academicJournals

Vol. 7(6), pp. 222-230, June, 2015
DOI: 10.5897/JDAE2015.0648
Article Number: 707C82C53052
ISSN 2006-9774
Copyright©2015
Author(s) retain the copyright of this article
http://www.academicjournals.org/JDAE

Journal of Development and Agricultural Economics

Full Length Research Paper

Metal silo grain storage technology and household food security in Kenya

Zachary Gitonga, Hugo De Groote and Tadele Tefera*

International Maize and Wheat Improvement Center (CIMMYT), ICRAF House, UN Avenue, Gigiri, P. O. Box 1041, 00621 Village Market, Nairobi, Kenya.

Received 21 March, 2015; Accepted 12 May, 2015

A treatment effect and ordered logit models were used to evaluate the impact of metal silo storage technology on household food security and factors influencing adoption of metal silo. Farmers' perception of the effectiveness of metal silo against larger grain borer and maize weevil was also analyzed. The most important factor households considered when choosing a storage facility was effectiveness against storage pests followed by security of the stored grain and durability of the storage facility. Metal silo adopters had 1.8 months more of adequate food provisioning than non-adopters. Compared to non-adopting households, metal silo adopters only sold a little portion of their maize initially to meet immediate cash needs and kept the bulk of it until the fifth month after harvest. Consumption was stable throughout the year for the metal silo adopters. Non-adopters sold most of their maize immediately after harvest and consumption was higher than sales. Household size, literacy of the household head and land size increased the likelihood of adopting the metal silo technology. Households with access to financial services (bank account and/or mobile money) were more likely to adopt metal silo. Distance to the nearest passable road reduced odds of adopting metal silo technology. The use of metal silos prevented damage by larger grain borer (LGB) and maize weevil for 98% and 94% of adopters, respectively. This study finds evidence that metal silo technology is effective against main maize storage pests and its adoption can significantly improve food security in rural households.

Key words: Food security, grain storage, metal silo, storage pest.

INTRODUCTION

Two-thirds of the people in eastern and southern Africa (ESA) live in rural areas where they make a living from agriculture, often from degraded and marginal lands, with little opportunity to diversify incomes through additional employment in non-farming activities. Addressing rural poverty and food insecurity is therefore central to any efforts to improve human well-being and livelihoods in the region (http://www.undp.org/mdg/, accessed 30 April, 2011). Cereal grains form a major part of crop production in Africa. One of the key constraints to improving food and nutritional security in Africa, however, is the poor post-harvest management that leads to 20-30% loss of

*Corresponding author. E-mail: t.tefera@cgiar.org tadeletefera@yahoo.com.

Figure 1. Metal silos.

grains, with an estimated monetary value of more than US$ 2 billion annually and can reach US$ 4billion (Zorya et al., 2011). Post-harvest losses remove part of the supply from the market contributing to food price spikes as was experienced between 2008 and 2011 by (Rosegrant et al., 2015). Postharvest losses also cause resource wastage because natural resources, human and physical capital are committed to produce, process, handle and transport food that no one consumes.

Apart from causing grain weight losses, incidence of pest attack of the stored grains is also linked to mycotoxin contamination and poisoning. In 2004, for example, one of the largest aflatoxicosis outbreaks occurred in rural Kenya, resulting in 317 cases and 125 deaths (Lewis et al., 2005). The main economically important storage insect pests are maize weevil *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae), the larger grain borer (LGB) *Prostephanus truncatus* Horn (Coleoptera: Bostrichidae), angoumois grain moth *Sitotroga cereallela*, Oliv. (Lepidoptera: Gelechiidae) and the lesser grain weevil *Sitophilus oryzae* Linne (Coleoptera: Curculionidae) (Markham et al., 1994).

Traditional storage practices in Africa countries cannot guarantee protection against major storage pests of staple food crops like maize (FAO, 2008; Gitonga et al., 2013). The lack of suitable storage structures for grain storage and absence of storage management technologies often force the smallholders to sell their produce immediately after harvest. Consequently, farmers receive low market prices for any surplus grain they may produce to avoid post-harvest losses from storage pests and pathogens (Kimenju et al., 2009; Tefera et al., 2011). Farmers also cannot use their harvest as collateral to access credit, (Semple et al., 1988; Tefera et al., 2011). It is therefore, crucial that appropriate, affordable storage technologies are readily available to farmers for them to safely store and maintain quality of their produce (Thamaga-Chitja et al., 2004). Safe storage of maize at the farm level is crucial, as it directly impacts on poverty alleviation, food and income security of the smallholder farmers.

