Hermetic bag for the storage of maize: Economic perspective in different Sub-Saharan African countries, food security and greenhouse gas emissions

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CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)

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Abstract

During storage, cereals and legumes are vulnerable to insects, rodents and fungi which can cause toxins formation, discoloration, damage and/or weight loss of the product. Hermetic bags prevent excessive insect infestation. The effects of hermetic bags for the storage of maize on food loss reduction and its effect on net greenhouse gas (GHG) emissions are assessed from field trials. The economic effects are analysed in different Sub-Saharan Africa countries. In data used from field trial typically, beyond 100 days significant losses occur with standard storage whereas with hermetic bags product losses are kept to a minimum. From an economic point of view the situation is more complex; interventions effectiveness depends mainly on the seasonal price fluctuation of the commodity. For own consumption, when the quality is less important, the use of hermetic bags is only more economical compared to other ways of storage after 100 days. As the quality of maize is well preserved by the hermetic bag, the return on the investment is faster when the maize is sold at the market. However, for countries with a low seasonal price gap the investment cannot be earned back.

Keywords

Food security; Losses; Hermetic bags; Economic analysis; Maize

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Contents

1. Introduction

Post-harvest losses (PHL) of dry food crops are a large problem in the Sub-Saharan region, especially for smallholder farmers. Globally, more than 500 million smallholder farmers grow crops on less than 10 hectares of land, with most of them located in developing countries [1]. Most of the crop (80%) in Sub-Saharan Africa is produced by smallholders. Post-harvest losses by smallholder farmers can be divided in three categories: in the field, during processing, and during storage [2]. During storage insects infestation is an important cause for losses in developing countries [3], [4]. For instance, 11% of maize is lost due to weevil infestation [5] in Ghana, which is almost half of the total post-harvest loss reported. In Kenia comparable results for maize losses due to insects were found [6].

To reduce the PHL from insects, farmers can use insecticides and/or improve their storage facilities at the farm. One possibility is the introduction of hermetic storage facilities, such as metal silos, plastic drums or plastic bags. Hermetic bags require relatively low capital investment, suiting to smallholder farmers capabilities.

We analyse whether introducing this type of interventions fits in a strategy of reducing food loose and GHG emissions and have in the same time a positive influence on the farmers income. This paper analyses net effectiveness of the interventions based on realistic estimates of the bag's performance. The results of different field trials for maize are used to estimate benefits of the hermetic bag during storage on, food security GHG emissions and economic perspective in different Sub-Saharan countries.

2. Background

Weevils, grain borer, red flour beetle and moths are common infestation insects [7], of which the larger grain borer (LGB) has an increasing impact on PHL. The first outbreak in African countries was in the 1970s and resulting losses are increasing since then. Weight reduction of 34%, with 80% of the grain damaged by the LGB are reported [8].

The problem is more complex if the crop is planted or stored nearby old granaries, which is the case with most of Africa's smallholder farmers. The infestation can easily move to and from storage sites. Moreover, using the same bins year after year without proper hygiene measures, provides a continuous chain of infestation. Insects can hibernate or even continue to feed on wooden structures of the store or hide between holes and cracks in the walls. They can then re-infest the new crop in the same store and resume feeding [9].

The mechanism for reduction of storage loss with a hermetic storage system is reducing the oxygen and increasing the carbon dioxide levels inside the system. This controls the activity and the number of life insects in the product. A part of the oxygen reduction is caused by the oxygen use of the insect themselves [10], [11]. However, during the low-oxygen-level steady state period of the storage, where insects are inactive, other oxidation processes have to be in equilibrium with the oxygen supply through the package material or through small holes in the liners [12-16].

For smallholder farmers hermetic bags are the simplest low-cost way to make a hermitic storage facility. A few different types of bag are tested in the field, like the Supergrainbag (GrainPro Inc. of Concord, Massachusetts, USA) and the Purdue Improved Crop Storage (PICS) bags [17]. The latter is introduced on large scale, promoted and supported by the Bill Gates foundation. Although the Supergrainbags have a higher barrier for oxygen, the resulting oxygen levels for both systems are comparable as well as the insect infestation reduction performance during storage [18]. According to Baoua [18] PICS bags have the advantage of lower cost, wider accessibility, and greater durability. Therefore, the PICS bags can be used for multiple seasons, effectively lowering their cost per unit stored substantially. A PICS bag consists of three layers: two liners of 80um high density polyethylene plastic (HDPE) fitted inside a woven sack. The two liners form the barrier for oxygen and moisture between the bag and the environment. A third woven PP bag provides the mechanical strength. Besides the reduction of insect activity the hermetic bags can also reduce the growth of fungi and production of aflatoxin especially when the grain is not completely dry at the start of the storage period [19] [20]. The working mechanism is the same reduction of oxygen in the sealed bag. Fungi respiration in maize with 18% or 20% moisture can reduce the oxygen level to almost zero within an hour.

