percentage points. Compared to the average PHL in maize in the control group, which was 11.8%, it implies that the 'Hermetic bags and training' intervention mitigated maize losses by 53% and the 'Training only' intervention mitigated losses by 26%. The study by Ndegwa et al. (2016) in Kenya found that the use of hermetic bags reduced maize grain damage by 71% compared to the control group. The reason why they find larger impact compared to ours might be the period the study covered, which was the first four months when the bags are very effective compared to our study which covered almost the whole storage period of about nine months. Maize farmers in our sample harvested 1968 kg of maize in a season; this implies that, on average, the 'Hermetic bags and training' intervention abated 124 kg whereas the 'Training only' intervention abated 61 kg in the season. Our results indicate that this amount may be sufficient to increase a household's food security status as captured by the HFIAS questions.

So, in the next step we assessed the impact of the interventions on household food insecurity as measured by HFIAS score and HFIAP categories. Results showed that the interventions had significant effects in improving household food security status. On average the households in the control group had a HFIAS score of 7.44. Households in the 'Hermetic bags and training' and 'Training only' treatments had lower HFIAS scores compare to the control group by 2.3 and 0.8 respectively. This is equivalent to a reduction of the HFIAS score by 30.9% and 10.8% for the 'Hermetic bags and training' and 'Training only' groups respectively. The two interventions also lowered the probability of treated households experiencing moderate or severe food insecurity, and increased the probability of being food secure or mildly insecure relative to the control group. We also found that the use of hermetic bags, when combined with post-harvest management training, had a larger impact compared to training only.

Table 5 The impact of the hermetic bag and training interventions on food insecurity and post-harvest losses in Tanzania (with controls)

Variable (units)	[1] Post-Harvest Losses	[2] Household Food Insecurity Access Scale	[3] Household Food Insecurity Access Prevalence	[4]	[5]	[6]
			Secure	Mild	Moderate	Severe
	OLS marginal effects	Negative Binomial marginal effects	Ordered probit marginal probabilities			
Hermetic bags and training	−6.519***	−2.421***	0.0852***	0.0794***	−0.0589***	−0.106***
	(0.946)	(0.719)	(0.0299)	(0.0283)	(0.0224)	(0.0360)
	[0.0000]	[0.0010]				
	{0.0009}	{0.0578}				
Training only	−3.022**	−1.126***	0.0514***	0.0479**	−0.0355***	−0.0637**
	(1.071)	(0.426)	(0.0182)	(0.0214)	(0.0132)	(0.0268)
	[0.0230]	[0.0220]				
	{0.0296}	{0.3397}				
Sex of head of hh [male = 1]	0.227	−1.011*	0.0505**	0.0471**	−0.0349**	−0.0627**
	(0.924)	(0.522)	(0.0216)	(0.0190)	(0.0143)	(0.0263)
Age of head of hh [years]	−0.00369	−0.00949	0.00070	0.00065	−0.00048	−0.00086
	(0.0435)	(0.0203)	(0.00077)	(0.00069)	(0.00055)	(0.00091)
Years of schooling of head of hh	0.0470	0.0171	0.00109	0.00102	−0.000756	−0.00136
	(0.163)	(0.0837)	(0.00342)	(0.00316)	(0.00236)	(0.00422)
Household size	0.168	0.910***	−0.0307***	−0.0286***	0.0212***	0.0381***
	(0.300)	(0.178)	(0.00924)	(0.00765)	(0.00606)	(0.0110)
Log value of assets	−0.340	−2.086***	0.0742***	0.0692***	−0.0513***	−0.0921***
	(0.553)	(0.193)	(0.0107)	(0.01000)	(0.0102)	(0.0103)
Maize farming experience (Years)	−0.0468	−0.0420**	0.00135	0.00125	−0.00093	−0.00167
	(0.0682)	(0.0201)	(0.00105)	(0.00093)	(0.00071)	(0.00127)
Time to the nearest market (minutes)	0.00209	0.000697	−0.00003	−0.00002	0.00002	0.00003
	(0.00525)	(0.00300)	(0.00008)	(0.00007)	(0.00005)	(0.00009)
Area of agricultural land cultivated (ha)	0.0748	−1.367***	0.0313***	0.0292***	−0.0216***	−0.0389***
	(0.263)	(0.213)	(0.00720)	(0.00844)	(0.00468)	(0.0111)
(Hermetic bags and training) - (Training only)	−3.497***	−1.295*	0.0338	0.0315	−0.0234	−0.0423
	((0.0019))	((0.0556))	((0.1975))	((0.1570))	((0.2101))	((0.1604))
Observations	390	390	390	390	390	390
R-squared	0.099					

Clustered robust standard errors in parentheses. Wild-cluster bootstrap-t p-values in square brackets. Randomisation Inference p-values in curly brackets

[+] p-values for the test of equality between the marginal effects of the two interventions are shown in double parentheses. The *p*-values are obtained from respective statistical test for each estimated model, F-statistic for OLS, z-statistic for negative binomial and chi-2 for ordered probit models

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$, assigned according to the p-values obtained using clustered standard errors

The square brackets, [], on top of the table, number the columns with results for easier reference in the text

The results we have obtained are characteristically similar to the study by Feder et al. (2004) in Indonesia which found that training increased farmers knowledge modestly, and the knowledge gained led to better pest management and reduced use of pesticides. The training provided in our study was short and particularly focused on post-harvest management practices. So, it was relatively cheaper (compared to the study of farmer field schools by Feder et al. (2004)) and economically effective (as analysed in Chegere et al. (in press) which used the same setting as our study). Moreover, the effect of hermetic bag supply on household food security status we found in this study is consistent with other studies in eastern Africa. Gitonga et al. (2013) found that metal silos were effective in reducing PHL in maize and had large impact on food security status of farm households. Similarly, Tesfaye and Tirivayi (2018) found that improved storage, namely metal silos, air tight drums, modern store or improved locally made structures, such as improved granaries positively affect household food security measured by dietary diversity, and self-reported food security.

