Effectiveness and Economics of Hermetic Bags for Maize Storage: Results of a Randomized Controlled Trial in Kenya

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Abstract.

Maize is a very important crop in Africa whose production is seasonal but consumption continuous. This makes it important to store it on-farm especially for the small scale farmers, but the traditional storage methods lead to high losses. This calls for more research and investment in improved storage technologies such as hermetic bags.

A randomized controlled trial was implemented in Kenya with treatment farmers using hermetic bags and control farmers conventional farmer practices. Hermetic bags were highly effective in controlling loss to an abated loss of 8.5% valued at KSh 307(US$ 3.6) for one season and KSh 918 (US$ 10.7) for three seasons, the recommended minimum times a bag can be re-used. The technology is economically viable with a benefit cost ratio of 1.6 for one season and 4.8 for three seasons.

Keywords: hermetic bags, maize storage, effectiveness, benefit cost,

1. Introduction

Maize is one of the most important food crops in the world and, together with rice and wheat, provides at least 30% of the food calories to more than 4.5 billion people in 94 developing countries (Shiferaw, Prasanna, Hellin, & Bänziger, 2011). Its production in Africa is highly seasonal but consumption is pretty constant over the year (Gitonga, De Groote, Kassie, & Tefera, 2013). This makes it important for the farmers to store their maize to be food secure and draw better prices from the sale of their surpluses.

In the past, African farmers used traditional methods for storing maize whereby maize was well dried, stored on the cob in suitable structures, then shelled for further storage (Golob, 1988). This was effective then, but recent changes in climatic conditions, (forcing farmers to store their maize when is not well dried) in combination with the accidental introduction of the LGB into African farms calls for improved farming systems particularly on post-harvest management of Maize (Dick, 1988). To escape from high losses associated with the factors above, farmers tend to sell their maize early when prices are low, leaving them vulnerable the rest of the year or until the next harvest. An assessment of post-harvest handling practices and food losses in a maize-based farming system in semi-arid areas of Central and Northern Tanzania carried out in 2012 observed that there were at least 7 months between two harvest seasons of each crop; while farmers sold the crops soon after harvest to cater for household expenditure (54%) and school fees (38%), the market prices increased significantly within six months of storage (Abass et al., 2014). Hence, farmers incur economic losses and also spend more on purchasing food.

Metal silos, a hermetic technology which had been tried and introduced to the farmers in Central America from the early 1990s and in Africa since 2008, are effective in reducing grain damage and losses from insect pests (Tefera et al., 2011). On-station trials demonstrated that metal silos are very effective in controlling maize weevils and the larger grain borer without any pesticide (De Groote et al., 2013). Although they work well and they have potential in improving household food security and income from maize, they are expensive, going for KSh 18,000 (US$ 210) for a 1ton silo, the size that is commonly ordered by the farmers and the smallest size considered to be cost effective (Simon & Groote, 2010). As a result, most farmers are not able to buy them unless subsidized or through group credits.

Hermetic bags, on the other hand, are fairly affordable, costing KSh 250 (US$ 3) for a bag with a 90 kg capacity. By the time this study was initiated, in 2013, two brands were being marketed in Africa by different companies. Purdue Improved Crop Storage (PICS bags^{TM}) and SuperGrainBag^{TM} . PICS bag is a simple, low-cost triple bagging technology originally developed for postharvest storage of cowpea but had been evaluated for applicability to maize storage mainly in West Africa (Baoua, Amadou, Ousmane, Baributsa, & Murdock, 2014). The three layers include an outer polypropylene bag and two inner linings of high density polyethylene (HDPE). Trials have shown that PICS bags can be used for maize storage even in areas with high prevalence of larger grain borer, but storage of maize should begin soon after harvest and drying to minimize bag damage that can occur when very high numbers of larger grain borers are present (Baoua et al., 2014).

The second brand, SuperGrainBag^{TM} is produced by GrainPro Inc. in the Philippines. Their bags are commercially available in Kenya and though the market is not fully developed since the technology is still new and the awareness levels are still low. Their bag consists of an outer polypropylene bag with an inner high density polyethylene (HDPE) lining. Famers have the option of buying only the inner lining from Grainpro and using it with their normal bags since the inner lining is the tool that maintains airtightness while in storage. The SuperGrainBags were tested on station and were effective, although under artificial infestation they were perforated by LGB (De Groote *et al.*, 2013).

A comparison of the PICs bags and SupeGrainBags with cowpeas concluded that they are similar in effectiveness and farmers who wish to store their cowpea grain with hermetic technology can choose between the two types of bags, taking into account price, availability and durability(Baoua, Amadou, Lowenberg-DeBoer, & Murdock, 2013). Moreover, the results of the on-station trials in Kenya demonstrated that the SuperGrainBags controlled insect pests well, but insect mortality was not complete and all bags in the trial were perforated, almost certainly by larger grain borers (De Groote et al., 2013).