For comparison with the hermetic bags, standard woven bags of polypropylene (PP) are taken with and without the use of insecticides. Insecticides appear less effective than using appropriate bags [21]. However, they are commonly used despite the health risks they are introducing [22].

3. Methods and data

Three situations are compared: storage in standard bags, storage in standard bags with a pesticide and storage in hermetic bags. The following system configuration and parameters are used. The product is maize, with attributed GHG emissivity of 1.56 kg CO_2-equivalent per kg harvested maize of the primary production in Sub-Saharan Africa [23]. Transport is neglected, since production for local markets is assumed. Energy use for drying is neglected, use of sun-drying is assumed when needed. Product losses during the drying period are not taken into account. In case product losses would occur, in this stage, they are equal for the three scenarios. Bags have a capacity of 90 kilogram, have dimensions 1370x700 mm, and can be used for 3 years/cycles. Standard bags and the outer layer of PICS bags are made of one layer of PP of 100 μm thickness, with 919 kg/m^3 density. The PICS bags inner layers are two layers of HDPE of 80 μm thickness, with 955 kg/m^3 density. The pesticide is Actellic 50CE, dosed at 8 ml/MT. GHG emissions related to the pesticide production are estimated at 9 kg CO_2-eq. per kg Actellic 50CE [24].

Data from five different field studies of the storage of maize in Sub-Saharan Africa are used to determine the PHL, quality and economic value of the maize during storage (Table 1).

In the economic evaluation two scenarios are calculated: home use and selling at the local market. The value of the maize at the beginning of storage is calculated as the market price at the harvest period with addition of the costs for the storage system. This is referred to as "In-house value" in $/kg. During storage quality loss occurs, this changes the calculated In-house value. For home use the weight loss in time is increasing the In-house value as the number of kilograms is decreasing. For home use it is interesting for farmers to use their own stored maize as long as the In-house value is lower than the market price. For this scenario it is assumed that the farmers have to buy good quality maize, whereas its own maize can be of lower quality. In the second scenario the maize is sold at a local market. For this scenario not only the weight loss is taken into account but also the penalties on the market price due to percentage of damaged grains in the offered grains. For the weight loss the weighted data of the studies from Table 1 are taken and aggregated into different storage periods. To determine the quality loss the amount of damaged grains with the standard deviation of every point is used. Assuming a normal deviation of the data points the exceedance chances of 10% and 20% damaged grains are calculated. All the chances of exceedance are added in a weighted form to come to an average amount of exceedance in a certain period. The penalties belonging to 10% and 20% damaged grains are combined with the exceedances and the market price at that period to obtain an average sales price. The farmer can expect profit if the average sales price is higher than the In-house price.

The effect of the PHL on the GHG emissions is determined with the use of the Agro-Chain Greenhouse Gas Emissions calculator, or ACGE calculator [25]. Next to the GHG emissions of the primary production and the storage solutions the PHL as resulting from the studies of Table 1 are used as inputs. The resulting GHG emissions in CO_2-eq. are outcomes of the ACGE calculator.

4. Results and discussion

PHL effect on food security

For realistic estimation, data for the actual PHL reduction, only practical field trials were taken whereby the bags are used in normal circumstances. Studies on the effect of hermetic bags on the insects infestation at laboratory settings are excluded. Although these studies, like from Affognon [26], gives exact results on the possible PHL reduction in the concerning circumstances and types of infections it will not give the losses expected when the grain has only a natural infestation. For maize a number of studies has been published based on a practical approach to be able to give a good estimation of the PHL reduction with hermetic bags.

In the published trials the weight loss measurements are mostly done indirectly since weighting the whole stored grain is impossible due to sampling and use of the stored grains for consumption. Therefore, to calculate the weight loss mostly indirect methods are used like: bulk density method, count and weight, conversion method and 100 gram weight [27], [28], [29].