Table 6 Correlation between post-harvest losses and food insecurity after interventions in Tanzania

	[1]	[2]	[3]	[4]	[5]
Variable (units)	Household Food Insecurity Access Scale	Household Food Insecurity Access Prevalence			
		Secure	Mild	Moderate	Severe
	Negative Binomial marginal effects	Ordered probit marginal probabilities			
Post-harvest losses (%)	0.189***	−0.00993***	−0.00945***	0.00832***	0.0111***
	(0.0164)	(0.00147)	(0.00101)	(0.00141)	(0.00127)
Sex of head of hh [male = 1]	−0.942	0.0537***	0.0511***	−0.0450***	−0.0598***
	(0.587)	(0.0188)	(0.0167)	(0.0142)	(0.0217)
Age of head of hh [years]	−0.00636	0.00025	0.00024	−0.00021	−0.00028
	(0.0170)	(0.00070)	(0.00067)	(0.00059)	(0.00078)
Years of schooling of head of hh	0.0507	−0.00084	−0.00080	0.00071	0.00094
	(0.0557)	(0.00293)	(0.00283)	(0.00246)	(0.00330)
Household size	0.603***	−0.0204***	−0.0194***	0.0171***	0.0227***
	(0.115)	(0.00550)	(0.00593)	(0.00429)	(0.00728)
Log value of assets	−1.916***	0.0756***	0.0719***	−0.0633***	−0.0842***
	(0.170)	(0.00943)	(0.00772)	(0.00939)	(0.00945)
Maize farming experience (years)	−0.00729	0.00052	0.00049	−0.00043	−0.00057
	(0.0167)	(0.00103)	(0.00095)	(0.00086)	(0.00112)
Area of agricultural land cultivated (ha)	−0.921***	0.0150**	0.0143*	−0.0126**	−0.0168*
	(0.166)	(0.00683)	(0.00739)	(0.00559)	(0.00872)
Time to the nearest market (minutes)	−0.00046	0.00002	0.00002	−0.00001	−0.00002
	(0.00197)	(0.00008)	(0.00008)	(0.00007)	(0.00010)
Log Amount harvested (kg)	−0.398*	0.0297**	0.0282**	−0.0248**	−0.0330**
	(0.219)	(0.0142)	(0.0134)	(0.0123)	(0.0155)
Maize stored for food per capita (kg/adult equivalent)	−0.0136***	0.000394***	0.000375***	−0.000330***	−0.000439***
	(0.00283)	(0.00011)	(0.00010)	(0.00009)	(0.00013)
Observations	390	390	390	390	390

Clustered robust standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

The square brackets, [], on top of the table, number the columns with results for easier reference in the text

Gitonga et al. (2013) observed that the use of improved storage enables the farmer to store maize longer because of lower risks of losses. This is another mechanism that can explain the effect of the supply of hermetic bags and training on household food security we observed. If farmers can store longer then they smooth consumption across the harvest and lean season and shield themselves from high price risks which they could face if they were to purchase maize during the lean season (Kadjo et al. 2018). Improved storage can also improve the quality of stored grain (De Groote et al. 2016; Ndegwa et al. 2016) and improvement in quality can lead to price premiums which may in turn increase farmers' income and ability to purchase food. A higher price can be expected for good quality maize because a discounted price is obtained by farmers for damaged maize in SSA markets (Kadjo et al. 2016).

6 Conclusions

For the rural poor who consume and earn their income mainly from own agricultural production, reduction of post-harvest losses (PHL) can play an important role in complementing efforts to address food security challenges. At the global level the issue of food losses in relation to food security has been given crucial importance. Sustainable Development Goal 12 aims to ensure sustainable consumption by, among others, reducing losses along the food chain, including PHL. In this paper, we analysed the impact of hermetic bag supply and training on post-harvest management on household food security status in a randomized controlled trial setting in Tanzania. The two interventions aimed to reduce maize post-harvest losses and eventually increase the food security status of small-scale farmers.

We first analysed the correlation between PHL and household food insecurity score and found a significant positive correlation between the two. The results from the randomized experiment showed that the two interventions had significant impact on reducing PHL and household food insecurity. A remarkable finding is that intervention with a combination of both post-harvest management training and the supply of hermetic bags had larger impact on reducing PHL and household food insecurity compared to an intervention with training only. These results suggest the importance of investing in interventions to reduce PHL to complement efforts to improve food security status for small-scale farmers. They also propound possible and affordable interventions that can reduce PHL and improve food security; training to farmers on post-harvest management and the use of an improved storage technology, hermetic bags. Notably, our findings suggest the importance of supplying material support in addition to training to minimize PHL and improve food security. Chegere et al. (in press) has shown that the interventions assessed in this study are economically feasible to small scale farmers in the area and the cost of their implementation is not high, opening windows for possible scaling up of the interventions in Tanzania.

Our study tried to use a rigorous experimental methodology to establish causality but is limited by the fact that the measure of PHL was subjective and did not compare the interventions with other possible techniques with the same end goal of reducing household food insecurity. Further studies can seek to use a more objective measure of PHL and can compare the economic viability of different techniques of reducing PHL and food insecurity.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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