Maize price seasonality in Ethiopia: Does access to improved grain storage technology increase farmers' welfare?

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Abstract

African seasonal price variability for cereals is two to three times higher than price variability on the international reference market. Seasonality is even more pronounced when access to storage is limited, leading to low opportunities for price arbitrage. This leads to low incomes and food insecurity for smallholder farmers during the lean season, the "higher price" season. One solution to reduce seasonal stress is the use of improved storage technologies. Using data from a randomized controlled trial, we study the impact of hermetic bags, a technology that protects stored maize grain against insect pests, and helps to store it longer, in a major maize-growing region of South-Western Ethiopia. We find considerable price seasonality: maize prices in the lean season are up to 36% higher than maize prices after harvesting. However, we find no evidence that hermetic bags improve welfare, except that these bags allowed for a marginally longer storage period of maize intended for sale. This "near-null" effect is due to the fact that maize storage losses in our study region are not as high as previous studies suggested, but just under 2% of annual storage. In addition, to safely store maize, farmers have benefited from the recent advance in access to a cheap but toxic alternative fumigant. We do find that farmers who are cash constrained store 5% less harvest, creating large scale price seasonality that further lowers farmers' welfare.

Keywords: Seasonality, Post-harvest Loss, Hermetic Storage, RCT, Ethiopia

JEL codes: C93, D15, O12, O13, O14

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Highlights

- Ethiopian maize farmers were provided with hermetic storage bags and training as part of a randomized control trial
- Despite large seasonal maize prices fluctuations, increased storage capacity only marginally changed farmer storage decisions and did not improve welfare
- Development agencies and policy makers had implicitly worked with the wrong counterfactual, over-estimating the potential gains from hermetic bags.

1. Introduction

Seasonality in African staple prices is about two to three times higher than the international reference market (Gilbert et al., 2017). Most farmers in Sub-Saharan Africa (SSA) rely on rain-fed agriculture with a single harvest season resulting in considerable seasonal variations in local food availability and prices (Kaminski & Christiaensen, 2014; Gilbert et al., 2017). Prices of staple grains are typically low right after harvest and rise gradually throughout the lean season. Yet many farmers appear not to able to take advantage of the apparent inter-temporal arbitrage opportunities. Instead, they often sell their yields soon after harvest when prices are low and buy in the lean season when prices are high (Stephens & Barrett, 2011; Burke et al., 2019). This behavior of 'selling low and buying high' undermines food security and reduces income among smallholder farmers (Christian & Dillon, 2018). Further pressure on farmer welfare is provided by the significant potential post-harvest losses, due to mold, rodents and other pests, inducing farmers to sell early.

There are two main explanations for the "sell low, buy high" puzzle (Stephens & Barrett, 2011; Burke et al., 2019). First, seasonality of prices may be caused by lack of access to improved storage technologies. Access to improved storage offers an opportunity to engage in temporal arbitrage. As storage capacity increases, storage risks decline, and more people may hold stocks during periods of low prices and release stocks during periods of high prices, thus smoothing commodity supply (and, hence, prices) over time. Aggarwal et al. (2018) address storage constraints in Kenya by providing farmers the option to store their maize collectively (in hermetic bags) with members of their village savings group. They find that households who received hermetic bags stored maize longer, thus received higher prices, and sold 23% more maize on average during the lean season. Omotilewa et al. (2018) also found that providing improved storage technology in rural Uganda resulted in farmers storing more maize for a longer period. Moreover, farmers with access to larger metal silo users, allows farmers to sell their maize up to five months after harvest (Gitonga et al., 2013). Better post-harvest management and storage facilities provide downstream incentives as they encourage farmers to invest and grow more crops (Kadjo et al., 2018), or adopt improved seeds (Omotilewa et al., 2018), which in turn may further reduce seasonality in food prices and consumption (Kaminski & Christiaensen, 2014).

A second explanation relates to liquidity constraints. Stephens & Barrett (2011), found that poor households which are liquidity constrained to be compelled to convert non-cash wealth in the form of grains into cash in order to take care of other needs. This is consistent with (Fafchamps & Minten, 2012) who find that for most farmers the decision to sell or not to sell is largely driven by the liquidity needs of the household rather than the price of the crop. Temporary liquidity constraints can be solved through access to credit. A range of empirical studies show that farmers are unable to exploit the price variation even if they have access to improved storage technologies, as long as there are credit constraints (Burke et al., 2019; Kadjo et al., 2018; Christian & Dillon, 2018; Stephens & Barrett, 2011; Basu & Wong, 2015). In Kenya for instance, Burke et al. (2019) find that access to credit increases farmer's income as it enables them to store their produce and sell when prices have gone up. In a well-functioning capital market, the opportunities to benefit from temporal arbitrage transactions will disappear. Supply after harvest falls, and increases several months later, during the lean season. Reduced food sales during the lean season, therefore, not only reduce producer income, it also leads to shortages or volatility in local food availability (as well as prices), indirectly affecting (poor) food consumers (Sheahan & Barrett, 2017). Most of the literature on hermetic bags has focused on their efficacy in reducing PHL, and the implications of credit constraints coupled with the bags in affecting smallholders' decisions at harvest (Burke et al., 2019; Kadjo et al., 2018, Channa & Ricker-gilbert, 2018). These studies recommend that expanding both access to affordable credit and the provision of hermetic bags enables farmers to better cope with seasonality.

We focus on Ethiopia, which is poorly integrated in international markets and has high spatial and temporal price variations (World Bank, 2018) and storage losses. We randomly vary access of an improved storage technology (hermetic bag) in a major maize-growing district in the South-Western part of Ethiopia. We use data from a household-level RCT, where randomly selected smallholder maize farmers received three Purdue Improved Crop Storage (PICS) bags for free, each with a storage capacity of 100kg of shelled maize (about 5% of annual harvest), along with a training in their proper use. The hermetic bag provides a triple layer hermetic (air tight) seal that protects stored grain by killing insects and neutralizing mold growth (Williams, et al., 2017). It is a way to store grain effectively without the use of storage pesticides (De Groote et al., 2013).