When only the amount of damaged grain was measured the studies were excluded from the weight loss calculation. Weight loss cannot be estimated from the percentage damaged grain as the ratio between weight loss and percentage weight loss is not uniform [27]. It varies amongst type and variety of the grain, insect species and applied storage time as can be derived from the data from Jat et al. [30].

We have derived average effects of hermetic bags and use of insecticides on post-harvest loss reduction. Studies used for the estimation of PHL during field trials of stored maize grain were from Likhayo et al. [31], Ndegwa et al. [32], Mlambo et al. [33], Ng'ang'a et al. [34] and Baoua et al. [35]. Table 1 shows some characteristics of these studies.

Table 1 Studies used for the estimation of PHL during field trials of stored maize grain in sub-Saharan Africa countries.

Reference	Country	Weight loss method	Storage time (days)	Number of households
Baoua et al. 2014 [35]	Ghana, Benin, Burkina Faso	100 grain weight	0-198	12*
Likhayo et al. 2016 [31]	Kenya	count & weight	90-270	32
Mlambo et al. 2017 [33]	Zimbabwe	count & weight	0-224	4
Ndegwa et al. 2016 [32]	Kenya	count & weight	0-122	540
Ng'ang'a et al. 2016 [34]	Kenya	count & weight	0-245	33

*maize obtained from local markets, others obtained directly from the field

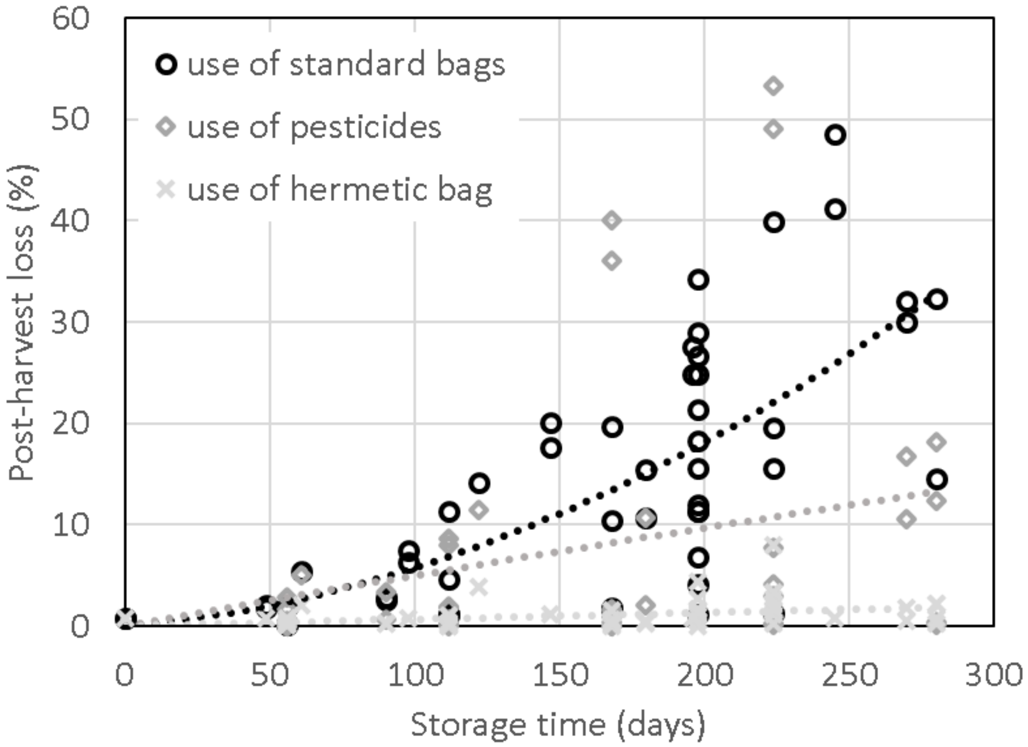


Figure 1. Post-harvest weight loss in % through insects in different storage scenarios (standard bags (circles), standard bags combined with pesticide (diamonds) and hermetic bags (crosses)) in field trials of maize storage, based on data from various literature sources [31-35]. The point are averages from different number of samples. The regression line is corrected for the underlying number of samples of the points.

The recorded weight losses show a very large scattering. Especially the values with the use of pesticides, where in some cases higher weight losses are recorded compared to untreated maize at the same storage times. This is not uncommon and reported also by other authors [36], [12]: a part of the farmers used pesticides because their product shows clear infestations trying to save their harvest. Despite this effort often a high recorded weight loss for the pesticide treated maize resulted which was originally designated to the reference maize storage. These numbers, however, were not removed from the data as this is common practice. Through hermetic technology losses of grain are significantly reduced, ensuring increased available of food-grade grain throughout the year.