Application of chemical insecticides has been recommended in order to protect against insect-pest and pathogen attack during storage (Dales and Golob, 1997). However, insecticides are frequently unavailable or too expensive for subsistence farmers in developing countries. As an alternative strategy to reduce postharvest maize grain losses in Africa, the International Maize and Wheat Improvement Center (CIMMYT) implemented an SDC funded project titled “Effective Grain Storage for Sustainable Livelihood of African Farmers,”. The project successfully introduced the development and fabrication of metal silo technology in Kenya and Malawi (CIMMYT, 2011). A metal silo is a cylindrical structure, constructed from a galvanized iron sheet and hermetically sealed (Figure 1). The metal silo technology has proven to be effective in protecting the harvested grains from attack not only from the storage insects but also from rodent pests (Tefera et al., 2011). The objectives of this paper were to assess the effectiveness of the metal silo storage technology against the main maize storage pests, impact of the metal silo on the length of storage of surplus, consumption and sale of maize.

METHODS

Econometric analysis

The study used the proportional-odds (Ordered logit) model to estimate the likelihood of a household going without food for a whole day or sleeping hungry. The dependent variables were two food security indicators assessing whether any member of the household went to sleep hungry or went a whole day without food. The responses were recorded and coded as follows:

0 = never; 1 = rarely (1-2 times); 2 = sometimes; 3 = often (>10times).

The odds ratio of being food insecure is assumed to be constant for all categories.

$$\text{logit}\ (p_1) \equiv \log \frac{p_1}{1 - p_1} = \alpha_1 + \beta' X$$

$$\text{logit}\ (p_1 + p_2) \equiv \log \frac{p_1 + p_2}{1 - p_1 - p_2} = \alpha_2 + \beta' X$$

$$\text{logit}\ (p_1 + p_2 + \ldots + p_k) \equiv \log \frac{p_1 + p_2 + \ldots + p_k}{1 - p_1 - p_2 - \ldots - p_k} = \alpha_k + \beta' X$$

Where $P_1 + P_2 + \ldots + P_k = 1$; β is a vector of coefficients and X is a vector of explanatory variables.

Ordered logit model simultaneously estimates multiple equations depending on the number of categories. The number of equations is equal to the number of categories minus one, which are three equations in this current study. The key assumption in ordered logit is the parallel regression, meaning that there is only one set of coefficients for each independent variable. This implies that the coefficients for the variables in the equations estimated simultaneously would not vary significantly if they were estimated separately except that the intercepts would vary. The error term is assumed to be normal with zero mean and unit variance (Greene, 2002).

Sampling and data collection

Sampling was conducted in two phases with the first phase targeting households that did not own metal silo (control group) and the second phase households that adopted metal silo for grain storage. Same questionnaire was used to interview the two groups. A baseline survey preceded the metal silo adopters' survey to allow for the comparison of the two groups. A list of sub-locations (Census, 2009) was obtained from Kenya National Bureau of Statistics (KNBS) and grouped into six maize production agro-ecological zones (AEZ). These are dry transitional (DT), dry mid altitude (DMA), moist mid altitude (MM), high tropics (HT) moist transitional (MT) and low tropics (LT). Proportionate to size random sampling was then used to select 120 sub-locations across the six (AEZ) based on the number of households in each zone. Chiefs and assistant chiefs provided a list of all households in each sub-location from which 12 households were randomly selected and interviewed per sub-location, resulting in a sample size of 1344. The household survey of the metal silo storage technology was conducted in 18 districts, distributed in three agro-ecological zones namely moist transitional, moist mid transitional and dry mid altitude.

The survey targeted all the farmers who had acquired metal silos either through the project implementation partners or through the artisans in Nyanza and Eastern provinces. A sampling list of 94 households distributed in 12 districts was obtained for the Nyanza region from which 73 households were interviewed. A list containing 51 metal silo owners distributed in 6 districts was obtained from Embu and all were interviewed. This resulted in treatment group of 124 households which was compared with the randomly selected control group.

Data collection was preceded by recruiting and training 18 enumerators and three supervisors from diverse cultural backgrounds. After the training the questionnaire was pretested and revised for primary data collection. Three teams were formed, each comprising of a supervisor, six enumerators and a driver. Enumerators were provided with laminated slides clearly showing various storage facilities and main grain storage insect pests as visual aids during the interview. Data was collected between October 2010 and March 2011.