Our results reveal considerable seasonal price variation: maize prices in the lean season are up to 36% higher than maize prices after harvesting. Credit constraints inhibit farmers from benefiting of this price gap, on average farmers store their maize for just 3 months after harvest, whereas prices peak after 5 months. While treatment farmers marginally increase the storage period of maize intended for sale, by two weeks, this does not translate into additional welfare. We find no changes in any of our welfare outcome indicators (maize yield, maize stored, maize loss, length of maize storage for consumption, length of maize storage for sale, maize income and food insecurity). This low-level impact of the hermetic bags may be explained by the surprisingly low storage losses in our sample – at baseline this was just under 2% of total maize harvested. This is remarkable given significant losses reported elsewhere (Hengsdijk & de Boer, 2017; FDRE, 2018). The low storage loss is likely due to cheaply available storage fumigants available in local markets. Close to all farmers (92%) use Aluminum Phosphide, during storage that effectively kill pests, attenuating any treatment effects due to hermetic bags. Fumigants may pose a health risk as they are very toxic (Fumigation Handbook, 2020; Sheahan & Barrett, 2017; Loha et al., 2018). The impact of improved storage technologies hence is limited. It seems that development agencies and policy makers had implicitly worked with the wrong counterfactual, over-estimating the potential gains from hermetic bags. Our null findings resonate with other studies in the region. For example, a randomized controlled trial (RCT) with farmers in Kenya showed that while losses in hermetic bags were very small (0.4%), losses in the control group using traditional bags were not that much higher (just 1.4%), as farmers tend to use chemical insecticides (Ndegwa et al., 2016). While our sample is not representative for the country, our findings question the magnitude of storage losses in South-Western Ethiopia. Qualitatively, farmers report that they use the hermetic bags to store maize for consumption and not for intertemporal sales, signaling that the health benefits of hermetic bags are more important to farmers. We further explore potential explanations for the reason why farmers do not store if storage losses are so low and why we observe seasonality in prices, despite the cheap maize storage alternative. We find that liquidity needs are part of the explanation. Farmers who are cash constrained (proxied by whether a household asked for credit in the last 12 months) seem to store less of their harvest.

The remainder of the paper is structured as follows. Section 2 reports the methodology. Section 3 describes the empirical strategy for estimation of treatment effects. Section 4 presents the results. In section 5, we conclude by discussing potential explanations for the marginal treatment effects of hermetic bags and policy implications of our results.

2. Methodology

To estimate the effects of improved on-farm storage on household welfare, we randomly allocated hermetic storage bags and training in their use to some households (treatment group), but not others (control group). The hermetic bags were provided as a loss-reducing storage alternative to the commonly used polypropylene bags.

2.1 Sampling of households and data collection

We use data from two rounds of a household-level panel survey. The experiment was implemented among 871 maize households in Gida Ayana woreda[1] (district) of Ethiopia, namely, located in the South-Western part of Ethiopia, East Wollega zone in Oromia region (Fig. 1**Fout! Verwijzingsbron niet gevonden.**). The choice of the region was motivated by the fact that it is the major maize growing area, with high price seasonality and diverse agro-ecological conditions. Within Gida Ayana[2], five neighboring kebeles (wards) were purposefully selected. Two kebeles, Dire Guda and Haro Misoma are in the lowlands, where temperature conditions are much warmer than in the highlands, with a higher rainfall variability. The remaining kebeles, Lalistu Anger, Werebo and Delessa are in the highland, much drier and close to the major city and regional market of the region. Samples within each kebele were drawn proportional kebele population size.

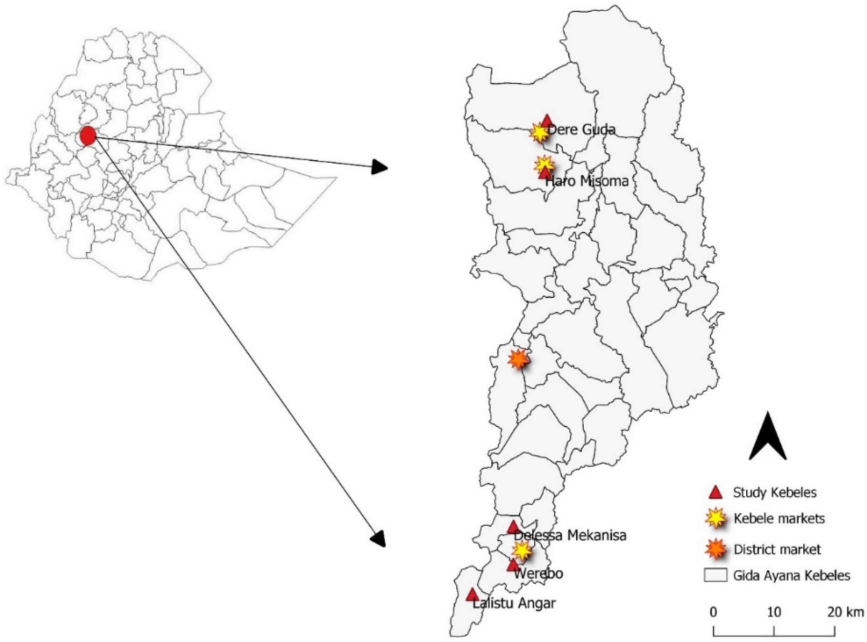

Fig. 1. Map of study sites and markets.

Note*:* Map of Ethiopia (left) and study district Gida Ayana (right), located in the western part of Ethiopia, East Wollega zone in Oromia region. The red triangles show the five study kebeles, yellow stars are the respective kebele markets, and the orange star shows the main district market. Source: Author’s own mapping.

[1] Ethiopia is administratively divided into regional states and chartered cities, zones, *woreda* (districts), *kebele* (wards), and gote (villages).

[2] Ayana town, the capital of the district, is located 444 km to the west of Addis Ababa and 112 km to the North of Nekemte, capital city of the zone.

Before implementing the RCT, a stakeholder workshop was organized during May 2017 to gain more insight into grain storage challenges for farmers in Ethiopia and identify a study area. During December 2017, we implemented our baseline survey and randomized households to receive three hermetic bags and a poster-based training by Shayashone PLC, sole distributor of PICS bags in Ethiopia. The implementation coincided with the harvest season (October to December), when farmers make their storage decisions (e.g. purchase of storage bags and pesticides). In May 2019, both treatment and control households were re-visited for the endline survey. The survey contained modules on household characteristics, household assets, household income sources, household expenditure, agricultural practices (crop grown, production, sales transaction, etc.), gender roles in maize storage and marketing, household participation in rural institutions, household source of information and food security.

In total, the baseline sample contained 871 households. For the endline survey we followed up with the same households. and were able to re-interview 854 households (426 households from the control and 428 from the treatment groups, see Table A2 for attrition discussion and analysis conforming the sample remains balanced across a wide set of variables). Table 1, provides a timeline of the research activities.

During May 2018, we organised focus group discussions to learn about consumption and marketing challenges, and experience with the hermetic bags.

Table 1. Timeline of intervention and data collection.

Activities	Date
Stakeholder consultation workshop on "storage and post-harvest technologies and policy in Ethiopia" and choice of study site	May 2017
Baseline household survey among 871 respondents; distribution of hermetic bags and poster-based training	December 2017-January 2018
Focus group with farmers and informal discussions and interviews with traders and stakeholders	May 2018
Household endline survey in among 854 respondents	May 2019

2.2 Experimental design

We use an individual complete block randomization design, using kebele's as blocks. Randomization was conducted in the field, after obtaining a list of all households for each kebele, from the respective kebele offices. The unit of randomization is the household. In total there are 435 exogenously treated households and 436 controls.