Best-fit curves in Figure 1 show that hermetic bags can help to reduce losses by insects to almost zero. In the reference situation (with polypropylene (PP) woven bags) the average loss on small farmer storage at the end of the storage season rises to 30%. The use of pesticide is also on average beneficial especially at longer storage times, however the results of the individual measurements are very scattered.

PHL effect on GHG emissions analysis

The effect of using any measure on GHG emissions requires taking into account two aspects. Firstly, any GHG emissions related to the production of the bags or the pesticide must be taken into account as increasing the GHG emissions associated with the commodity. In the case of the hermetic bags the PICS bags are taken for GHG calculations. The two HDPE liners of the PICS bag will increase the GHG emission compared with a traditional woven polypropylene bag. Secondly, the PHL must be taken into account as it increase the GHG emissions/kg maize. The impact on GHG emissions is calculated for three scenarios: storage in standard bags, storage in hermetic bags, or in-bag treatment with a pesticide in combination with storage in standard bags. Table 2 gives the GHG emissions for the packaging system in the three scenarios. The impact of packaging system is less than 0.1% compared to the impact of the primary production.

Table 2 GHG emissions for packaging for the different scenarios (kg CO_2-eq. emissions per kg food-grade maize)

	Weight PP [g/bag]	Weight HDPE [g/bag]	Pesticide [g/bag]	CO2 impact pesticide		CO2 impact packaging	
				[g/bag]	[g/kg maize]	[g/bag]	[g/kg maize]
Standard bag	176					176	1
Pesticide	176		0.8	7	0.08	176	1
PICS bag	176	293				469	2

The GHG emissions are calculated for the whole lifespan and full capacity of the bag, using the storage loss fits given in Figure 1. Results of GHG emission analysis for the reference case (storage in standard bags) and the interventions are shown in Figure 2. The emissions related to PICS bags production are significantly smaller than the impacts related to product losses. Thus, the PICS bags contribute to net reduction of GHG emissions per unit maize marketed for consumption after storage times of 30 days and longer.

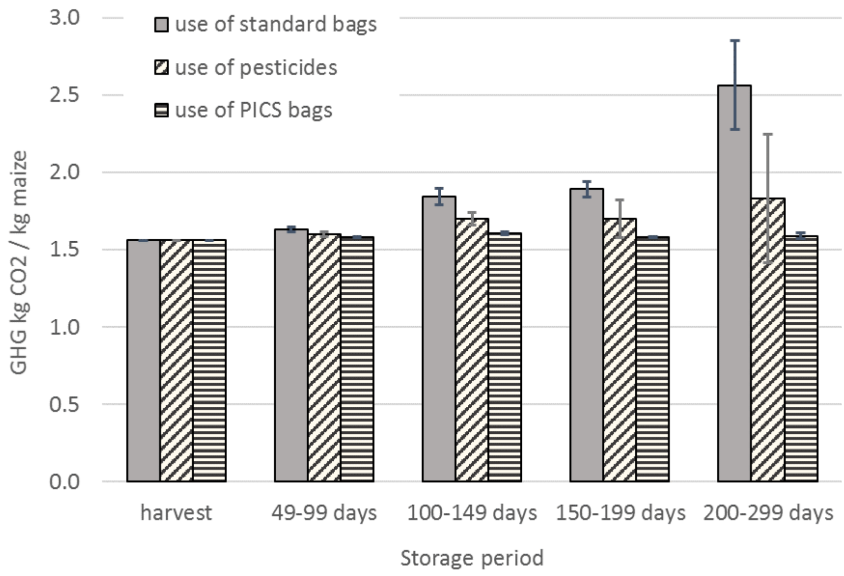


Figure 2. Specification of calculated GHG emissions along the supply chain for the scenarios in time (kg CO_2-eq. emissions per kg food-grade maize). Error bars represent 95% confidence limits.

Economic effect on costs and benefits

Interventions are only feasible in case of a positive business case in which the required investments balance the economic benefit of the interventions. In Sub Saharan Africa smallholder farmers produce a median of 730 kg maize/farm. 49% of the smallholder farmers sells their maize, and a total 23% of all maize is sold. [37]. Beside a direct need for cash, the risk of an economic devaluation during time can be a large driver for the farmer to sell their product directly after harvest. Often at this moment, the price is much lower compared to later in the season when the product supply is lower. So for a farmer it is interesting to know if he can benefit economical by storing his grain and the best way for this to make the highest profit on the market or reducing the cost for home consumption.