Data cleaning was done in SPSS and analysis using stata software. The mean difference on key demographic and social economic variables between the two groups was tested using a student t-test. The dependent variables were two proxies of severe food insecurity (Going the whole day without food or sleeping hungry) were regressed against demographic and social economics factors. A two stage regression was fitted to compare the effect of metal silo use on months of adequate household food provisioning (MAHFP) between the two groups while checking for possible self-selection bias. The likelihood ratio test for the independence of the primary and selection equations indicated no evidence of self selection in adoption of metal silo technology by the adopters. MAHFP is measured by asking the respondents the number of months they did not have enough food to feed their families and using that information in computing the months of adequate food provisioning.

RESULTS

Household characteristics for adopters and non-adopters of metal silo

Both adopters and non-adopters of metal silo technology were dominated by male headed households (Table 1). The average age of the household head was about 53 years for both groups. Males aged between 15-64 years constituted 52 and 54% of the primary decision maker in maize farming for the non-adopters and adopters, respectively. The proportion of aged male decision makers is significantly higher for the adopters (15%) than for non-adopters (7%). The average household size was seven and six persons for adopters and non-adopters, respectively. Meta silo adopters had 25 years of farming experience compared to 28 years for non-adopters. Adopters also on average had 10 years of formal schooling and 95% were literate compared to 7 years and 83% literacy for non-adopters. More metal silo adopter households (78%) had savings account in a commercial bank than non-adopters (47%). Mobile banking was more popular with 97% of adopter households owning a virtue M-PESA account compared to 74% for non-adopters. Metal silo adopters were more food secure than non-adopters. Households that adopted metal silo were significantly closer to the passable road (1.5 km) than non-adopters who on average were 3.1 km away from the road. Adopters were more endowed in land and cultivate an average of 8 acres annually compared to 5 acres cultivated by non-adopters. Metal silo adopters on average lost 3 kg of grain per season to storage pest while non-adopters lost 75 kg. The amount of grain lost to pest by metal silo adopters was from grain kept aside in bags for consumption to avoid frequently opening the silo.

Maize storage technologies used by households

Most non-adopters (60%) used a space in the house and improved granaries (17%) to store their maize (Table 2). Some households stored their maize in the kitchen over smoke. Most metal silo adopters (78%) used metal silo for maize storage. However, they also kept aside some maize in the bag inside the house for regular consumption to avoid opening the silo more frequently. Traditional granaries were less popular probably because they are not secure and prone to attack by storage pests. Security was one of the most important factors farmers considered when choosing a storage facility.

Factors farmers consider before choosing maize storage technology

When choosing grain storage technologies, farmers

Table 1. Household social economic characteristics.

Variable	Mean		t-test for Equality of Means		
	Non-adopters	Adopters	Difference	t	p>t
Demographic characteristics					
Gender of the household head (%)	81.00	86.00	5.00	-1.426	0.156
Age of the household head (years)	53.41	53.30	1.16E-01	0.102	0.919
Household size	6.02	6.95	-9.21E-01	-3.392	0.001
15-64 yrs male primary decision maker	0.52	0.54	-2.38E-02	-0.514	0.608
15-64 yrs female primary decision maker	0.35	0.29	6.14E-02	1.453	0.148
>64 yrs male primary decision maker	0.07	0.15	-7.46E-02	-2.307	0.023
>64 yrs female primary decision maker	0.06	0.02	3.62E-02	2.430	0.016
Literacy level of the household head	0.83	0.95	-1.23E-01	-5.742	0.000
years of schooling of the household head	7.07	10.27	-3.20E+00	-7.988	0.000
Household's years of farming experience	27.72	24.56	3.15E+00	2.400	0.018
Social economic characteristics					
Total annual income? (000'KES)	186.42	386.11	-2.00E+05	-3.811	0.000
Acres of land owned by the household	4.42	9.11	-4.69E+00	-2.712	0.008
Total land cultivated in the year	4.65	8.23	-3.57E+00	-4.868	0.000
Bags of shelled maize	9.11	12.09	-2.99E+00	-1.779	0.077
Months of food insecurity in one year	2.27	0.93	1.34E+00	7.600	0.000
Savings/bank account	0.47	0.78	-3.15E-01	-8.054	0.000
M-Pesa account (virtual banking account)	0.74	0.97	-2.33E-01	-11.886	0.000
Distance to the nearest passable road (KM)	3.12	1.52	1.59E+00	4.048	0.000
Social event	0.24	0.30	-5.52E-02	-1.183	0.239
Loss due to storage pests (kg)	74.92	3.42	7.15E+01	10.224	0.000

Table 2. Storage facilities used by rural households.

