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Does access to improved grain storage technology increase farmers' welfare? Experimental evidence from maize farming in Ethiopia

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Abstract

Seasonal price variability for cereals is two to three times higher in Africa than on the international reference market. Seasonality is even more pronounced when access to appropriate storage and opportunities for price arbitrage are limited. As smallholder farmers typically sell their production after harvest, when prices are low, this leads to lower incomes as well as higher food insecurity during the lean season, when prices are high. One solution to reduce seasonal stress is the use of improved storage technologies. Using data from a randomised controlled trial, in a major maize-growing region of Western Ethiopia, we study the impact of hermetic bags, a technology that protects stored grain against insect pests, so that the grain can be stored longer. Despite considerable price seasonality—maize prices in the lean season are 36% higher than after harvesting—we find no evidence that hermetic bags improve welfare, except that access to these bags allowed for a marginally longer storage period of maize intended for sale by 2 weeks. But this did not translate into measurable welfare gains as we found no changes in any of our welfare outcome indicators. This 'near-null' effect is due to the fact that maize storage losses in our study region are relatively lower than previous studies suggested—around 10% of the quantity stored—likely because of the widespread use of an alternative to protect maize during storage, for example a cheap but highly toxic fumigant. These findings are important for policies that seek to promote improved storage technologies in these settings.

KEYWORDS
Ethiopia, hermetic storage, randomised controlled trial, seasonality, welfare

JEL CLASSIFICATION
C93, D15, O12, O13, O14

1 | INTRODUCTION

Seasonality in African staple prices is about two to three times higher than in 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 variation in local food availability and consequently prices (Gilbert et al., 2017; Kaminski & Christiaensen, 2014). Prices of staple grains are typically low after harvest and rise gradually throughout the lean season. Many farmers appear unable to take advantage of the apparent inter-temporal arbitrage opportunities. Instead, they often sell their production soon after harvest when prices are low and buy in the lean season when prices are high (Burke et al., 2019; Stephens & Barrett, 2011). This behaviour of 'selling low and buying high' undermines food security and reduces income among smallholder farmers (Christian & Dillon, 2018).

There are two main explanations for the 'sell low, buy high' puzzle (Burke et al., 2019; Stephens & Barrett, 2011). First, seasonality of prices may be caused by lack of access to improved storage technologies. Such technologies reduce post-harvest losses (PHL), due to mould, rodents and other pests, and offer an opportunity to engage in temporal arbitrage. As storage capacity increases, storage losses 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.

A number of authors have studied the impact of such technologies. Aggarwal et al. (2018) address storage constraints in Kenya by providing farmers with 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 benefitted from higher prices by selling 23% more maize on average during the lean season. Omotilewa et al. (2018) also find that providing improved storage technology in rural Uganda resulted in farmers storing more maize for a longer period. Moreover, farmers who adopted the metal silos, a locally produced alternative hermetic storage technology, sold their maize up to 5 months after harvest (Gitonga et al., 2013). Better post-harvest management and storage facilities also provide production 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. Poor households that are liquidity constrained might be compelled to convert non-cash wealth in the form of grains into cash in order to take care of other needs (Stephens & Barrett, 2011). This is consistent with Fafchamps and Minten (2012) who find that for most farmers the decision to sell is largely driven by the liquidity needs of the household rather than the price of the crop. Reduced food sales during the lean season not only reduce producer income, but also lead to food shortages or volatility in local food availability (as well as prices), indirectly affecting (poor) food consumers (Sheahan & Barrett, 2017). Temporary liquidity constraints can be solved through access to credit. A range of empirical studies show that farmers are unable to exploit seasonal price variation even if they have access to improved storage technologies when there are credit constraints (Basu & Wong, 2015; Burke et al., 2019; Christian & Dillon, 2018; Kadjo et al., 2018; Stephens & Barrett, 2011). In Kenya, for instance, Burke et al. (2019) find that access to credit increases farmers' income as it enables them to store their produce and sell when prices are higher.