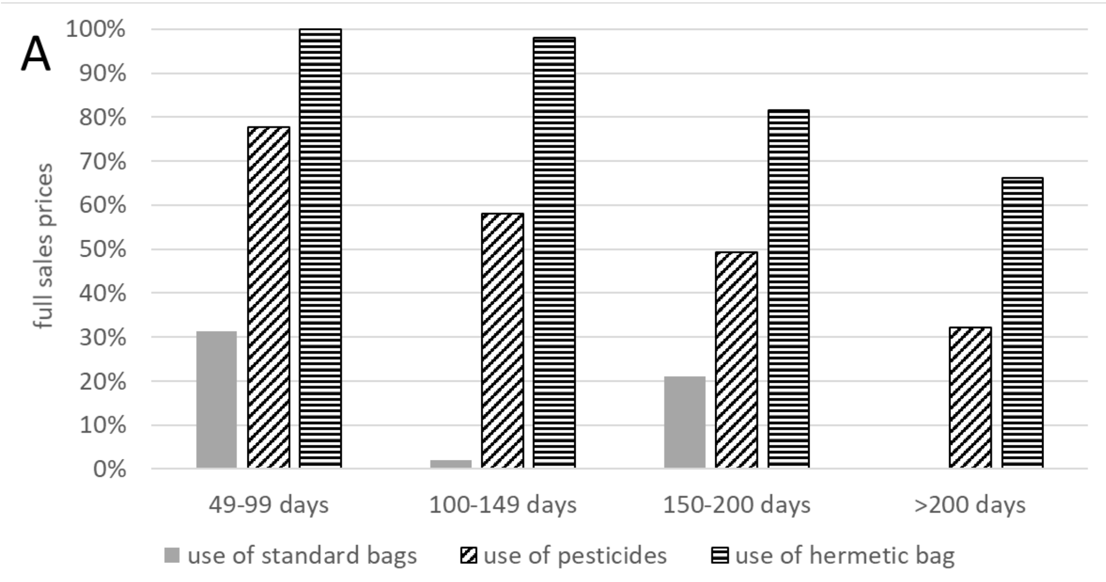
In the economic calculation of the interventions in this study are both home use and the sales situation considered. These calculations consist of three parts: the direct loss of economic value by the actual weight loss of maize (see Figure 1), the effect of revenue losses due to quality reduction and the price fluctuation during the year.

Quality of the grain

In formal trade, national or regional authorities or trading organizations dictate quality grades. Batches with defect percentages above predefined thresholds will be rejected or discounted, resulting in large economic and product loss. Jones *et al.* concluded that beans with levels of 5–10% insect damage can generally be sold with a moderate discount, whereas beans with over 20% insect damage are largely unmarketable [38]. Rejected batches may still be used for own consumption or animal feed. For the calculation the poor-quality class Maize has a lower price, and maize categorized as unmarketable for human consumption a further reduction to animal feed price is used.

From the studies of table 1 all the separated measurements of the maize samples are graded with a quality classification system based on the fraction of damaged grains: good product (<10% damage), poor quality product (10-20% damage) and unmarketable for human consumption product (>20% damage).

The ratios between good, poor and unmarketable maize varies during the storage period and depends on the used packaging system. Based on the qualities ratios inside the bags it can be determined to what extend the full sales price can be gained. Figure 3 shows that use of pesticides or hermetic bags leads to much higher market value due to lowered amount of damaged grains. In case of storage shorter than 5 months use of the hermetic bag yields close to zero damaging resulting in full economic benefits from the maize sales. After 7 months still for more than 60% of the volume the full market price applies. Use of the pesticide also has a clear economic benefit compared to use of the standard bags, with a close to 80% good product share for maize stored up to 3 months. In comparison to the hermetic bags a faster decline in economic value of pesticide treated maize is observed for intermediate storage periods of 3-6 months. A striking reduction in market value is observed for use of the standard bags during the first 150 days of storage, with less than 5% of the volume of good quality, and more than 90% of unmarketable quality. The slightly improvement of the quality between 150-200 days is due to a number of good quality samples in this period of the paper from Baoua *et al.* [35]. Which was explained by low infestation rate and very dry product. Storage in standard bags for more than 200 days leads to so much damaged grains that all maize is of unmarketable quality. Hence, it is clear that already at short storage times the hermetic bags, and to a lesser extent use of pesticides, have clear benefits for the maize quality and thereby the maize value on the market.