The intervention consisted of providing three hermetic bags free of charge, along with a poster-based training on their proper use (Fig. 2). The hermetic bag is called the Purdue Improved Crop Storage (PICS) bag and is a three-layer hermetic bag that consists of an outside layer of woven polypropylene and two inner layers of polyethylene. The bag is an example of hermetic storage, which is based on the depletion of oxygen in the storage through natural processes and replacing it with carbon dioxide, suffocating insect pests. In Ethiopia, a hermetic bag costs about 55 Ethiopian Birr (ETB, or ~USD 1.6, and can hold 100 kilograms of shelled maize. The hermetic bags can be used for up to 3 years. In contrast, conventional, single layer, woven polypropylene bag costs about USD 0.2, provides limited protection against insect pests and is generally used only once. Moreover, PICS bags remove the need to use synthetic pesticides, which makes them safer to use for households (Sheahan & Barrett, 2017; Loha et al., 2018).

The training sessions, given by Shayashone PLC were held at the homestead of treatment farmers. The hermetic storage bags were provided after the conclusion of the baseline household survey.

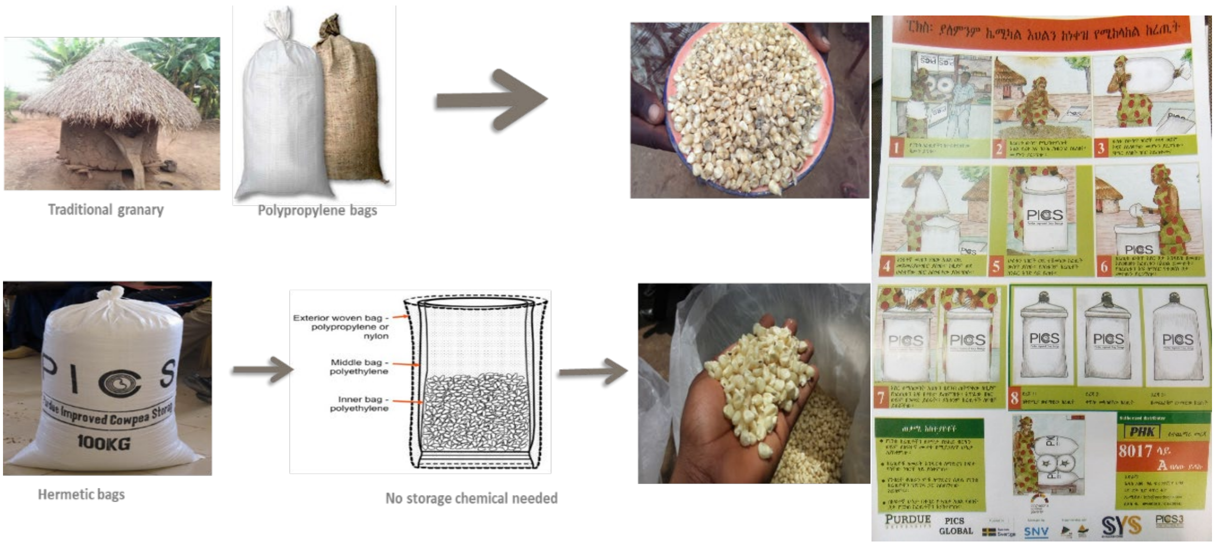

Fig. 2. Maize storage practices and hermetic bags training poster.

Note: Maize storage practices in the study district are shown on the top left pictures and hermetic bags training poster used during intervention on the right (e.g. eight guided steps on how to properly use the bags). The maize grains on top show maize not treated pesticides. The two pictures at the bottom left show a hermetic bag of 100 kg indicating its hermetic features. Source: Adapted from Omotilewa et al., 2018.

3. Empirical strategy for estimation of treatment effects

Our dependent variables include seven welfare outcomes at the household level: maize yield (kg/ha); percentage of maize stored; percentage of maize losses; length of maize storage for consumption (in days); length of maize storage for market (in days); income from maize sales (ETB), and household food insecurity (HFIAS); income from maize sales (ETB). We compare households based on their random assignment to receive hermetic bags (T_i). Following (McKenzie, 2012), we use an ANCOVA specification adding baseline data on the outcome where available, in order to maximize power. The ANCOVA model is estimated using a least squares regression, specifically we estimate:

$$Y_{it1} = \beta_0 + \theta T_i + \beta_1 X_{it0} + \beta_2 Y_{it0} + \mu_k + \varepsilon_{ik} \tag{1}$$

Where, Y_{it1} is the outcome variables at endline; T_i, equals 1 if a household was randomly assigned to receive a set of hermetic bags (treatment) and 0 otherwise (control); X_{it0} is a vector of household characteristics that were not balanced at baseline (see below: total maize income, land owned, land under maize, off-farm income and access to microfinance); Y_{it0}, outcome variables at baseline, and μ_k is the kebele fixed-effect to account for our blocked randomization.

We further explore the prospect of treatment heterogeneity in our sample by interacting the treatment status variable (T_i), with baseline covariates of interest, mainly if the household was credit constrained (proxied by whether a household asked for credit in the previous 12 months). Denoting a given baseline covariate as Z_{i0}, we estimate the following specification:

$$Y_{it1} = \beta_0 + \theta T_i + \beta_1 X_{ito} + \beta_2 Y_{it0} + \beta_3 Z_{i0} + \beta_4 (Z_{i0} * T_i) + \mu_k + \varepsilon_{ik} \tag{2}$$

4. Results

4.1 Sample

Descriptive statistics of the respondents in our sample are included in Table 2. Most of household heads were male of an average age 44 years old, who lived in a household with about 5 people. The average term in school is two and a half years, implying that the majority has just a few years of primary education. Approximately 80% of households owned a mobile phone.

In terms of financial access, only 30% of households had access to microfinance services, and 20% have asked for credit in the last 12 months. The surveyed households are typically smallholders with an average land size of just under 2 hectares. Maize is the major crop planted, with an average yield of 3827/ha, just below the mean national maize yield of 4000kg/ha (Central Statistical Agency, 2019). The large majority of farmers sold their maize output right after harvest (55%). The share of households that consumed maize is 23% at the time of interview, while 18% stored for own consumption later in the season. Regarding the quantity of maize lost during storage, farmers' self-reported storage losses represent just 2% of total maize harvested. This is small and reflects the widespread use of pest control methods. Overall, 92% of farmers apply storage pesticides to prevent losses. Respondents are balanced with respect to most characteristics (see Table A2), an F-test of the equality of means across all variables is not significant (F-stat = 0.49). Treatment households are however on average wealthier, with higher maize income and land ownership and greater access to microfinance.

Table 2. Descriptive statistics of sample households.