In this paper we contribute to the small but growing literature on the human welfare impacts of access to improved storage technologies, and more specifically of access to hermetic bags for maize storage in Ethiopia. The Ethiopian maize market is a compelling case to study storage and seasonality, as maize production is highly seasonal and price fluctuations are apparently exacerbated by poor storage technology. Most farmers produce maize during one agricultural season per year, so they need to store their maize to bridge the lean season and protect them from price fluctuations. Improved storage technologies, in particular hermetic bags, offer new possibilities allowing farmers to store longer, as the risk of storage losses is removed, and without the use of pesticides, further improving grain quality and safety (De Groote et al., 2013). This is an important issue in Ethiopia as maize represents 30% of total cereal production, mostly grown by poor smallholders (World Bank, 2018).

To measure the causal effects of access to hermetic bags[1] on household welfare, we provided farmers access to those in a major maize-growing district in the western part of Ethiopia. We use data from a randomised controlled trial (RCT), where 871 randomly selected smallholder maize farmers received three Purdue Improved Crop Storage (PICS) bags, a type of hermetic storage bag, for free, each with a storage capacity of 100 kg of shelled maize, along with instructions on their proper use. We compare the treatment group of farmers who received access to hermetic bags to those who did not and examine the impact of improved storage on a range of outcome variables: maize yield; percentage of maize stored; percentage of maize losses; length of maize storage for consumption; length of maize storage for sale; income from maize sales; and household food insecurity. We hypothesise that the decrease in quantity lost increases the amount of grain available for sale and household consumption and that the aggregate effect of increased quantity available for consumption and sale, higher sales prices, improved income, and longer storage duration is improved food security.

The remainder of the paper is structured as follows. Section 2 reports the methodology. Section 4 describes the empirical strategy for estimation of treatment effects. Section 5 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

2.1 | Sampling of households and data collection

We use data from two rounds of a household-level panel survey conducted in combination with a randomised controlled experiment that was implemented among 871 maize growing households in Gida Ayana woreda,[2] East Wollega zone in the Oromia region, located in the western part of Ethiopia. The choice of the region was motivated by the International Food Policy Research Institute's (IFPRI) study on farmers' grain storage and losses in Ethiopia (Bachewe et al., 2020). The study indicates that the areas with the greatest PHL in maize are located in the south-west maize growing areas in the country, in particular the administrative zone of East Wollega (see Figure A1 in the Appendix S1). Moreover, the area is known to have high price seasonality and diverse agro-ecological conditions.

[1]The hermetic bag provides a triple layer hermetic (air tight) seal that protects stored grain by killing insects and neutralising mould growth (Williams et al., 2017). It is a way to store grain effectively without the use of storage pesticides (De Groote et al., 2013).

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

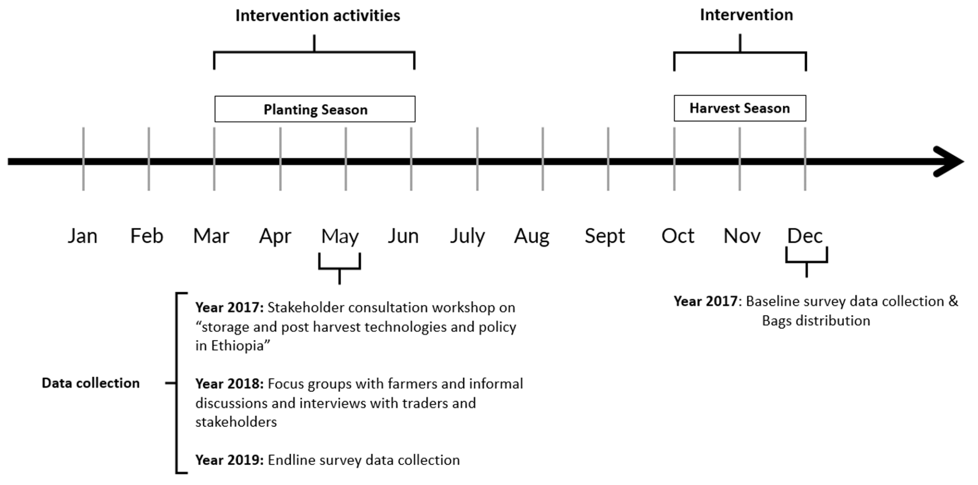

FIGURE 1 Agriculture calendar and timeline of intervention and data collection.

