Does access to improved grain storage technology increase farmers' welfare? Evidence from a randomized trial in Ethiopia

PHOTO: Betelhem M. Negede | Gida Ayana district, East Wollega zone.

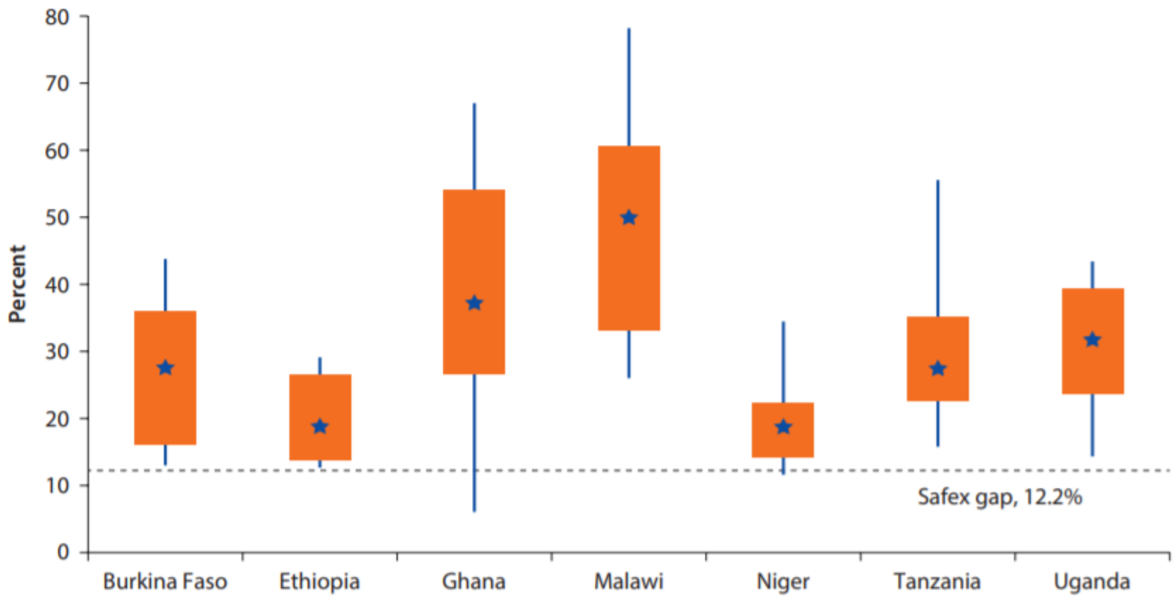
KEY MESSAGES

- Ethiopian maize farmers were provided with hermetic storage bags and training as part of an RCT. Intervention allowed for a small increase of the storage period of maize intended for sale, by 14 days.
- Maize prices in the lean season are up to 36% higher than maize prices after harvesting.
- Storage losses in the study area were lower than commonly thought (2% of total maize harvested) due to the widespread use of Aluminum Phosphide—a cheap, but harmful storage pesticide. It is widely adopted and accepted by farmers hindering investment in quality enhancing technologies and weakening food safety.
- Development agencies and policy makers had implicitly worked with the wrong counterfactual, over-estimating the potential gains from hermetic bags.
- There is a need to reinforce pesticide governance in Ethiopia. Despite having policies on pesticide registration, distribution and use, enforcement of the laws at local levels should be strengthened coupled with training on the proper use and side effects of pesticides to farmers.

INTRODUCTION

African seasonal price variability for cereals is two to three times higher than price variability on the international reference market (Figure 1). 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.

Figure 1. Maize Price Seasonal Gaps in Africa.



Source: Gilbert, Christiaensen, and Kaminski 2017. Note: End points of the vertical lines indicate the maximum and minimum; the endpoints of the boxes, the 80 and 20 percentiles; and the stars, the median seasonal price gap across the different markets within each country.