Variable name	N	Mean	Std. Dev.	Min	Max
Household characteristics					
Gender of household head (1=Male)	871	0.96	0.2	0	1
Household age	871	44.1	12.2	18	68
Household size	871	5.3	2.1	0	9
Years of schooling	871	2.6	3.3	0	10
Access to MFI (1=yes)	871	0.3	0.5	0	1
Owns mobile phone (1=yes)	871	0.8	0.4	0	1
Asked for credit (1=yes)	871	0.2	0.4	0	1
Maize output					
Maize harvest quantity (kg)	871	4422.2	2630.8	0	9700
Land owned (ha)	871	1.9	1.6	0	6
Land under maize (ha)	871	1.2	0.6	0	2.3
Maize yield (kg/ha)	871	3826.7	1536.5	0	6600
Storage pesticide used (1=yes)	871	0.92	0.3	0	1
Maize stored for consumption (%)	871	18.2	20	0	98
Maize sold after harvest (%)	871	55.7	24.2	0	99
Maize consumed (%)	871	23.5	20.6	0	66.7
Maize lost (%)	871	1.8	3.4	0	8.3

Note: Data from baseline survey (2017/18). N = 871. Data presented here has been winsorized at the upper level at the 95 percentile to remove extreme values.

4.2 Technology used to store maize

At baseline, we collected data on how and where farmers stored their maize harvest. The most common storage container is the polypropylene bag, used by almost 75% of the respondents, due to its availability and affordability. The traditional granary is the second most popular storage facility, used by 22% of the respondents. Other storage facilities are rare, they include in-house storage (1%), community storage facility (1%), and improved granary (1%).

4.3 Seasonal price variation for maize

Next, we assess variation in maize prices throughout the agricultural calendar. We aggregate market participation into two periods: a harvest period (October to December) and a lean period (January to September). The seasonality in agriculture puts farmers in a situation where they have to decide how to meet their consumption needs in the season soon after harvest, which we call here the 'harvest season', and in the season prior to the next harvest which we call the 'lean season'. We plotted maize price seasonality for 2018 based on farmers' self-reported monthly maize prices (see Figure 3). In our study district, maize prices increase gradually from 4.7 ETB/kg in October (beginning of the harvest season) to peak at 6.4 ETB/kg in September (end of the lean season). This inter-temporal price seasonality leads to a 36% increase in maize prices (ETB 170/100kg) which highlights potential arbitrage opportunities to storage.

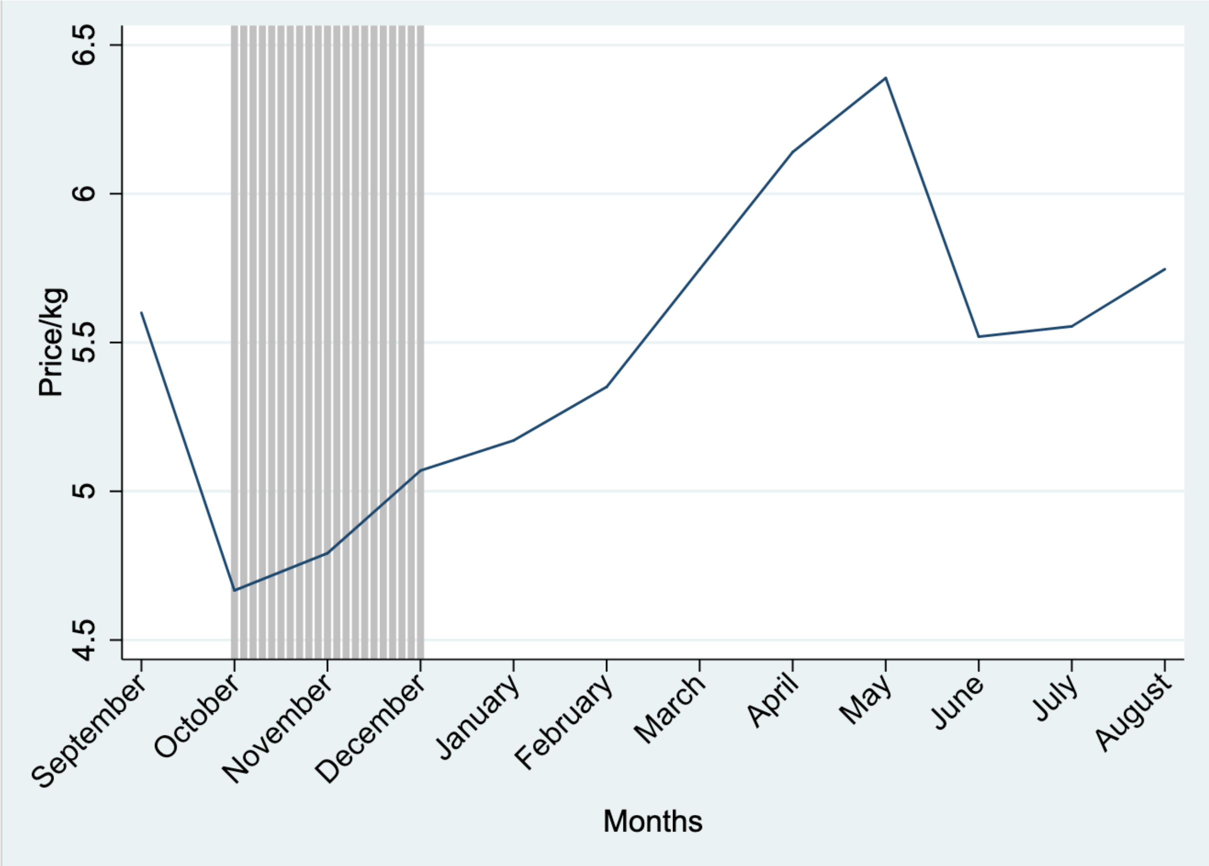

Figure 3. Seasonality of maize price

Note*:* Authors' computation based on self-reported monthly maize prices, N=854. Harvest season shaded in grey.

4.4 Take-up of hermetic bags

Adoption of the (freely provided) technology was high. All treatment households used at least one of the bags and 85% of households used all three hermetic bags they were given (Table 3). Surprisingly, bags were not used to exploit temporal arbitrage opportunities. Instead, the majority of farmers largely used them to store maize for their own consumption (97% of respondents). A likely reason was that toxic storage pesticides are not needed in the hermetic bags. For home consumption, farmers thus may have adopted a safety-first approach. This suggests that the role of the hermetic bags is more relevant to farmers for food safety rather than economic returns.

Table 3. Adoption and purpose of hermetic bags.

	N	Percent
Number of hermetic bags used		
Only one	39	9.11

Only two	25	5.84
All three	364	85.05
Purpose of grain storage in hermetic bags		
Consumption	416	97.2
Marketing	12	2.8
Total	428	100

Note*:* Data from midline survey (2019). N = 428. Treatment households were asked how many of the three hermetic bags they were given they actually used and for what purpose (e.g. consumption or marketing).