Before implementing the survey and experiment, a stakeholder workshop was organised during May 2017 to gain more insight into grain storage challenges for farmers in Ethiopia and to identify a specific study area. During December 2017, we implemented the baseline survey followed by the experiment. The implementation coincided with the harvest season (October to December), when farmers make their storage decisions (e.g., purchase of storage bags and pesticides). During May 2018, we organised focus group discussions to learn about consumption and marketing challenges, and the experience with the hermetic bags. In May 2019, both treatment and control households were revisited 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, and household 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 Tables A1 and A3 in the Appendix S1, for attrition discussion and analysis confirming the sample remains balanced across a wide set of variables). Figure 1 provides a timeline of the research activities.

2.2 | Experimental design

We use an individual complete block randomisation design, using kebeles as blocks. The unit of randomisation is the household. Randomisation was conducted in the field by one of our researchers and field coordinator prior to the baseline survey. We first obtained the list of households of each kebele (smallest administrative unit), from the respective kebele offices. The households were then numbered and each assigned a random number, after which they were sorted by that random number. The top first ranked households, up to the number required for that kebele were selected. Every other household was assigned to the treatment group, the rest to the control. Treatment assignment was revealed to farmers privately after baseline data collection by enumerators. The training for the bags involved a demonstration individually at each treatment household homestead.

In total there are 435 exogenously treated households and 436 controls across five kebeles (Table A2). The intervention consisted of providing three hermetic bags free of charge, along with a poster-based instruction on their proper use provided by Shayashone PLC, the sole distributor of hermetic bags in Ethiopia (Figure A3). The hermetic bags used were the Purdue Improved Crop Storage (PICS) bags, which consist of three layers: an outside layer of woven polypropylene and two inner layers of polyethylene, which is based on the depletion of oxygen in the storage through natural processes and replacing it with carbon dioxide, suffocating insect pests.

At the time of our study, a hermetic bag cost 50 Ethiopian Birr (ETB, or US$0.95,[3] with a storage capacity of 100 kg of shelled maize). The hermetic bags can be used for up to 3 years. In contrast, a conventional, single layer, woven polypropylene bag costs about US$0.20, provides limited protection against insect pests, and is generally used only once. Moreover, hermetic bags remove the need to use synthetic pesticides, which makes them safer to use for households (Loha et al., 2018; Sheahan & Barrett, 2017). Shayashone PLC provided the hermetic bags and instructions at the homestead of each treatment farmer. The hermetic storage bags were provided after the conclusion of the baseline household survey. Our experiment involved no explicit references to storage as savings and, unlike Aggarwal et al. (2018), we did not provide encouragement that the stored maize be used for later sale. These differences in the experimental design matter for the interpretation of the results.

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 (in ETB), and household food insecurity (using the Household Food Insecurity Access Scale). We compare households based on their random assignment of hermetic bags (T_i). Following McKenzie (2012), we use an ANCOVA specification adding baseline data on the outcome where available, in order to maximise power. The ANCOVA model is estimated using a least squares regression. Specifically, we estimate:

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

where Y_{it1} is the outcome variable of household i at endline t_1; T_i is the treatment variable, taking the value of 1 if household i was randomly assigned to receive a set of hermetic bags (treatment) and 0 otherwise (control); $\boldsymbol{X}_{it0}$ is a vector of household characteristics that were not balanced at baseline t_0 (e.g., land owned, land under maize, off-farm income and access to microfinance); Y_{it0} are outcome variables at baseline; μ_k are kebele (k) fixed-effects to account for our blocked randomisation; and ε_{ik} is the remaining individual error term.

4 | RESULTS

4.1 | Socio-economic and demographic variables

Descriptive statistics of the respondents in our sample are shown in Table 1. The majority of our sample households (90%) are male-headed, with a household size of five people. The average

[3] 1 ETB = 0.02 USD, using the exchange rate of 2022.

TABLE 1 Descriptive statistics of sample households.