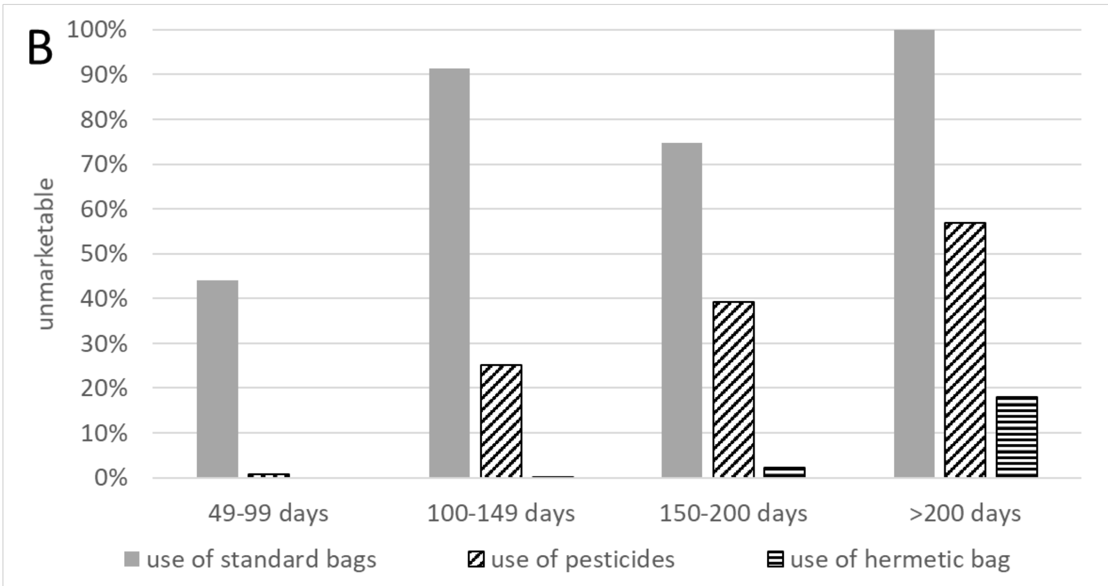


Figure 3. Post-harvest maize quality based on the amount of damaged grains by insects during different storage scenarios. Based on field data from Mlambo, et al., Ng'ang'a et al., and Baoua et al. [33] [34] [35]. A: % of full sales price when damaged grains level is less than 10%. B: % Unmarketable for human consumption, more than 20% damaged grains.

Seasonal price fluctuation

Keeping the Maize quality high and the losses low by using hermetic bags by the farmers are able to store their crop at harvest time when prices are low, and can wait to sell the maize until market prices are higher [39]. And even when the maize is used solely for home consumption the can avoid high market prices at the end of the storage season. The difference in the market price is called the seasonal gap and is the mean driving force to store grains. A high seasonal gap makes storage more profitable. This seasonal gap, however, differs for every country [40], [41].

For the economic cost and benefit analysis three different situations that exist in Africa are evaluated, represented by Uganda, Malawi and Zambia. Malawi has a high seasonal gap, Uganda harvests twice a year with a moderate seasonal gap, and Zambia has a small variation of the price during the year. The typical price fluctuations in the three countries are given in Figure 4.