4.5 Main Treatment Effects

We next examine if improved storage technology and training increased welfare outcomes (see Table 4). Across our measures, we find few impacts. All treatment effects are small and not statistically significant, except for the length of storage for maize farmers intend to sell (column 5). Here, treatment households increased the time form harvest until their last sales by about 14 days. Even though the arbitrage gain is very small and marginally significant, we know from the baseline data that farmers sell their maize within 1 to 4 months after harvest season. Therefore, the marginal maize price advantage farmers with hermetic bags obtain by storing longer than 4 months and 14 days is almost 1 ETB per kg (100 ETB/bag of maize), which indicates that the hermetic bags allow farmers to delay their sales and marginally benefit from higher prices. These largely null results could be explained by the fact that farmers only face small storage losses to begin with (below 2%). In addition, three hermetic bags can only store a fairly small quantity of harvested maize (below 10%). Moreover, 81% of farmers who were not using all three bags, reported damage by rodents as the major reason. Damage by rodents on the outer polypropylene bags was commonly reported, which would make the bags no longer hermetic, becoming ineffective and not reusable (see Figure A1). Taken together, it seems storage technology is not the main binding constraint for farmers to benefit from price arbitrage.

Table 4. Hermetic bags and welfare

	Outcome variables						
	(1) Maize yield (kg/ha)	**(2) Percentage of maize stored (%)**	**(3) Percentage of maize loss (%)**	**(4) Length of storage for consumpt ion (days)**	**(5) Length of storage for sale (days)**	**(6) Total maize income (ETB)**	**(7) HFIAS score**
Treatment effect	144.7	0.179	-0.0135	-4.495	13.29**	161.7	0.0297
	(89.91)	(1.209)	(0.0255)	(6.664)	(6.014)	(837.7)	(0.130)

Lagged outcome variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Village fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	**854**	**854**	**854**	**854**	**854**	**854**	**854**
Mean DV	**3861.31**	**24.43**	**0.12**	**272.75**	**101.98**	**16296.6**	**0.82**
SD DV	**1484.98**	**18.44**	**0.38**	**102.52**	**95.83**	**14488.06**	**1.93**

Note: Data is from baseline (2017/18) and endline (2019) surveys. We estimate an ANCOVA specification using standard errors clustered at village level in parentheses; Stars indicate significance levels: *p<0.10, **p<0.05, ***p<0.01. "Mean DV" and "SD DV" are the mean and standard deviation of the dependent variable. In addition, we controlled for variables that are imbalanced in Table A2 (e.g. land owned, land under maize, off-farm income and access to microfinance).

4.6 Heterogeneity in treatment effects

We explore treatment effect heterogeneity by interacting the treatment status with baseline covariates of interest. Across the outcomes, we do not find significant interaction effects between the treatment status and access to credit (see Table 5). However, households who are cash constrained (proxied by whether a household asked for credit in the last 12 months) store 5% less than those who are unconstrained. Liquidity constraints, therefore, could explain why we observed maize prices seasonality and why farmers do not store, despite the cheap maize storage alternative.

Table 5. Hermetic bags, credit and welfare

	Outcome variables						
	Maize yield (kg/ha)	**Percentage of maize stored (%)**	**Percentage of maize loss (%)**	**Length of storage for consumption (days)**	**Length of storage for sale (days)**	**Total maize income (ETB)**	**HFIAS score**
Treatment status	184.335*	0.498	-0.031	-2.263	14.539**	4.096	0.001
	(103.047)	(1.427)	(0.026)	(7.439)	(6.890)	(937.111)	(0.148)
Asked for credit (1=yes)	248.813	-4.605**	0.025	-9.166	-14.190	1524.142	-0.035
	(160.721)	(1.967)	(0.047)	(11.516)	(9.573)	(1387.117)	(0.216)

Asked for credit*Treatment status	-177.536	-1.077	0.076	-10.887	-5.511	937.933	0.068
	(213.337)	(2.718)	(0.078)	(16.013)	(14.054)	(2009.714)	(0.313)
N	**854**	**854**	**854**	**854**	**854**	**854**	**854**
Mean DV	**3861.31**	**24.43**	**0.12**	**278.19**	**104.02**	**16296.6**	**0.82**
SD DV	**1484.98**	**18.44**	**0.38**	**95.96**	**95.69**	**14488.06**	**1.93**

Note*:* The specification uses data from baseline (2017/18) and endline (2019) surveys. Standard errors clustered at *woreda* level in parentheses; Stars indicate significance levels: *p<0.10, **p<0.05, ***p<0.01. "Mean DV" and "SD DV" are the mean and standard deviation of the dependent variable. The outcome variables are regressed on the treatment status, the standardized baseline heterogeneity variable (access to credit), and an interaction term (access to credit*treatment status). In addition, we controlled for variables that are imbalanced in Table A2 (e.g. land owned, land under maize, off-farm income and access to microfinance). In Table A5 we control for household size, because if smaller households are more cash constraint it might be a confounding effect. However, we find no significant changes in treatment effect heterogeneity.

4.6 High initial investment cost of hermetic bags

Future investments by farmers in hermetic bags requires that the bags provide higher profits compared to other existing technologies. Despite the fact that freely-provided hermetic bags are adopted by all our treatment households and might provide a safer alternative storage, it is important to know if the bags are profitable for smallholder farmers in the region. Table 6, summarizes selected parameters (capacity, cost/unit, life span) for hermetic bags and the two dominant practices of storing maize grains in the study region. The least costly option is the traditional granary (452 ETB/100kg) which indicates a large initial outlay but also has a long-life span. The cost for the commonly used polypropylene bags is 25 ETB/100kg (10 ETB for the purchase of the bag, plus pesticide and labor costs). While the bag is not expensive it does involve more than one pesticide treatment application to reduce insect pest damage; also, farmers usually sell maize along with the polypropylene bag. Hermetic bags, on the other hand, are relatively expensive: they cost 55ETB/100kg and have a lifespan of 3 years if used properly. These cost evaluation results suggest that the major adoption challenge with hermetic bags is the high initial investment cost (e.g. 55ETB/100kg compared to 10 ETB/100kg polypropylene bags), which is substantial for smallholder farmers given their limited financial resources. Nevertheless, farmers besides the requirement for the upfront investment, could still earn a return of 115 ETB/100kg (170-55 ETB/100kg) by using hermetic bags to sell their grains duirng the lean season. Therefore, providing credit could be useful if the interest rate still allows them to earn some profit by storing. In addition, the hermetic bag technology is more cost-effective than the common storage technologies in storing maize on-farm, as the benefits of the technology continue to increase through the three-year lifespan of the product if perforation of the bag is avoided.

Table 6. Cost of storing maize in alternative facilities

Storage Facility	Maize Capacity (kg)	Cost/100kg (ETB)	Life Span (Years)	Cost/100kg/ year	Labor cost (ETB/100kg)	Pesticide cost (ETB/100kg)	Total cost (ETB/100kg)
Traditional granary	1800	11	10	1.1	12	4	17.1
Hermetic bag	100	55	3	18.3	0	0	18.3
Polypropylene Bag	100	10	1	10	12	4	26

Note*:* The cost calculations of the different storage types in the table are based on our own experimental evidence and farmers reported data. Labor cost refers to the labor hired to aerate fumigant before consumption or sell. The last column shows the total cost of storage in birr per 100kg per year (1USD=41ETB).