Variable name	Mean	SD	Min	Max
Household characteristics				
Gender of household head (1 = male)	0.9	0.1	0	1
Household head age	44.2	12.3	18	68
Household size	5.3	2.1	0	9
Any education (1 = yes)	0.5	0.5	0	1
Access to MFI (1 = yes)	0.3	0.5	0	1
Owns mobile phone (1 = yes)	0.8	0.4	0	1
Maize output				
Maize harvest quantity (kg)	4446.4	2650.1	0	9800
Land owned (ha)	1.9	1.6	0	6
Land under maize (ha)	1.2	0.6	0	2.3
Maize yield (kg/ha)	3814	1521.4	0	6600
Maize stored (% kg stored/total harvest)	18.2	20	0	98
Maize sold after harvest (% kg sold/total harvest)	55.8	24	0	100
Maize consumed (% kg consumed/total harvest)	23.5	20.5	0	100
Maize storage loss (% kg lost/maize stored)	10	4.5	0	100
Maize storage technology				
Storage pesticide (1 = yes)	0.9	0.3	0	1
Polypropylene bag (%)	75			
Traditional granary (%)	22			
In-house storage (%)	1			
Community storage facility (%)	1			
Improved granary (%)	1			

Note: Data from baseline survey (2017/18). $N = 871$. Data presented here has been winsorised at the upper level at the 95th percentile to remove extreme values. MFI stands for microfinance institutions.

household head age is 44 years old. The higher number of men in our sample is because we invited household heads and the head of a typical household in Ethiopia is male. The advantage of using household heads is that it avoids potential confounding effects that different roles and positions within the family may have on the results. The average time in school is 2.5 years, implying that the majority had 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 40% had to repay a loan at harvest (mainly for fertiliser).

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 4446 kg/ha, just above the mean national maize yield of 4000 kg/ha (Central Statistical Agency, 2011). The share of households that stored maize was 18%, and those that consumed maize was 23% at the time of interview. The majority of farmers sold their maize production right after harvest before storage (56%). When farmers were asked about their maize storage behaviour in the last 12 months prior to intervention, only 16% and 3% of households stored for consumption and sale only, respectively. Whereas 81% of households stored for both consumption and sale, less than 1% stored for seed for the next harvest season. Regarding the quantity of maize lost during

TABLE 2 Adoption and purpose of hermetic bags.

How many of the three hermetic bags you were given for free are you currently using?	1 = own consumption; 0 = marketing		
	0	**1**	**Total**
Only one	1	38	39
%	8.3	9.1	9.1
Only two	1	24	25
%	8.3	5.8	5.8
All of the three	10	354	364
%	83.3	85.1	85.1
Total	12	416	428
	100	100	100

Note: First row has *frequencies* and second row has *column percentages*. Data from endline 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).

storage, farmers' self-reported losses represent around 10% of the quantity stored. This reflects the widespread use of pest control methods. Overall, 92% of farmers applied storage pesticides, in particular aluminium phosphide (AP), to prevent losses during storage (Figure A3). The fumigant is readily available and effectively eliminates maize weevil and flour beetles. Farmers directly mix AP tablets with the grains to be stored (Table A4). AP tablets are cheap, each 100 kg bag of stored maize requires two tablets which cost just ETB 4 (~US$0.10). For a typical farmer, with a production of 3826 kg, storage costs using AP amount to just ETB 153 (US$3.80). The most common storage container was 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 were rare; they included in-house storage (1%), community storage facility (1%) and improved granary (1%).

Before assessing the impact of the intervention, we investigated the success of the randomisation process. Respondents were balanced with respect to most characteristics (see Table A3), as shown by an F-test of the equality of means across all variables that was not significant (F-stat = 0.49). Treatment households were, however, on average wealthier, with higher maize income and land ownership and greater access to microfinance.

4.2 | Take-up of hermetic bags

Table 2 shows that the 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 received. However, bags were not used to exploit temporal arbitrage opportunities. Instead, the majority of farmers reported to have used them to store maize for their own consumption (97% of respondents). A likely reason is that maize is their staple crop and farmers adopt a safety-first approach. Given the small number of storage bags provided (representing 10% of their harvest) and as the market seemingly does not penalise ‘toxic maize’ or provide a premium for ‘safe maize’, treated farmers adjust their storage decisions based on improved storage constraints and priorities. They actually prefer to consume the safe maize rather than sell it. This finding is consistent with studies that have shown that market incentives affect production and marketing decisions, in general (Bernard et al., 2019; Casaburi & Macchiavello, 2015), and for food quality and safety, specifically (Bernard et al., 2017; Hoffmann et al., 2022; Hoffmann & Jones 2018; Magnan et al., 2021). In line with these studies, the role of the hermetic bags seems to be more relevant to farmers for food safety rather than economic returns, as suggested in Omotilewa et al. (2018).