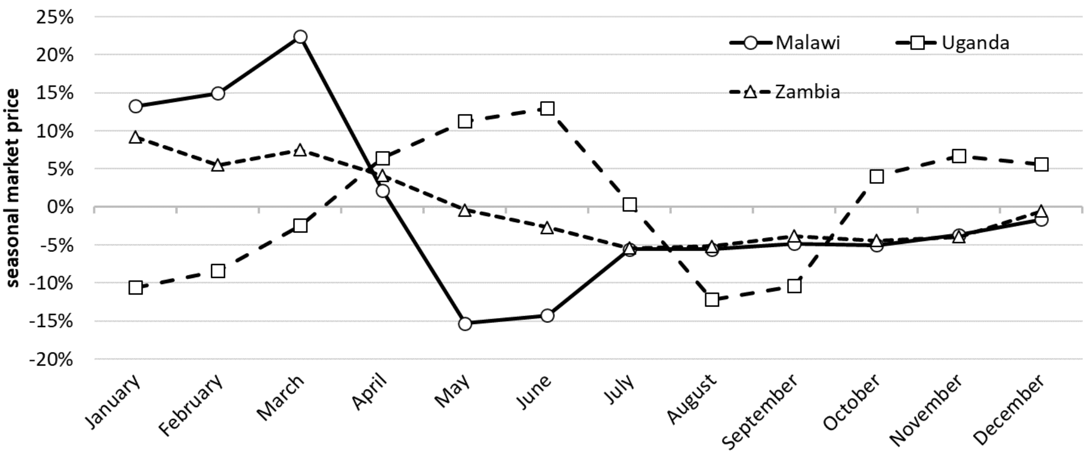


Figure 4. Season price fluctuation of maize, discount (negative values) or surplus in % on the average year price (30 $c/kg Maize) in different countries, data from [40] [41]

Profit for the farmers

To estimate the economic benefits of the different storage ways for the farmers an in-house price is calculated during the season. The in-house price starts with the market price during the harvest period (Malawi, Zambia: May, Uganda: January and August). So not the cost price of the farmer as we want to look at the effect of the storage on the profit of the farmer. To this market price the cost for storage are added from Table 3: depreciation of the bag and pesticides costs. Assumed that the bags are used ones per year and the cost of pesticides are made directly after the harvest and are independent on the storage time. This result in an in-house price of the maize at the start of the storage. During the storage some of the maize is loss as shown in (figure 1). This loss result in an increase of the in-house price. When a 50%

weight loss is recorded at a specific storage period, the in-house price will be twice the price as in the beginning of the season. The resulting of the in-house prices per kilogram maize during storage for the three countries and the different storage methods are presented in Table 4, together with the market price of the same period. Independent of the country the in-house price of maize stored in a standard bag start lower as for the other storage systems, however increases every storage periods. The hermetic bag start higher but the price is stable through the whole storage period. Also the use of pesticides show some benefits compared to the standard bag from a period more than 150 days.

When the market price is higher as the in-house price in the same period it will be cheaper for the farmer to use their own maize instead of buying maize on the market to feed the family.

In Table 5 the savings for a farmer are calculated using his own harvest. In this calculation the quality loss in not taken into account and the maize, the farmer has to purchase for replace his own maize, is only available at good quality. This table shows that it is not so evident that hermetic bags are beneficial at all storage times. Compared with normal bags, hermetic bags have only lower cost prices after 100 days. For storage times till 3 months a normal bag seems preferable. In the case of Zambia better not store the maize at all. Only for long storage times with the hermetic bag you can expect a little lower In-house price than the market price in this country.

Table 3 Parameters used to calculate In-house price during storage

	Value	Unit	Reference
base price maize	0.30	$/kg	[41]
bag size	90	kg	
discount 10-20% damaged	8	%	[38]
discount >20% damaged	16	%	
PP woven bag 90 kg	0.47	$/90 kg	[32]
pesticide cost	0.70	$/90 kg	
PICS bag 90 kg	3.37	$/90 kg	
life time PP woven bag	3	Year	
life time PICS bag	3	Year	

Table 4 Calculated In-house price/kg maize during different types of storage and in different African countries. Bold numbers: average cost price is lower as the market price at that period. Storage and use of grain for own consumption is profitable. Green cells: Lowest In-house price for that storage time and country

storage period (days)	Uganda				Malawi				Zambia			
	market price [$c/kg]	price stored grain [$c/kg]			market price [$c/kg]	price stored grain [$c/kg]			market price [$c/kg]	price stored grain [$c/kg]		
		standard bags	pesticides	hermetic bag		standard bags	pesticides	hermetic bag		standard bags	pesticides	hermetic bag
harvest	27	27	28	28	26	26	26	27	30	30	31	31
49-99	29	**28**	29	**28**	28	**26**	**27**	**27**	28	31	32	31
100-149	33	**29**	**30**	**28**	29	**28**	**28**	**27**	29	32	33	31
150-199	30	32	**30**	**28**	29	30	**29**	**27**	29	35	34	31
200-299	27	35	31	28	34	34	**30**	**27**	33	39	35	**31**

Table 5 Calculated savings for the farmer of consuming their own maize instead purchase the maize on the market during storage with different types of storage methods and in different African countries with a lifespan of the bags of three years. Positive number: Storage and use of grain for own consumption is profitable. Green cells: Best choice for that storage time and country.