5. Discussion and conclusions

Based on a large dataset from a randomized controlled trial in Ethiopia, we build upon the limited previous experimental research on the size and determinants of post-harvest losses (PHL) in developing countries. We identify mechanisms behind the persistence of these challenges. The main hypothesis motivating this study was that access to hermetic bags will allow farmers to reduce storage losses and encourage them to store longer and benefit from price seasonality, and thus increase their overall income and improve households' food security.

We find that farmers who received three hermetic bags for free, a capacity of about 10% of their total maize harvested, marginally increased the average time they store maize before selling by 14 days (on average farmers store maize for 104 days). This arbitrage gain is relatively small and we do not find hermetic bags increase maize incomes. We also find no significant effect on the other welfare outcomes. Looking further into the heterogeneity in treatment effects, we find that farmers who are credit constrained store almost 5% less than those who are unconstrained. Liquidity constraint, therefore, could explain why we observed maize prices seasonality and why farmers do not store until prices increase, despite the cheap maize storage alternative. This might suggest that farmers have cash needs other than food.

In this study, we evaluated the impact of an intervention that distributed hermetic bags to a randomized group of farmers. Therefore, our results should not be interpreted as evidence that hermetic bags do not perform well for maize storage in Ethiopia. Rather the data tells us that the intervention to promote hermetic bags did not have tangible effects on treatment households.

There are several potential explanations for the limited short-term impacts of hermetic bags. First, the intervention tried to address storage losses, a severe constraint for many farmers in Sub-Saharan Africa. A meta-analysis of measurements based on grain samples estimates maize post-harvest losses of 25.6% on average (Affognon et al., 2015). These post-harvest losses mainly occur during storage when insect infestation and mold damage the harvested produce (Affognon et al., 2015). However, for our sample of South-Western Ethiopian farmers, PHL represent just 2% of annual crop yield. It seems that development agencies had the wrong counterfactual in mind, that led to over-estimated potential gains from hermetic bags. Estimates for wider Ethiopia vary extensively from 4% to 30% (Bachewe et al., 2018). One reason for the low storage loss observed in our sample is that the majority of farmers have benefited from a cheap and effective alternative, Aluminium Phosphide (AP), a storage fumigant, for maize grain storage (Figure A2). This attenuates treatment effects. The fumigant is readily available and effectively eliminates maize weevil and flour beetle. Farmers directly mix AP tablets with the grains to be stored. AP tablets are cheap: each 100kg bag of stored maize requires two tablets which cost just ETB 4 (~USD 0.1). For a typical famer, with a yield of 3826, storage costs using AP amount to just ETB 153 (USD 3.8).

However, there are serious potential health risks for the farmer and consumer. Rather than directly mixing the tablets with the grains, they should be placed in moisture-permeable envelopes or sachets, to retain the toxic residual dust (Fumigation Handbook, 2020). Also, if the store or the bag is not gas tight, the phosphine gas generated (each 3 gram tablet generates 1 gram phosphine gas, PH_3) may leak and pose health threat to humans and animals (Fumigation Handbook, 2020, Sheahan & Barrett, 2017). Phosphine is rapidly absorbed by inhalation, ingestion, and skin or mucosal contacts by humans. This can result in the rapid onset of gastrointestinal signs and symptoms including nausea, epigastric pain and vomiting. Cardiovascular manifestations of acute overexposure to phosphine include hypotension. However, most farmers are unaware of these health risks. Over 60% of farmers in our sample do not know how they can be exposed to toxins of the fumigant, and do not take appropriate precautions or use protective equipment (Table A4). In order to get rid of the gaseous residue farmers should aerate the grains. While 80% of farmers do aerate the maize grains before consumption, just 7% aerate the maize grains before taking them to the market, posing a health risk to consumers. According to government policy, only licensed technicians are authorized to purchase and handle AP (USAID, 2013). For example, World Food Program-Ethiopia uses AP in its warehouses, by certified Ministry of Agriculture personnel, with clear guidelines over proper dosage, material, duration, and worker protection.

Recent alarming reports indicate that AP has increasingly been used for suicide. A number of studies report that AP has become the most common cause of acute poisoning with oral ingestion in Ethiopia (Sultan et al., 2017). Studies in India also show that AP poisoning accounts for 68% of pesticide related deaths (Meena et al., 2015). The uncontrolled application of tablets and lack of proper protective clothing's also increases the exposure of humans and animals in the surrounding areas gas AP (USAID, 2013). For example, during focus group discussions, some farmers confirmed small ruminants (such as chicken), that died after eating grains treated with AP. We held informal meetings with traders in the respective kebeles as well as in the major grain market at the capital city of Ethiopia, Addis Abeba, and all traders informed us that they use AP as a storage pesticide. Even though there is a regulation on AP in Ethiopia, the regulatory body is not strong enough and often leads to "the do it yourself" practice. This uncontrolled application of tablets may also lead to resistance development of some types of weevils to phosphine. From focus group discussions, we have additionally learned that farmers are worried about the health consequences of the fumigant. Since AP reacts with moisture in the air to produce phosphine (hydrogen phosphide) which is highly toxic to all forms of animal and human life, the people directly applying the fumigant are the ones that are more vulnerable than the consumers. This is in-line with our finding that all treatment farmers used the bags mainly to store maize for home consumption rather than marketing. This suggests that the role of the hermetic bags is more with regards to food safety rather than economic returns. This further explains as to why farmers only aerate their maize grains before consumption and not the ones they sell to the market[3]. Therefore, our findings lay a foundation for more detailed investigation about AP and make more urgent the need for multidisciplinary analysis on the health effects of this fumigant use in Ethiopia. Where chemical pesticides are used to reduce PHL but inadvertently lead to poor health outcomes, then an unfortunate trade-off exists between PHL reduction and meeting the broader objectives from hermetic bags.

A second possible explanation for the lack of impact, could be that maize losses might occur at a different stage of the value chain (e.g. during harvest or transport as found by Ambler et al., (2018) in Malawi). This implies that future interventions would be better focusing on other stages of the post-harvest process than storage.

A third possible explanation relates to the possible low treatment dosage. We provided households three hermetic bags, which allowed improved store for just 10% of average total maize harvested. This enables households to benefit from an up to 36% increase in prices. The maximum effect on maize income is therefore just 3.6%.