Storage structure	Non-adopters (N=1344)	Adopters (n=124)
	Percent	Percent
Metal Silo	0.3	78.2
Basket (Adita)	4.5	2.4
Large pot	1.1	0.0
Separate structure used for maize storage	9.4	15.3
space in house used for maize storage	59.7	48.4
Traditional crib (round bottom)	5.5	7.3
Traditional granary (cylindrical shape)	7.4	3.2
Traditional storage over fire in kitchen	6.3	2.4
Improved granary (wicker wall)	3.2	8.1
Improved granary (wooden wall)	13.5	4.0
Other structure	0.7	10.5
plastic containers	0.1	0.0

considered effectiveness against insect pest as very important criteria, followed effectiveness against rodent, security of the stored grain and the lifespan or durability of the technology (Figure 2). Many farmers did not consider cost of acquiring and maintaining the technology important. This is because if the technology met the conditions farmers considered important to them, they would likely recoup their investments in the technology over time through better prices emanating from delayed sale.

Maize stored in metal silos was effectively protected from LGB in 98% and from maize weevil in 92% of the

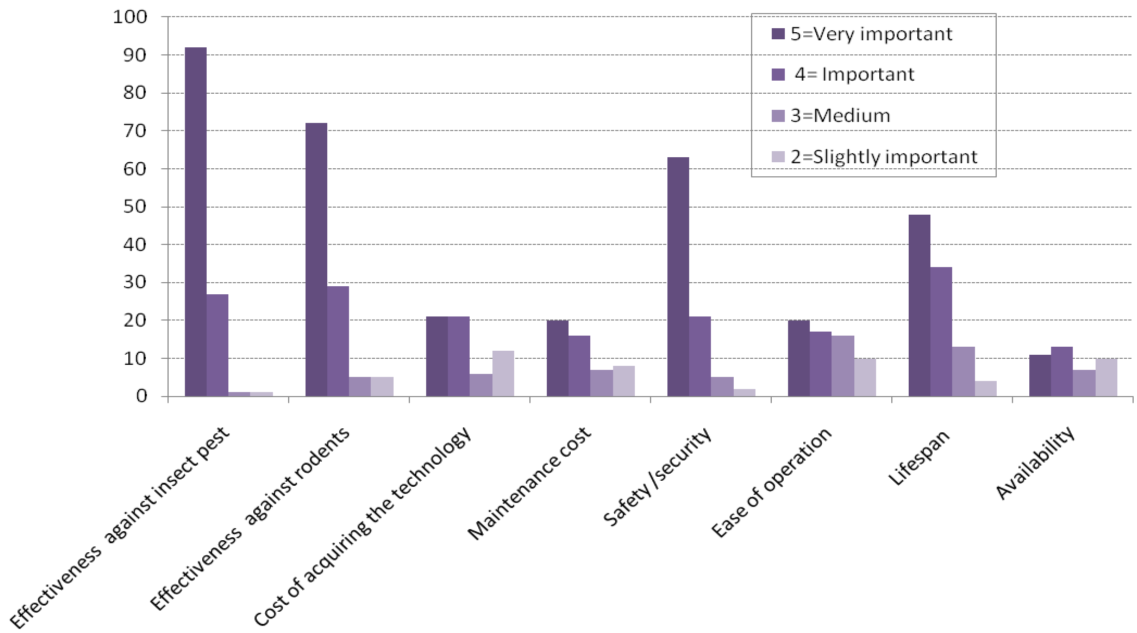

Figure 2. Determinants of storage technology choice by rural households.

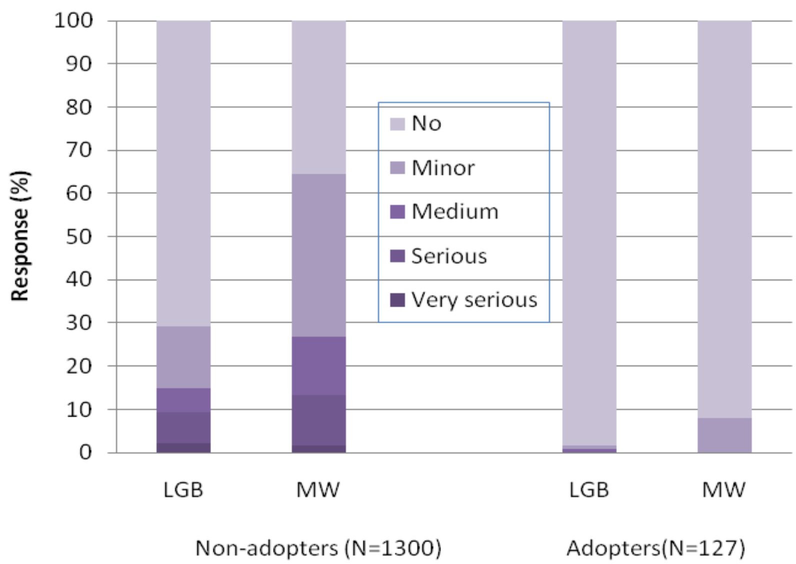

Figure 3. Households' perception of LGB and maize weevil damage.

households that owned silos (Figure 3). Households that did not have metal silo suffered more storage losses of between two and15% from LGB and maize weevil compared to metal silo adopters.