4.2.1 | Cost of alternative storage technologies

Investments by farmers in hermetic bags require that the bags provide higher profits compared to other existing technologies. Table 3 summarises selected parameters (capacity, up-front cost, lifespan) for hermetic bags and the two dominant technologies for storing maize grains in the study region. The least costly option is the traditional granary (17 ETB/100 kg) which indicates a large initial outlay but also a long lifespan. The second option is storing in the common polypropylene bag, which costs 26 ETB/100 kg (10 ETB for the purchase of the bag and 16 ETB for the pesticide and labour costs). Although 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. The last option, hermetic bags, on the other hand, are relatively expensive: they cost 50 ETB/100 kg but have a lifespan of 3 years, costing 16.6 ETB/100 kg. These costs suggest that a major challenge is the high initial investment cost of hermetic bags (e.g., 50 ETB/100 kg compared to 10 ETB/100 kg polypropylene bags). Nevertheless, farmers could still earn a return of 120 ETB/100 kg[4] by using a hermetic bag to sell their grain during the lean season, despite the requirement for the up-front investment. In contrast, the return on investment for the two most prevalent storage facilities, traditional granary and polypropylene bag, is 160 ETB/100 kg. In addition to the economic benefits, the associated health benefits of hermetic bags need to be considered, as traditional storage requires application of pesticides. Furthermore, 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 3-year lifespan of the product if perforation of the bag is avoided.

4.3 | Seasonal price variation for maize

Next, we assess variation in maize prices throughout the agricultural calendar. We aggregated 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 plot maize price seasonality for 2018 based on farmers' self-reported monthly maize price sales (right axis in Figure 2). In our study district, maize prices increase gradually from 4.7 ETB/kg in October (beginning of the harvest season) to a peak at 6.4 ETB/kg in May (the lean season). This inter-temporal price seasonality implies a 36% increase in maize prices (170 ETB/100 kg), highlighting potential arbitrage opportunities to storage. However, most farmers sell immediately after harvest; 40% of farmers sell their maize in the first month after harvest (left axis in Figure 2). By the time prices peak, in May, only 6% of farmers sell their maize, implying that the benefit from higher prices does not accrue to the majority of farmers.

In a competitive market, the difference between harvest time and lean season prices should reflect the costs of storage, which involves opportunity costs of holding stocks, storage

[4]We arrive at 120 ETB per 100 kg, as in total there is a 170 ETB/100 kg increase in maize prices obtained from the inter-temporal price seasonality of 36% (Figure 2). As a result, if a farmer invests in a hermetic bag, with an initial cost of 50 ETB, they can have a return of 120 ETB per 100 kg (170–50 ETB per 100 kg).

TABLE 3 Cost of storing maize in alternative facilities.

Storage facility	(1) maize capacity (kg)	(2) up-front cost (ETB/100 kg)	(3) lifespan (years)	(4) cost/100 kg/year	(5) labour cost (ETB/100 kg)	(6) pesticide cost (ETB/100 kg)	(7) Total cost (ETB/100 kg)	(8) return on investment (ETB/100 kg)
Traditional granary	1800	11	10	1.1	12	4	17.1	159
Hermetic bag	100	50	3	16.6	0	0	16.6	120
Polypropylene bag	100	10	1	10	12	4	26	160

Note: The cost calculations of the different storage types in the table are based on researchers' own experimental evidence and farmers' reported data. In column 5, labour cost refers to the labour hired to aerate fumigant before consumption or sale. Column 6 refers to the fumigant (pesticide) cost, which is the average cost incurred to buy pesticides when farmers store maize; this cost does not apply to hermetic bags because they do not require pesticides. Column 7 shows the total cost of storage in birr per 100 kg per year (1 ETB = 0.02 USD), and in column 8, the return on investment (ROI) for each storage facility is presented, taking into account the 36% increase in maize prices (170 ETB/100 kg) due to inter-temporal price seasonality.