5.1 Policy implications

Our findings have several policy implications. First, our study suggests that PHL during storage seems to be less of a concern to farmers in Ethiopia, at least smaller than is commonly reported in the literature. Second, though the use of fumigants is not an ideal and safe storage technology, it is widely adopted and accepted by farmers hindering investment in quality enhancing technologies and weakening food safety. Hence, there is a need to reinforce pesticide governance in Ethiopia. Despite having policies on pesticide registration, distribution and use, implementation of the laws at the local levels should be strengthened coupled with training on

[3] This is further confirmed by our communication with RIKILT (Institute of Food Safety) in Wageningen. A pesticide expert working there informed us that the fumigant is poisonous mainly for the user (in our case farmers), because it is highly volatile. We wanted to do a residue test of AP in the maize grains, but the expert told us that there is no reference material to perform residue tests, because it is volatilized easily.

the proper use and side effects of pesticides to the farmers. Third, most studies on hermetic bags in SSA found that farmers use hermetic bags to store grains for own consumption, rather than for marketing (Kadjo et al., 2018; Channa & Ricker-gilbert, 2018). We also find this pattern among treatment households in our study area, farmers that store maize in hermetic bags do so mainly to obtain better quality maize for household consumption. Economic motives to sell maize later in the season at higher price appear less important. Whereas most interventions on improved storage technologies are persuaded on the premise that farmers will sell their stored maize in the lean season, when prices are higher. This is yet another important evidence for policies that seek to improve grain management and promote hermetic bags. For example, anecdotal evidence from farmers who used hermetic bags in our study area suggests that the lack of grain quality controls discourages farmers to invest in quality. Traders only examine physically for breakage and obvious physical impurities when they buy maize and do not ask if pesticides were applied. Therefore, farmers are less incentivized to use hermetic bags to store maize for marketing. The Ethiopian government and stakeholders should encourage and support efforts to provide for independent verification of grain quality, as well as the enforcement of uniform grain standards. This would reward the adoption and investments in quality enhancing technologies and best practices, strengthening food safety along the value chain.

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Authorship contribution statement

Betelhem Negede: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing - original draft. Hugo de Groote: Funding acquisition, Conceptualization, Design, Methodology, Investigation, Writing - review & editing. Bart Minten: Conceptualization, Methodology, Investigation, Writing - review & editing Maarten Voors: Conceptualization, Methodology, Investigation, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

A1. ***Pre-analysis plan.*** We pre-registered our experimental design at the American Economic Association's registry prior to the analysis of any follow-up data (https://www.socialscienceregistry.org/trials/2635). The pre-analysis plan specified that in the second year an increase in area and production, as well as in income and consumption is expected, also investment in more hermetic bags. In the long run, we expected increased market integration, with farmers increasingly producing for the market. However, due to political instabilities in the study area in 2018, we could not make the hermetic bags available in the study district, which prevented us from analyzing the impact of the technology on outcomes such as production and market integration (e.g. the effects are very small/null). Moreover, maize storage losses were supposed to be measured through count and weigh method or farmer's estimate, and we expected to decrease storage losses by giving the bags. However, for similar reasons we could not conduct the count and weigh method as planned. Therefore, in this study we report maize storage losses as the total maize post-harvest losses experienced by the household as a percentage of the amount of maize stored. Finally, the PAP has not specified methods for addressing attrition bias, which are also included in this study. We decided on the monotonicity assumption for trimming bounds, thus report estimates of trimming bounds.

Attrition. The overall attrition rate is 1.95%. Relative to other studies in the region, our attrition rates are comparable or lower (Omotilewa et al., 2018). Attrition is slightly different across the groups. It is 2.3% in the control group and 1.6% in the treatment group, meaning a differential attrition of 0.7 percentage points. The main reason for attrition was migration out of the area, due to political instabilities and ethnic violence that occurred in the area early 2018.

Table A1. Sample size by study kebele during baseline and endline.

	Baseline			Endline		
Name of *kebele*	Control	Treatment	Overall	Control	Treatment	Overall
Delasa Mekenisa	86	86	172	82	80	162
Dire Guda	74	74	148	74	74	148
Haro Misoma	53	53	106	52	53	105
Lalistu Angar	96	96	192	93	94	187
Werebo	126	127	253	125	127	252
Total	435	436	871	426	428	854

Note: Table shows sample of household heads interviewed at baseline survey (2017/18), and at endline survey (2019). From the 871 households in our baseline sample, we were able to re-interview 854 households (426 households from the control and 428 from the treatment groups).

To test for the presence of attrition bias in our sample, we regress our outcome variables and other baseline covariates on a binary indicator equal to one for attrited households, and zero otherwise. We find no significant differences between attrited and non-attrited households for all outcome variables. For other covariates, we find significant differences for three variables. Attrited households have a smaller family size (1.5), own less land (0.66 ha), and live at further distance from the market (2 km). These findings suggest that younger households with fewer family members are more mobile, and likely migrate in search of better opportunities. Despite the systematic differences across these three variables, there was relatively low rate of attrition, and thus no significant impact on the three variables due to the randomly assigned treatment.

	Maize yield (kg/ha)	Percentag e of maize stored (%)	Percentage of maize loss (%)	Length of storage for consumpt ion (days)	Length of storage for sale (days)	Total maize income (ETB)	HFIAS score	Househol d size	Land owned (ha)	Distance to market (km)
Attrition	12.10	-2.337	0.466	-7.305	-21.77	-5,560	0.641	1.546***	0.665**	2.064*
	(272.1)	(4.86)	(0.63)	(-6.06)	(-22.8)	(-3.59)	(-0.41)	(-0.37)	(-0.29)	(-1.16)
Constant	3,904***	20.56***	1.336**	324.6***	139.4***	18,574***	1.876***	3.824***	1.279***	6.735***
	(261.9)	(4.81)	(0.62)	(-5.47)	(-22.62)	(-3.57)	(-0.39)	(-0.37)	(-0.29)	(-1.13)
Observations	871	871	871	871	871	871	871	871	871	871
R-squared	0.000	0.000	0.000	0.004	0.001	0.004	0.002	0.009	0.003	0.002

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

Table A2. Balance of baseline characteristics between experimental groups.