storage period (days)	Uganda			Malawi			Zambia		
	profit use own grain [$c/kg]			profit use own grain [$c/kg]			profit use own grain [$c/kg]		
	standard bags	pesticides	hermetic bag	standard bags	pesticides	hermetic bag	standard bags	pesticides	hermetic bag
harvest	0	-1	-1	0	-1	-1	0	-1	-1
49-99	2	1	1	2	1	1	-3	-3	-3
100-149	4	4	5	1	0	2	-4	-4	-2
150-199	-2	0	2	-1	0	2	-6	-5	-3
200-299	-8	-4	-1	0	4	7	-7	-2	1

If the farmer decide to sale his Maize in a certain period the quality of the maize will becomes relevant for the profit as poorer quality maize result in lower sales prices. In Table 6 these discounts are taken into account and show the extra profit (or lose) the farmer can make by the storage of the maize selling it in a certain period.

If the farmer, in Uganda or Malawi, wants to commercialize his maize, use of the hermetic bags is the best way to make a profit. Large margins can be made when the market value is on the highest point. The reduction of quality loss in the hermetic bags makes this type of storage already profitable at sales from two months in Uganda and Malawi. For a farmer in Zambia it does not seems interesting at all to store his maize in any way due to the low seasonal gap.

When storing Maize in a standard bag it is not likely that the farmer can make more profit by waiting until higher market prices. The use of pesticides can result in a higher profit if the storage time kept below 150 days in Uganda or below 100 days in Malawi.

Table 6 Calculated profit for the farmer of selling their maize during storage with different types of storage methods and in different African countries with a lifespan of the bags of three years. Positive number: selling at this point is profitable. Green cells: Best choice for that storage time and country.

storage period (days)	Uganda			Malawi			Zambia		
	profit at sales [$c/kg]			profit at sales [$c/kg]			profit at sales [$c/kg]		
	standard bags	pesti cides	hermetic bag	standard bags	pesti cides	hermetic bag	standard bags	pesti cides	hermetic bag
harvest	0	-1	-1	0	-1	-1	0	-1	-1
49-99	0	**1**	**2**	0	**1**	**2**	-4	-3	-2
100-149	0	**2**	**6**	-3	-1	**2**	-7	-4	-2
150-199	-4	-2	**2**	-3	-1	**2**	-8	-6	-2
200-299	-9	-6	-2	-4	**1**	**6**	-8	-4	**1**

The investment costs in hermetic bags are still quite high, see Table 3. Combined with the high variation in quality and weight loss the investment in hermetic bags will not be every year profitable. The cash flow of the farmer as well as his experience with the amount of loss during traditional storage will probably be decisive for his willingness to invest in hermetic bags.

This becomes even more relevant if the lifespan of the bags is reduced from three years to one year. After one harvest the hermetic bags showed already some holes in the liners, mostly made by the insects [12], [35]. Although the hermetic bags are still functional with a small number of holes in the liner, the bag will be more vulnerable for disruptions, thereby losing its efficiency, in time. None of the used studies has used the bags more than two times, therefore the lifespan is not exactly known. At the other hand, maize is a relative cheap product. Using hermetic bags for more expensive crops, as cowpeas, can make hermetic bags either for own use ore sales more profitable as now calculated for maize.

5. Conclusions

From the perspectives of food security and greenhouse gas emissions the intervention of hermetic bags to store maize in Sub-Saharan Africa works out positively compared to use of standard bags or use of standard bags combined with a pesticide. In the period of 100-149 days of storages this becomes visible as then the average weight loss from the standard bag was above 15% where the hermetic bag kept this value below 3%.

For the quality of the maize the difference becomes already significant at short storage times. At a storage period of 49-99 days the quality of the standard bag was reduced to 44% unmarketable maize and only 31% would be able to be sold at the full market price, were maize stored in the hermetic bags did not show any reduction of quality for that period.

The net economic effect depends on storage time, seasonal price variations, weight loss and quality. Seasonal price variability differs a lot amongst African countries affecting the result largely. When the maize is used for own consumption standard bags are the best choice until 100-149 days, hermetic bag becomes preferable at longer storage times.

For storage to sale the maize later in the season is the quality of the maize beside the weight loss, also important. As hermetic bags maintaining the maize quality during storage very well, are these bags most suitable for this. In a countries with high or moderate seasonal price fluctuation, hermetic bags can be profitable already after 50 day of storage.

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