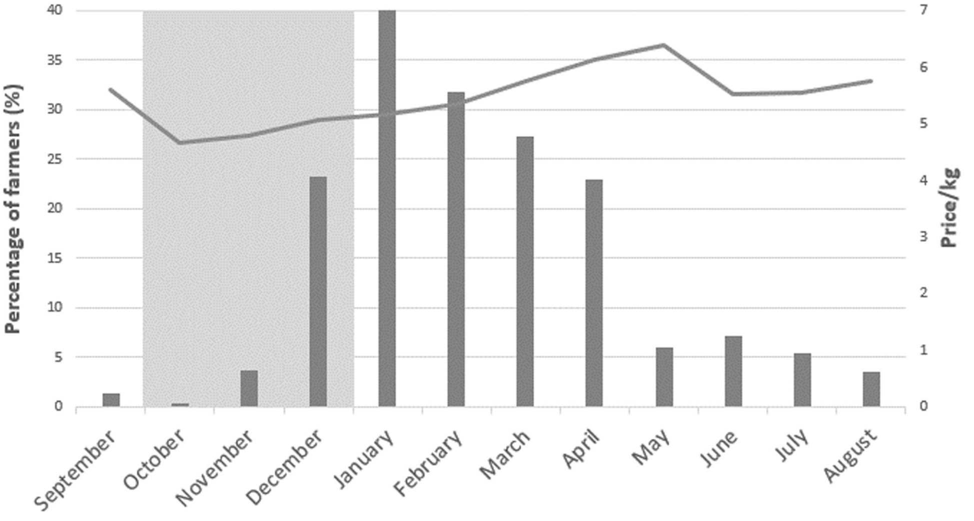

FIGURE 2 Maize price seasonality and timing of sales. *Note*: Authors' computation based on self-reported monthly maize sale prices in 2018/2019. $N = 854$. Graph includes maize sold in June, July and August 2018 and not 2019. The question asked was: 'seasonality in maize storage, sale, purchase and consumption in the last 12 months', therefore, the graph represents prices for May–December 2018 and January–April 2019.The harvest season is between October and December (shaded in grey). As we did not collect the amount of maize sold by farmers each month, we instead plot the percentage of farmers who reported to have sold maize each month (left axis and vertical bars). The right axis—and horizontal line—represents maize price per kilogram based on farmers' self-reported monthly maize price sales.

losses, the costs of labour and capital, and profit (Timmer et al., 1993). However, only in a well-functioning capital market, the opportunities to benefit from temporal arbitrage transactions will disappear. From our data, only 30% of farmers have, for example, access to microfinance, in order to be able to benefit from the opportunity cost of capital of 10% for 6 months. Moreover, there are differences in this price seasonality over time. A report on cereal markets performance in Ethiopia (World Bank, 2018) shows that there is significant price seasonality for maize in Ethiopia (varying from 26% to 40%) and that the average amplitude is 28% for maize producers in Nekemte, the nearest major market to our study district (Figure A4), 8% lower than during our study period.

4.4 | Impact of hermetic bags on welfare outcomes

Table 4 presents the Intent-to-Treat (ITT) effects to a household that randomly received three hermetic bags with a capacity of 100 kg each on several outcome variables. Across our measures, we find few impacts. All treatment effects are small and not statistically significant, except for impacts on the length of maize storage intended for sale (column 5). Here, treatment households increased the time from harvest until their last sales by about 14 days. Even though the arbitrage gain is small and only 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. Anecdotal evidence from farmers who used the hermetic bags suggests that the lack of grain quality controls discourages farmers to invest in grain quality. Traders only examine obvious physical impurities when they buy maize and do not

TABLE 4 Hermetic bag treatment effects.

	Outcome variables						
	(1) Maize yield (kg/ha)	**(2) Maize stored (%)**	**(3) Maize storage loss (%)**	**(4) Length of storage for consumption (days)**	**(5) Length of storage for sale (days)**	**(6) Total maize income (ETB)**	**(7) HFIAS score**
ITT	116.895	0.187	−0.278	−4.118	13.450**	137.463	0.029
	(82.299)	(1.226)	(0.580)	(6.691)	(6.060)	(820.951)	(0.165)
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
N	854	854	854	854	854	854	854
Mean DV	3832.07	18.12	8.47	317.28	117.64	11570.49	2.70
SD DV	1524.48	20.02	2.21	76.15	84.70	9719.11	3.40

Note: Data are from baseline (2017/18) and endline (2019) surveys. We estimate Intent to Treat effects using an ANCOVA model with 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. We control for variables that are imbalanced in Table A3 (e.g., land owned, land under maize, off-farm income and access to microfinance), see Table B1 (in Appendix S1) for ITT estimates selecting controls using a double post lasso procedure.

ask if pesticides were applied. Therefore, farmers have no incentive to use hermetic bags to store maize for marketing.