OBJECTIVES

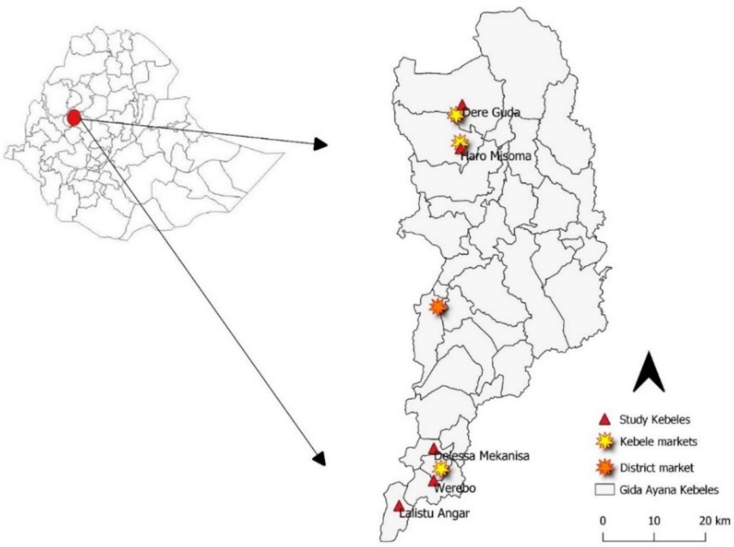
We focus on Ethiopia, which is poorly integrated in international markets and has high spatial and temporal price variations[1]. While there is a growing literature on the size and determinants of PHL in cereals, there is limited evidence on the effectiveness of innovations aiming to reduce losses during storage. This is the first study in Ethiopia to explore the role of improved storage technologies in enabling farmers to move maize grains from times of low prices to times of high prices, in a major maize-growing district in the South-Western part of Ethiopia. The aim of this paper is therefore to assess the impacts of an intervention providing farmers access to both training and improved storage technology, on the farm level welfare outcomes of adopters.

[1] World Bank. (2018). CEREAL MARKET PERFORMANCE IN ETHIOPIA: Policy Implications for Improving Investments in Maize and Wheat Value Chains.

METHODOLOGY

A randomized controlled trial (RCT)[2] was implemented among 871 maize farmers (435 treatment and 436 control) in Gida Ayana, a *woreda* (district) in Western Ethiopia, (Figure 2). Within the *woreda (districts)*, five neighboring *kebeles* (sub-districts) were selected. The choice of the region is mainly motivated by the fact that it is the major maize growing area, with a diverse agroecological conditions (mainly hot and humid). [3]Dire Guda and Haro Misoma are lowland villages, where temperatures are much higher than in the highlands, and with a higher rainfall variability. Lalistu Anger, Werebo and Delessa, on the other hand, are located in the highlands, and are much drier. All five villages have one maize season per year, and maize is the main staple food. For the baseline, 871 farmers were selected and visited, and we were able to re-interview 854 farmers (426 farmers from the control and 428 from the treatment groups) at the endline. 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.

Figure 2. Map of study sites and markets.



Note: Author's own mapping.

INTERVENTION

The intervention consisted of providing three hermetic bags (with a capacity of 100 kg of maize each) free of charge, along with a poster-based training on their proper use (Figure 3). The hermetic bags used in this study are called Purdue Improved Crop Storage (PICS) bags. They consist of a three layer hermetic bag, with one outside layer of woven polypropylene and two inner layers of polyethylene, which make the bag hermetic. Inside the bags, oxygen is depleted through natural processes which suffocates insect pests. The bags are thus a way to store grains effectively without the use of storage pesticides[4].The training was provided by Shayashone PLC,

[2] For more information about the pre-analysis plan: https://www.socialscienceregistry.org/trials/2635

[3] We were based on IFPRI's report on *Farmers' grain storage and losses in Ethiopia (2018)* for the choice of the study area.

[4] De Groote, H., Kimenju, S. C., Likhayo, P., Kanampiu, F., Tefera, T., & Hellin, J. (2013). Effectiveness of hermetic systems in controlling maize storage pests in Kenya. *Journal of Stored Products Research*, *53*, 27–36.

the sole distributor of PICS bags in Ethiopia. The training sessions were held at the homestead of each treatment farmer household. The hermetic storage bags were provided after the baseline household survey.

Figure 3. 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 adapted from (Omotilewa et al., 2018), show a hermetic bag of 100 kg indicating its hermetic features.