Comparison of maize sale and consumption pattern for metal silo adopters and non-adopters

Both metal silo adopters and non-adopters sold some of their maize soon after harvest to meet immediate household cash needs. Metal silo users delayed selling their maize only disposing a little in the first month (Figure 4). They sold much of their maize five months after harvest to benefit from better prices. Amount of maize sold declined sharply until the seventh month when the remaining maize was sold off to give room to next harvest. Maize takes between 3 and 4 months to mature in dry regions and 5-6 months in mid and high altitude areas. Consumption was stable and smooth throughout

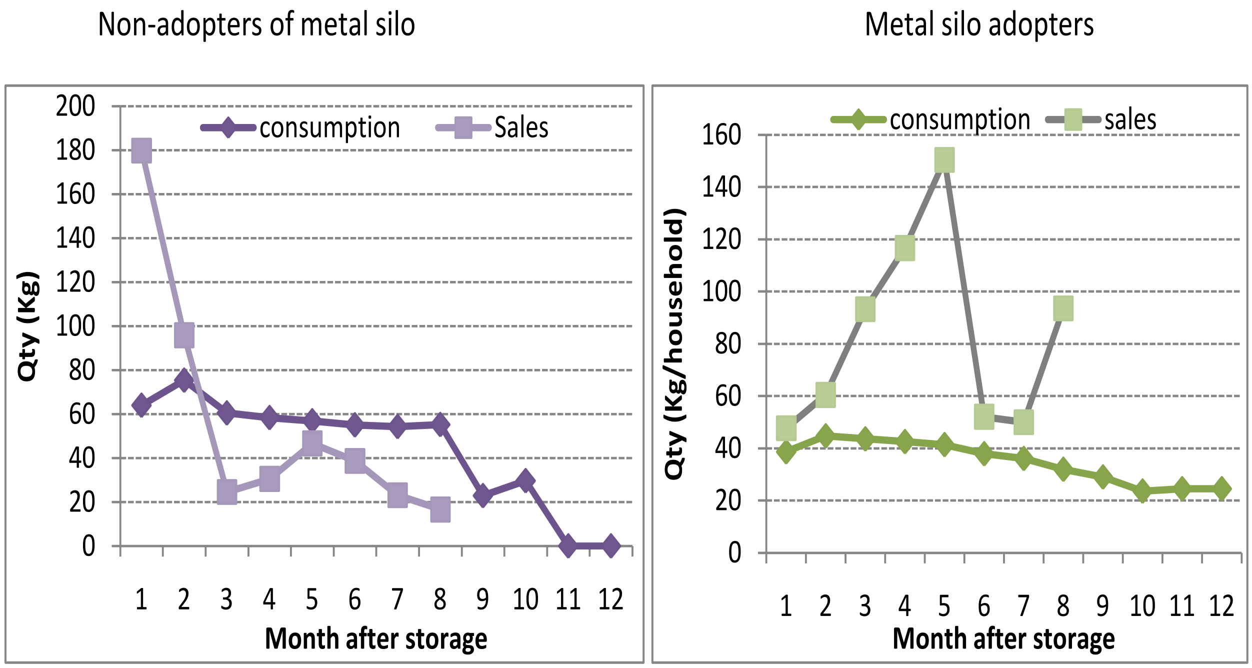

Figure 4. Comparison of sales and consumption by metal silo adopters and non-adopters.

the year for the metal silo adopters (Figure 4). The consumption curve was below the sales curve implying that much of the grain was sold than consumed. Households that adopted metal silo for maize storage were food secure for a whole year.

Unlike metal silo adopters, non-adopters sold much of their grains within the first month after harvest. Consumption curve was above the sales curve except for the first two months after harvest. This meant that by the mid of second month, much of the grain had already been sold and whatever little that remained was kept for food. The grain reserves got exhausted by the eleventh month and households had to buy from the market.

Ordered logit model

Households in potential agro-ecological zones like moist mid altitude (MMA), moist transitional (MT) and high tropics were less likely to sleep hungry or go a whole day without food than households in dry mid altitude.