These results are not surprising in hindsight, given the widespread use of fumigation, but we had hypothesised an effect based on the initial assumptions. Three hermetic bags can only store a fairly small quantity of harvested maize (below 10%). Given that there was no increase in quantity stored or yield effects among treated households, one of the main effects of the intervention could be improving food security through longer storage to improve consumption, as found in Omotilewa et al. (2018). However, we do not find any evidence for this. Our findings therefore contradict other experimental evidence on the use of hermetic bags, such as Brander et al. (2021) and Chegere et al. (2022). Interventions in these studies (in Tanzania) had a significant effect on storage losses, food security and quality of maize grains, length of storage for sale, and cost of storage protection.

Our results therefore suggest that some of these outcomes depend on local market structure, as well as the availability of a competing storage technology (e.g., the fumigant).[5] Similarly, a recent RCT in Tanzania, where treated maize farmers were provided with two hermetic bags, found no significant average effect on maize inventory in the lean season or net maize sales across the year (Channa et al., 2022). They also found that self-reported maize losses during storage were only 12 kg on average per household, even lower as a percentage of maize harvested, which is 1559 kg. Major explanations given are the use of cheap storage chemicals and selling early because of the risk of storage losses. Though they do not mention the type of storage chemical used, they indicate that one application of storage chemicals costs TSh 374/100 kg bag (17 cents/bag) on average, whereas a hermetic bag costs US$2.30. Similarly, an 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 much higher (just 1.4%), as farmers tend to use chemical insecticides (Ndegwa et al., 2016).[6]

Taken together, it seems improved storage technology in our study district is not the main binding constraint for farmers to benefit from price arbitrage. It is known that smallholders decide to store grains under multiple binding constraints, such as liquidity constraints and access to improved grain storage. Therefore, by providing access to an improved storage technology, we solved only part of the constraints. Thus, even among treated households, liquidity constraint at harvest may well play an important role in their decisions to store maize (Stephens & Barrett, 2011).[7]

5 | DISCUSSION AND CONCLUSION

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 therefore prices (Gilbert et al., 2017; Kaminski & Christiaensen, 2014). Prices of staple grains are

[5]Chegere et al. (2022) used a randomisation at the village level and provided farmers hermetic bags that would store about 60% of their expected harvest. Also, the control groups' PHL at baseline was 12%, much higher than ours. Brander et al. (2020) used a matched-pair cluster randomisation design (where clustering was done at the level of farmer groups organisations) and provided five hermetic bags for free and estimated joint effects of the provision of hermetic bags and training on welfare outcomes. While access to five hermetic bags also implies that farmers need to choose between consumption and sales, the proportion of the total maize production that is lost post-harvest is 31% at baseline, compared to less than 2% in our study. Both studies do not mention anything about the type of pesticides used by farmers in their context.

[6]The storage insecticides used in Kenya, however, are dusts, not fumigants, and are much less toxic, and its use by farmers is permitted.

[7]For example, Channa et al. (2018) combine the distribution of hermetic bags with credit provision to farmers in Kenya, and find farmers receiving both credit and bags store 29% more maize than the control group. However, they do not find additional storage among the group that only received hermetic bags.

typically low right after harvest and rise gradually throughout the lean season. Therefore, reducing post-harvest losses (PHL) and providing access to improved storage technologies could have important implications for both food security, by providing more food for home consumption over a longer period, and improved income, by storing grain longer and selling it later at a higher price.

To test the impact of access to improved storage technologies, we implemented a randomised controlled trial in Western Ethiopia, where maize farmers were provided hermetic bags for free. Our results reveal considerable seasonal price variation: maize prices in the lean season are up to 36% higher than after harvesting. On average farmers stored their maize for just 3 months after harvest, whereas prices peak after 5 months. While treatment farmers marginally increased the storage period of maize intended for sale by 14 days (or by 13%, as farmers on average store maize for 104 days), this did not translate into measurable welfare gains as we found no changes in any of our welfare outcome indicators. However, caution is warranted and our results should not be interpreted as evidence that hermetic bags per se do not improve household welfare. Rather, the results indicate that the intervention with hermetic bags, under the given circumstances, did not have tangible effects on treatment households in our study sample.