RESULTS

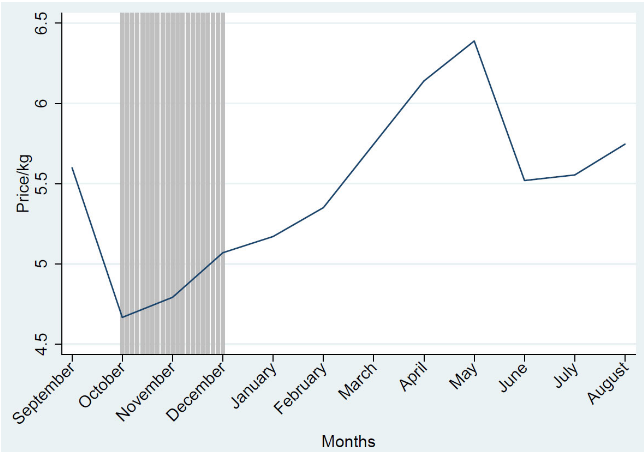
The most common storage container is the polypropylene bag, used by almost 75% of the respondents, due to its availability and affordability. The traditional granary is the second most popular storage facility, used by 22% of the respondents. Other storage facilities are rare, they include in-house storage (1%), community storage facility (1%), and improved granary (1%).

Inter-temporal price seasonality, leads to a 36% increase in maize prices (ETB 170/100kg). 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 (

https://doi.org/10.1016/J.JSPR.2013.01.001

Figure 4). 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.

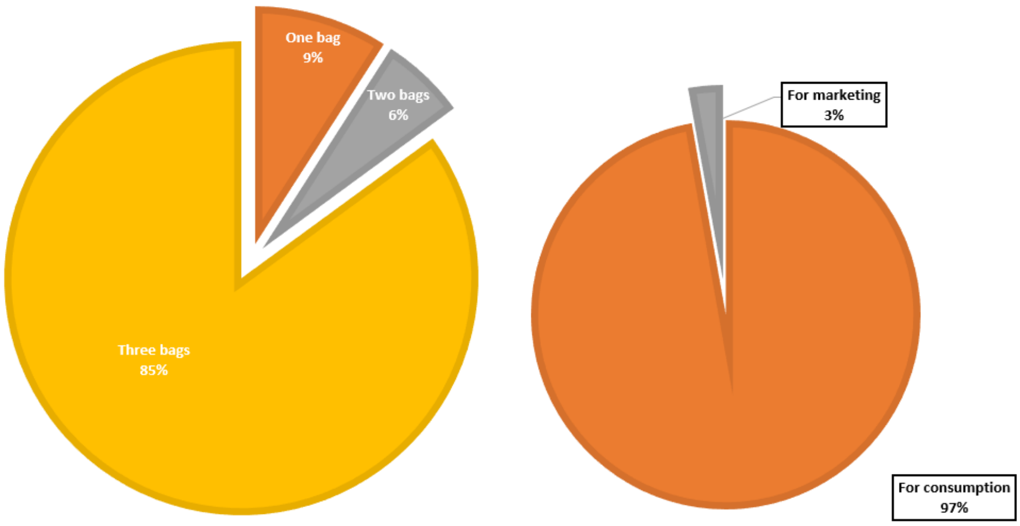
Figure 4. Seasonality of maize price in 2018.



Note: Authors' computation based on farmers' self-reported monthly maize prices using midline survey dataset (2019). N=854.

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 (Figure 5Fout! Verwijzingsbron niet gevonden.). 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 adopted a safety-first approach. This might suggest that the role of the hermetic bags is more relevant to farmers for food safety rather than economic returns.

Figure 5. Adoption and purpose of hermetic bags.



Note: Authors' computation using baseline survey dataset (2017/18). N=870.

Access to hermetic bags and training increased few welfare outcomes. All treatment effects are small and not statistically significant (Table 1), except for the length of storage for maize farmers intend to sell (column 5). Treatment

	Outcome variables						
	(1) Maize yield (kg/ha)	(2) Percentage of maize stored (%)	(3) Percentage of maize loss (%)	(4) Length of storage for consumption (days)	(5) Length of storage for sale (days)	(6) Total maize income (ETB)	(7) HFIAS score
Treatment effect	144.7 (89.91)	0.179 (1.209)	-0.0135 (0.0255)	-4.495 (6.664)	13.29** (6.014)	161.7 (837.7)	0.0297 (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 Dependent Variable (DV)	3861.31	24.43	0.12	272.75	101.98	16296.6	0.82
Standard Deviation (SD) DV	1484.98	18.44	0.38	102.52	95.83	14488.06	1.93

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 (2%). In addition, three hermetic bags can only store a fairly small quantity of harvested maize (below 10%). Taken together, it seems the intervention did not change a binding constraint for farmers to benefit from price arbitrage.