An increase in household size by one member increased the chance of sleeping hungry by 5% and going without food the whole day by 17%. Distance from the main road was also associated with likelihood of a household being food insecure. Factors associated with reduced household food insecurity include adoption of metal silo technology, owning a mobile phone virtual account or a bank savings account. Male headed households were more likely to go without food the whole day compared to those headed by females (Table 3).

Two-stage treatment effect model

The dependent variable in this model was the number of months a household went without food for a period of one year. The model shows that female headed households were less food insecure than for male headed households. Households with literate heads and larger land parcels were also less food insecure. Interestingly, households that hosted large social events like wedding and burial were less food insecure compared to households that did not host such events. Generally households are food insecure by 3.5 months but this period is reduced by 1.8 months when households adopt metal silo storage technology (Table 4).

The household size, literacy of the household head, land size and possession of a savings account in a bank or virtue mobile phone-based account increases the odds of adopting metal silo technology. However, distance to the nearest passable road reduced the odds of metal silo technology adoption. The likelihood ratio test for the independence of the primary and selection equations yield a *p*-value of 0.5949. We fail to reject the null hypothesis that rho=0 and conclude that there is no evidence of self-selection in adoption of metal silo technology by the adopters.

DISCUSSION

This study demonstrated that 96% reduction in maize grain losses was achieved after acquisition of the metal

Table 3. Ordinal logit regression food security indicators.

Category	Variables	Sleep hungry				Go whole day with no food			
		Odds ratio	Std. Err.	z	P>z	Odds ratio	Std. Err.	z	P>z
AEZ	Low tropics	1.4	0.4	1.21	0.227	0.46	0.19	-1.84	0.066
	Moist mid altitude	1.0	0.2	-0.39	0.951	0.52	0.14	-2.42	0.016
	Dry transitional	1.1	0.3	0.02	0.834	0.92	0.25	-0.29	0.768
	Moist transitional	0.7	0.2	-1.70	0.129	0.31	0.09	-4.09	0.000
	High tropics	0.4	0.1	-3.26	0.001	0.07	0.04	-4.79	0.000
Demographic	Household size	1.1	0.0	1.97	0.067	1.17	0.04	4.49	0.000
	Household head Gender	0.9	0.2	-0.31	0.641	1.62	0.36	2.15	0.031
	Household head literacy	1.3	0.3	1.38	0.311	1.00	0.01	-0.37	0.710
	Experience in farming (years)	1.0	0.0	3.94	0.000	0.94	0.03	-1.70	0.089
Social economics	Savings account	0.4	0.1	-5.48	0.000	0.96	0.03	-1.4	0.162
	M_Pesa account	0.8	0.1	-1.56	0.108	0.24	0.06	-5.45	0.000
	Distant to the nearest passable road (km)	1.0	0.0	1.97	0.049	0.74	0.15	-1.42	0.154
	Land owned (acres)	1.0	0.0	-1.01	0.321	0.99	0.02	-0.64	0.521
	Total annual cultivated land (acres)	1.0	0.0	-1.08	0.397	0.99	0.02	-0.31	0.756
	Nl income	0.9	0.1	-1.49	0.146	1.01	0.01	0.97	0.330
	Metal silo ownership (1=Yes,0 otherwise)	0.2	0.1	-2.74	0.003	0.27	0.20	-1.74	0.082
	Number of observations		1408				1416		
	LR chi2(16)		144.21				184.2		
	Prob > chi2		0.00				0.00		
	Pseudo R2		0.0804				0.1494		
	Log likelihood =		-824.66				-524.25		

silo by the farmers. The metal silo is easy to handle and can be produced in different sizes, from 100 to 3000 kg grain holding capacity, based on requirements. The metal silo, which is a tried-and-tested technology in Latin America offers the following major advantages to African farmers: (i) maintains the quality of the stored product; (ii) air tightness creates effective non-residual fumigation; (iii) avoids the use of insecticides; (iv) requires little space and can be placed inside house; (v) reduces post-harvest losses to virtually nil if properly used; (vi) enables smallholder farmers to take advantage of fluctuating grain prices; (vii) prevents rodents and other pests/pathogens that could potentially harm consumer health; and (viii) can be built in-situ with local labour and easily available materials (FAO, 2008; Tefera et al., 2011).

After adopting the metal silo, farmers delayed selling the bulk of their grains until later in the season to benefit from improved prices. Metal silo adopters were also food secure for 1.8 months longer than non-adopters. Poverty reduction and food security will not be realized if farmers are unable to store grains and sell surplus production at attractive prices. Food security exists when all people, at all times, have access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life (Pinstrup-Andersen, 2009).