Baseline variables	(1) Control Mean/SE	(2) Treatment Mean/SE	(3) t-test Difference (1)-(2)
Dependent variables			
Maize yield (kg/ha)	3949.9	3910.9	38.9
	[120.9]	[85.8]	
Percentage of maize stored (%)	18.4	18.1	0.3
	[0.9]	[0.9]	
Percentage of maize loss (%)	1.8	1.8	-0.1
	[0.2]	[0.2]	
Length of storage for consumption (days)	281.7	276.7	5
	[4.5]	[4.6]	
Length of storage for sales (days)	114	124.1	-10.1
	[4.2]	[4.2]	
Total maize income (ETB)	12073.8	13948.7	-1875 **
	[551.6]	[595.4]	
HFIAS score	2.5	2.5	0.04
	[0.1]	[0.1]	
Household characteristics			
Age of hhd head (years)	44.8	43.8	1.02
	[0.6]	[0.6]	
=1 if hhd received education	0.5	0.5	-0.06
	[0.02]	[0.02]	
Household size	5.2	5.5	-0.3
	[0.1]	[0.1]	
=1 if hhd owns radio	0.2	0.2	-0.004
	[0.02]	[0.02]	
=1 if hhd owns mobile phone	0.8	0.8	-0.02
	[0.02]	[0.02]	
Production and storage practices			
Years of growing maize	18.4	19.3	-0.9
	[0.5]	[0.5]	
Land owned (ha)	1.8	2.1	-0.3**
	[0.1]	[0.1]	
Land under maize (ha)	1.2	1.2	-0.1*
	[0.03]	[0.03]	
Percentage of maize stored (%)	18.4	18.1	0.3
	[0.9]	[0.9]	
=1 if hhd uses storage pesticide	0.9	0.9	-0.03
	[0.02]	[0.02]	
=1 if hhd uses fertilizer	0.6	0.7	-0.01
	[0.02]	[0.02]	
Off-farm income (ETB)	1492.3	1879	-386.7*
	[140.9]	[160.5]	
Tropical Livestock Unit	3.5	3.7	-0.3
	[0.2]	[0.2]	
Access to finance			
=1 if hhd has access to credit	0.2	0.2	0.03
	[0.02]	[0.02]	
=1 if hhd has access to microfinance	0.3	0.4	-0.09***
	[0.02]	[0.02]	
Savings amount (ETB)	1509.7	2006.1	-496.4
	[221.5]	[239.6]	
Market access			
Distance to market (km)	8.7	8.876	-0.2
	[0.3]	[0.3]	

Male headed household (%)	96.3	95.7	
Farming as major occupation (%)	98.2	97.5	
N	426	428	
Clusters	5	5	
F-test of joint significance (F-stat)			0.49 (0.48)
F-test, number of observations			854

Note: The value displayed for t-tests are the differences in the means across the groups, with clustered standard errors at the village level. Stars indicate whether the differences are significant: *p<0.10, **p<0.05, ***p<0.01. The value displayed for F-tests are the F-statistics. HFIAS is the Household Food Insecurity Access Scale questionnaire to measure household food insecurity

Storage. The photo below is an example of improper storage of hermetic bags by a treatment farmer. It does not fulfill one of the main criteria of hermetic storage from the training poster (e.g. stack hermetic bags on elevated platforms.

Figure A1. Handling of hermetic bags by treatment households.

Note: The three white bags on the floor are the three hermetic bags given during the intervention. This photo is an example of a treatment farmer who reported that the bags were damaged by rodents. We further asked enumerators to verify among every treatment households if the hermetic bags were properly closed (83%), stored on a raised platform (70%), and stored in a clean area (72%).

Perceived benefits of hermetic bags. In table below we summarize treatment households perceived benefits of hermetic bags, ease of use/handling, and how they perform in terms of grain quality as compared to Aluminium Phosphide (N=428).

Table A3. Perceived benefits of hermetic bags.

Learning experience questions	**Response**	**Percent**
Preference for hermetic bags compared to Aluminium Phosphide.	• Hermetic bags • Aluminium Phosphide • Both	78 5 17
Perception about ease of use of hermetic bag relative to other types of technologies used.	• Very easy • Easy • Neutral • Difficult • Very difficult	35 53 6 4 2
Grain quality stored in hermetic bags relative to other types of storage technologies used.	• Better • Indifferent • Worse	96 4 0
Grain taste when stored in hermetic bags relative to other storage technologies used.	• Better • Indifferent • Worse	92 8 0

Figure A2. Aluminium Phosphide, storage fumigant.

Note: The figure shows a container of the widely used fumigant, Aluminium Phosphide. Also known as Celphos as a trade name:. The tube contains 30 tablets (each 3 gram).

AP practices. In table below, we asked all households in our sample (N=854) about their AP practices, use and knowledge.

Table A4. Application and access of Aluminum Phosphide.

Questions	Response	Percent
Where do you buy AP?	• From open market • Drug store	93 7
Who first introduced you to the use of AP?	• Extension services • Input dealers • Other farmers • Media	15 8 76 1
Mix AP with maize you store for own consumption?	• Yes • No	72 28
Amount applied on maize stored for own consumption?	• 1 • 2 • >2	66 28 6
Aerate maize grains before consumption?	• Yes • No	80 20
Who carries out aeration before consumption?	• Household head • Spouse • Both • Hired labour	11 82 5 2
Mix AP with maize you store for market?	• Yes • No	72 28
Amount applied on maize stored for market?	• 1 • 2 • >2	75 22 3
Aerate maize grains before sell?	• Yes • No	7 93
Who carries out aeration before sell?	• Household head • Spouse • Both • Hired labour	50 26 15 9
How do you determine correct dosage?	• From pesticide label • Based on observation of live insects • Based on vendor recommendation • Based on other farmers recommendation • Based on extension off. recommendation	3 35 15 40 6

How do you determine how long fumigation should last?	• From pesticide label • Based on observation of live insects • Based on vendor recommendation • Based on other farmers recommendation • Based on extension off. recommendation	6 29 20 40 45
How worried are you in using AP?	• Not at all worried • Slightly worried • Somehow worried • Moderately worried • Extremely worried	23 22 18 21 16
Can you read and understand instructions of the label?	• Yes • No	19 81
Do you understand the sign on the pesticide label?	• Yes • No	27 73
Have you received training on how to use and handle pesticides?	• Yes • No	2 98
Do you know how you can be exposed to pesticides?	• Yes • No • I do not know	21 62 17
Do you use any protective measures when applying pesticides?	• Yes • No	21 79

Table A5. Heterogeneity in treatment effects controlling for household size.

	Outcome variables						
	Maize yield (kg/ha)	**Percentage of maize stored (%)**	**Percentage of maize loss (%)**	**Length of storage for consumption (days)**	**Length of storage for sale (days)**	**Total maize income (ETB)**	**HFIAS score**
Treatment status	168.9 (103.6)	0.0705 (1.393)	-0.0316 (0.0259)	-2.132 (7.495)	13.50** (6.860)	-89.28 (929.1)	0.0189 (0.148)
Asked for credit (1=yes)	245.1 (160.9)	-4.348** (1.891)	0.0239 (0.0466)	-9.226 (11.60)	-14.14 (9.675)	1,574 (1,367)	-0.0727 (0.217)

Asked for credit*Treatment status	-128.1	0.165	0.0814	-11.28	-2.565	1,125	0.0494
	(214.1)	(2.654)	(0.0788)	(16.04)	(14.18)	(1,970)	(0.313)
N	**854**	**854**	**854**	**854**	**854**	**854**	**854**
Mean DV	**3861.31**	**24.43**	**0.12**	**278.19**	**104.02**	**16296.6**	**0.82**
SD DV	**1484.98**	**18.44**	**0.38**	**95.96**	**95.69**	**14488.06**	**1.93**

Note: The specification uses data from baseline (2017/18) and endline (2019) surveys. Standard errors clustered at *woreda* level in parentheses; Stars indicate significance levels: *p<0.10, **p<0.05, ***p<0.01. "Mean DV" and "SD DV" are the mean and standard deviation of the dependent variable.