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Table 1. Hermetic bags impact on welfare

Note: Data is from baseline (2017/18) and midline (2019) surveys. We estimated 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 **Fout! Verwijzingsbron niet gevonden.** (e.g. land owned, land under maize, off-farm income and access to microfinance).

Cost evaluation among storage technologies suggests that the major adoption challenge with hermetic bags is the high initial investment cost. 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 2, 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. 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 2. 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).

CONCLUSIONS

Farmers who received three hermetic bags for free, a capacity of about 10% of their total maize harvest, increased the average time they store maize before selling by 14 days (from average of 104 days). This arbitrage gain is relatively small and this result is consistent with our finding that the effect of hermetic bags on maize income is negligible.

There are several potential explanations for the limited short-term impacts of hermetic bags.

- Low treatment dosage. We provided households three hermetic bags, which allowed 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 only 3.6%. And this is likely too small to be detected.
- In Ethiopia, estimates of post-harvest loss (PHL) vary extensively from 4% [5] to 30% [6]. However, in our study area PHL represents just 2% of annual crop yield. It seems that attention to storage technologies by development agencies and policy makers is based on a faulty assumption, that led to over-estimated potential gains from hermetic bags. 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. This attenuates treatment effects, as the causal effect of hermetic bags requires a counter factual without AP.

WHAT IS ALUMINIUM PHOSPHIDE?

Aluminum phosphide (AP), locally known as “rat poison”, is an inexpensive, but highly toxic fumigant, commonly used for maize grain storage. The fumigant is readily available, sold in a tablet form, and is used for the control of maize weevils and flour beetles in stored maize

[5] Bachewe, F., Minten, B., Taffesse, A. S., Pauw, K., Cameron, A., & Endaylalu, T. G. (2018). Farmers ’ grain storage and losses in Ethiopia, (March).

[6] Food and Agricultural Organization ofthe UnitedNations (FAO). (2018). “National Statistics on Post-Harvest Losses and FoodWaste.” Rome.

(Figure 6). 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 maize farmer, with a yield of 3861, storage costs using AP amount to just ETB 154 (USD 3.8).

Figure 6. 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).

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 dusts [7]. 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. 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. Almost 80% 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. According to government policy, only licensed technicians are authorized to purchase and handle AP[8]. 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.

The uncontrolled application of tablets and lack of proper protective clothing's also increases the exposure of humans and animals in the surrounding areas. 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 (*sub-districts) as well as in the major grain market at the capital city of Ethiopia, Addis Ababa, 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. Also since AP reacts with moisture in the air to produce

[7] Fumigation Handbook, 2020.

[8] USAID. (2013). Phosphine Fumigation of Stored Agricultural Commodity - Programmatic Environmental Assessment, (November), 77.

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.

- Maize losses might have occurred at a different stage of the value chain (during harvest or transport). This implies that future interventions would be better focusing on other stages of the post-harvest process than storage. [9]

POLICY LESSONS

- PHL during storage seems to be less of a concern to maize farmers in Western Ethiopia, at least smaller than is commonly reported in the literature.
- 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 the proper use and side effects of pesticides to the farmers.
- Most studies on hermetic bags in Sub Saharan Africa found that farmers use hermetic bags to store grains for own consumption, rather than for marketing[10]. 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.
- There is a need 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.

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[9] Ambler, K., de Brauw, A., & Godlonton, S. (2018). Measuring postharvest losses at the farm level in Malawi. *Australian Journal of Agricultural and Resource Economics*, *62*(1), 139–160. https://doi.org/10.1111/1467-8489.12237

[10] Kadjo, D., Ricker-gilbert, J., Abdoulaye, T., Shively, G., & Baco, M. N. (2018). Storage losses , liquidity constraints , and maize storage decisions in Benin, *49*, 435–454. Other studies also found similar results in Kenya (Channa & Ricker-Gilbert, 2018), and in Uganda (Omotilewa et al., 2018). However, the use of AP by farmers and small traders is not common in these East African countries. They use Actellic Dust (insecticide); AP is rather used by large traders and millers.

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CIMMYT
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