Several people in Africa, however, are food insecure. Despite significant advances in modern food storage methods, many smallholder farmers in developing countries still rely on traditional storage methods for storing grain. Although relatively simple and inexpensive to construct and maintain, traditional storage systems lead to substantial post-harvest losses (Mughogho, 1989). Inadequate post-harvest storage contributes significantly to food insecurity. The metal silo can play an integral part in ensuring domestic food supply, and in stabilizing food supply at the household level by smoothing seasonal food production, as demonstrated by the households that have already adopted the technology. The metal silo is air-tight. As a result, respiration of the biotic components of the grain mass (fungi, insects and grain) increases CO_2 and reduces O_2 concentrations that limit insect development

Table 4. Two stage least squares: Impact of metal silo on food security.

Number of observation	**1428**		
Design df	1425		
F (11, 1415)	5.43		
Prob > F	0.0000		
	Coefficient.	Std. Err.	P>t
Months of food insecurity			
Household size	0.03	0.024	0.222
Household head Gender	-0.45	0.163	0.006***
Household head Age (yrs)	-0.01	0.005	0.121
Household head literacy	-0.38	0.213	0.071*
Hosting big social events	-0.47	0.139	0.001***
Savings account	-0.10	0.145	0.481
M_Pesa account	0.24	0.171	0.160
Distant to the nearest passable road (km)	-0.01	0.009	0.148
Land owned (acres)	-0.01	0.006	0.043**
Total annual cultivated land (acres)	0.00	0.010	0.963
Metal silo adoption	-1.83	0.625	0.004***
_cons	3.45	0.474	0.000***
Metal silo adoption			
Household size	0.04	0.019	0.051**
Household head Gender	0.18	0.163	0.274
Household head Age (yrs)	0.00	0.004	0.929
Household head literacy	0.54	0.223	0.016**
Savings account	0.43	0.117	0.000***
M_Pesa account	0.59	0.203	0.004***
Distant to the nearest passable road (km)	-0.04	0.023	0.080*
Land owned (acres)	0.01	0.005	0.034**
Total annual cultivated land (acres)	0.02	0.008	0.015**
Primary decision maker (15-64 yrs female)	-0.18	0.126	0.163
Primary decision maker (>64yrs male)	0.34	0.203	0.090*
Primary decision maker (>64yrs female)	-0.35	0.316	0.266
_cons	-3.11	0.451	0.000***
/athrho	0.14	0.128	0.286
/lnsigma	0.84	0.026	0.000***
Rho	0.14	0.125	
Sigma	2.32	0.059	
Lambda	0.31	0.292	
LR test of indep. eqns. (rho=0): chi2(1)=0.28 Prob>chi2=0.5949			

Note *** significant at 1%; ** significant at 5% and * significant at 10%.

(Navarro and Donahaye, 2005). Farmers choose storage technology based on its effectiveness against storage insects. The metal silo is a useful food security element in the grain storage and distribution chain. Smallholder farmers with a metal silo could feed their family year round and free to decide when to bring surplus harvest to market. Grains, particularly maize and beans can be stored in the metal silo for up to three years without any problem (SDC, 2008). This helps schools, urban dwellers and smallholder farmers to set aside the reserves needed when changing climate conditions or natural disasters lead to crop failure (FAO, 2008).

The metal silo empowers smallholder farmers. The metal silo not only offer the opportunity to smooth hunger between staple crop harvests but farmers also are able to improve farm incomes by storing crops and selling it at premium prices when demand outstrips supply later in the post-harvest period. Quality is an important determination of crop retail prices (Kohl and Uhl, 1998) and effective storage is crucial to improving agricultural incomes and food security for smallholder farmers. Following the introduction of metal silos, adopting farmers have learnt to monitor the market and time their produce sales to coincide with right market conditions for better returns. Farmers use the additional income to improve their living standards. A follow-up visits to adopting farm families showed that and some had ventured in enterprises with higher returns like commercial poultry farming and goat fattening. Even though most household heads were males, metal silos were mainly managed by women. Managing the metal silo amd its content can improve women's status and self-esteem (SDC, 2008).

Apart from its effectiveness in mitigating storage losses, engaging in metal silo fabrication and marketing can create jobs for the youth and rural enterprise development (Tefera et al., 2011). For instance, in Latin America, the POSTCOSECHA Programme (Postharvest Program) relied on a large number of local tinsmiths for the production of metal silo (SDC, 2008). In 2007, there were 892 metal silo manufacturers working in El Salvador, Guatemala, Honduras and Nicaragua. The metal silo manufacturing activity provided an additional source of income for tinsmiths. When they were not working in the fields, they spent their time producing metal silos. From the production of metal silos alone, tinsmiths annually earned a net annual income of about US $ 470 (SDC, 2008). This study has demonstrated that the same can be replicated in Africa with wider promotion and adoption of metal silo technology among millions of smallholder grain producers. This study finds evidence that metal silo technology is effective against main maize storage pests and its adoption can significantly improve food security in rural households.