There are two potential reasons to explain this low-level impact of the hermetic bags. A first explanation is the relatively low storage losses in our sample—at baseline this was around 10% of the quantity of maize stored. This is much lower than the reported storage losses estimates in Ethiopia, which range from 24% (Hengsdijk & de Boer, 2017) to 30% (FAO, 2018). This can be attributed to the widespread use of cheap storage fumigants widely available in local markets, mainly aluminium phosphide.[8] Almost all farmers (92%) used this fumigant at baseline, which effectively kills pests attenuating any treatment effects due to hermetic bags. Despite its efficacy, the use of these fumigants can cause considerable health risks due to their toxicity (Fumigation Handbook, 2020; Sheahan & Barrett, 2017; Loha et al., 2018). The uncontrolled application of tablets and lack of proper protective clothing increases the exposure of humans and animals in the surrounding areas (USAID, 2013). 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 who apply the fumigant are most vulnerable, not 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. Anecdotally some farmers reported that they use hermetic bags to store maize for future consumption and not for future sales, suggesting that farmers recognise the health benefits of hermetic bags. The uncontrolled application of tablets may further lead to the development of resistance to phosphine by insects. Another potential reason why farmers may avoid selling grains stored in hermetic bags is that maize grains are typically sold in a bag on the market. However, since hermetic bags are expensive, farmers may not want to give them away, and it requires a lot of work to re-bag 100 kg of maize. Secondly our null impact relates to the low treatment dosage, as compared to other studies (Brander et al., 2021; Chegere et al., 2022).[9] For our sample, three bags could contain just 10% of maize harvest, a fraction too small to benefit much from price arbitrage. Similarly, a recent RCT in Tanzania, where treated maize farmers were provided with two hermetic bags,

[8]Aluminium phosphide (AP) is officially registered as a legal pesticide by the Ethiopian Ministry of Agriculture, but regulations are not put in practice on the ground. In particular, AP is commonly bought and used by farmers, but only licensed technicians are authorised to purchase and handle it. For example, World Food Program-Ethiopia uses AP in its warehouses, by certified Ministry of Agriculture personnel. However, proper dosage, material, duration, and also a decent protection for the workers is required. 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 a health threat to humans and animals (Fumigation Handbook, 2020).

[9]Brander et al. (2021), for example, provided up to five bags per farmer, while Chegere et al. (2022) provided the number of bags that would store about 60% of their harvest.

found no significant average effect on maize inventory in the lean season or net maize sales across the year (Channa et al., 2022). However, our results still stand in contrast to Omotilewa et al. (2018), who found that offering a household one free 100 kg hermetic bag reduced PHL from 3% to about 1%.[10]

Our findings are important for policies that seek to improve grain management and promote hermetic bags. They highlight the context specificity of the benefits of having access to hermetic bags, in this case due to the availability of a competing storage technology, and they indicate the importance of financial and economic assessments that pay attention to cheap alternatives in the market, but with possible important health externality costs attached to it. Moreover, further effort is required to do more correct measurements of post-harvest losses in the value chains in these settings as to better pinpoint at which stage of the value chain these losses are most important and are best addressed. Our findings further suggest that the role of the hermetic bags is more important to food safety than to economic returns, consistent with previous findings in the region (such as Omotilewa et al., 2018, in Uganda).[11] These results therefore indicate the need for multidisciplinary analysis on the health effects of fumigant use in Ethiopia.

AUTHOR CONTRIBUTIONS

Betelhem M. Negede: Conceptualization, methodology, investigation, data curation, formal analysis, writing—original draft. Hugo de Groote: Funding acquisition, conceptualization, design, methodology, investigation, writing—review and editing. Bart Minten: Conceptualization, methodology, investigation, writing—review and editing. Maarten Voors: Conceptualization, methodology, investigation, writing—review and editing.

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[10]The sample from our study has an average maize area of 1.2 ha and a production of 4446 kg of maize, which is significantly more than the 0.5 ha and 928 kg of maize from the smallholder farmers in their sample who are comparatively poorer.

[11]This further explains why farmers aerate their maize grains before consumption and not the ones they sell to the market. This is 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 volatilised easily.

CONFLICT OF INTEREST STATEMENT

The authors declare no competing interests. The authors did not receive financial or non-financial benefits from donors or any other partners related to any of the interventions presented here.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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