Conflict of Interest

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENT

This work was supported with funding from the Swiss Agency for Development and Cooperation (SDC).

REFERENCES

CIMMYT (2011). Effective Grain Storage for Better Livelihoods of African Farmers Project. Completion Report June 2008 to February 2011. International Maize and Wheat Improvement Center (CIMMYT), Mexico.

Dales MJ, Golob P (1997). The protection of maize against *Prostephanus truncatus* (Horn), using insecticide sprays in Tanzania. Int. J. Pest Manage. 43:39-43.

FAO (2008). Household metal silos: key allies in FAO's fight against hunger. Food and Agriculture Organization of the United Nations, Rome (Italy).

Gitonga ZM, De Groote H, Kassie M, Tefera T (2013). Impact of metal silos on households' maize storage, storage losses and food security: An application of a propensity score matching. Food Policy 43:44-55.

Greene HW (2002). ECONOMETRIC ANALYSIS. Fifth ed. Pearson Education, Inc., Upper Saddle River, New Jersey, 07458, New Jersey.

Lewis L, Onsongo M, Njapau H, Schurz-Rogers H, Luber L, Kieszak S, Nyamongo J, Backer L, Dahiye AM, Misore A, DeCock K, Rubin C (2005). Aflatoxin Contamination of Commercial Maize Products during an Outbreak of Acute Aflatoxicosis in Eastern and Central Kenya. Environmental Health Perspectives P. 113.

Kimenju SC, De Groote H, Hellin J (2009). Cost effectiveness of the use of improved storage methods by small scale farmers in ESA countries: preliminary economic analysis Report submitted to SDC. International Maize and Wheat Improvement Centre (CIMMYT), Nairobi, Kenya.

Kohl RL, Uhl JN (1998). Marketing of Agricultural Products, eighth ed. PrenticeeHall, Upper Saddle River, New Jersey.

Markham RH, Bosque-Perez N, Borgemeister C, Meikle WD (1994). Developing pest management strategies for the maize weevil, *Sitophilus zeamais*, and the larger grain borer, *Prostephanus truncatus*, in the humid and sub-humid tropics. FAO Plant Prot. Bull 42:97-116.

Mughogho MJK (1989). Malawi: food security issues and challenge for 1990's, *In* M. Rukuni, et al., eds. Food security policies in the SADCC region. Proceedings of the Fifth Annual Conference on Food Security Research in Southern Africa, October 16-18, 1989, ed. University of Zimbabwe and Michigan State University Food Security Research in Southern Africa Project. Department of Agricultural Economics and Extension, Harare. pp. 31-36.

Navarro S, Donahaye J (2005). Innovative Environmentally Friendly Technologies to Maintain Quality of Durable Agricultural Produce, p. 203-260, *In* S. Ben-Yehoshua, ed. Environmentally Friendly Technologies for Agricultural Produce Quality. CRC Press,, Boca Ratón, Florida.

Pinstrup-Andersen P (2009). Food security: Definition and measurement. Food Sec. 1:5-7.

Rosegrant WM, Magalhaes E, Valmonte-Santos AR, D'Croz DM (2015). Returns to investments in reducing postharvest food losses and Increasing Agricultural Productivity growth. Working paper. CGIAR.

SDC (2008). Latin America Section: Fighting Poverty with Metal Silo and Job Creation. . Swiss Agency for Development and Cooperation, Berne. Switzerlan.

Semple RL, Hicks PA, Lozare JV, Castermans A (1988). Towards integrated commodity and pest management in grain storage: A Training Manual for application in humid tropical storage systems FAO, Rome., Philippines pp. 1-526.

Tefera T, Kanampiu F, De Groote H, Hellin J, Mugo S, Kimenju S, Beyene Y, Boddupalli PM, Shiferaw B, Banziger M (2011). The metal silo: An effective grain storage technology for reducing post-harvest insect and pathogen losses in maize while improving smallholder farmers' food security in developing countries. Crop Prot. 30:240-245.

Thamaga-Chitja, J.M., S.L. Hendriks, G.F. Ortmann, and M. Green. 2004. Impact of maize storage on rural household food security in Northern Kwazulu- Natal. J. Family Ecology Consumer Sci. 32:8-15.

Zorya S, Morgan N, Rios LD (2011). Missing food: The Case of Postharvest Grain Losses in Sub-Saharan Africa 60371-AFR. The World Bank, Washington, DC.