Although maize is a major food crop in East Africa, the hermetic bags have so far not been formally tested with maize on farms in the region, a crucial step to help build local evidence on the effectiveness of the technology. In addition, there is no literature on the economic analysis of the hermetic bags for the subsistence farmers. Therefore, the technology needs to be tested on-farm to assess its effectiveness in reducing grain damage under farmer management, and conduct the economic analysis by comparing their cost to their accrued benefits. To fill this gap, randomized controlled trials (RCTs) were conducted with farmers in Kenya with the following objectives: 1) to test the effectiveness of the hermetic bags in reducing postharvest grain loss in comparison to farmer practice, and 2) to establish the economic viability of investing in the technology by comparing the benefits to the costs.

2. Methodology

2.1. Conceptual frame work – impact pathways

One of the main purposes of improved storage technologies is to reduce infestation levels of post-harvest pests, in particular insect pests such as maize weevils and larger grain borers, to reduce grain damage and weight loss. Hermetic bags, a modern improved storage technology, have reduced exchanges of gasses between stored maize and the environment. After the oxygen is depleted, insects suffocate and die (Baoua, Margam, Amadou, & Murdock, 2012). Moreover, metabolism is reduced and fungal growth is stopped, which improves the preservation of the grain quality. As a result, the farmers adopting hermetic bags are expected to have more and quality grain to consume or to sell, improving their food security and increasing their farm income from the sale of quality maize at a later stage, especially when there is shortage of maize and high prices in the market.

To measure the effectiveness of the technology under farmer conditions, hermetic bags were compared to standard farmer practice in an on-farm trial. To avoid selection bias between users and non-users of the new technology, participants were randomly assigned to either treatment or control.

2.2. Study design and empirical framework

The study design is a Randomized Controlled Trial (RCT) with farmers assigned randomly to treatment and control groups. The treatment farmers were given hermetic bags in sufficient quantity to store all their maize for one season while the control farmers were expected to maintain their normal practice in storage of maize. Some of the control farmers used pesticides while others did not, but this was left to their own decision and was not assigned. In practice, farmers tend to use pesticides when they observe a certain level of insect infestation.

The study was implemented in two sites: Moidabi location in Naivasha Sub-county and Githioro location in Bahati Sub-county, both from Nakuru County. These locations were purposively selected as key informants supplemented by exploratory visits indicated presence of surplus maize production, good accessibility throughout the year and evidence that farmers experience substantial grain losses due to storage insects. Further, farmers do not use improved storage methods because there have been no grain storage interventions or projects implemented in the areas, so there is a potential demand for effective and safe storage methods.

For the selection of the participants, a multistage sampling design was used. A sampling frame of all the villages within the locations was generated: 10 villages from Modabi location and seven from Githioro location, having left out 2 villages in Githioro location which were townships and non-farming settlements. Probability proportional to size was used to select four villages from each location, giving us eight villages in total. A second sampling frame was generated with the names of all household heads from the selected villages. Simple random sampling was used to select 75 households from each village, and 600 households in total.

(Figure 1)

All households were visited for the baseline interview. During this interview, the respondents were asked to throw a dice once and all the even numbers were assigned to the treatment group while all the odd numbers were assigned to the control group. This is a random method and, since it is participatory and transparent, a comfortable and acceptable way of assigning the farmers either to the treatment or control groups. That notwithstanding, it has the risk of not resulting to exactly equal number of farmers for the two groups though it should be close.

To measure the effectiveness of the bag, a sub-sample of 270 farmers was randomly selected (from the larger sample of 600 farmers involved in the study) for physical observations, including sampling of the grain and estimating damage and losses. The sub-sample was randomly selected using stratified sampling whereby randomization was done within the treatment and control groups separately. Given that farmers' approximation of post-harvest loss was higher for Nakuru than for Naivasha, we selected 13 farmers per village from Naivasha and 15 farmers per village from Nakuru so as to maintain the power of the test at 80%.

(Table 1)

2.3. Survey instruments and data collection

The baseline survey consisted of a personal interview of all participating farmers using a pretested questionnaire with eight modules covering information on household characteristics, house hold assets, land ownership and crop income, households income levels and sources, maize storage and marketing dynamics, household food security and food frequency. Baseline data were collected from all 594 participating households, of which 301 were assigned to the treatment group and 293 to the control group, depending on the results of throwing a dice once. The baseline survey took place in October and November 2013 and was carried out by a team of 13 trained enumerators and 2 supervisors. The treatment farmers were then given a voucher with their details and the number of bags needed for one season. They redeemed their vouchers during training and demonstration sessions held soon after the survey was completed.

For the subsample of 270 households, grain samples were collected twice: after two months of storage, in February 2014, and after four months of storage, in April 2014. During the visits, samples were collected with special sampling spears, produced by Pneumac England, with five openings at different heights and fetched from 5 different parts of the bags starting with the center, then North, South, East and West of the bag. On average, an amount of 500g of maize was thus collected from each bag. The samples were subsequently packed in clear plastic sample bags, labeled with identification information about the household and the storage bag it came from. The samples were then sent to the CIMMYT entomology laboratory at Kiboko for analysis which included observations of the live and dead numbers of maize weevils and LGBs, the number of undamaged and damaged grains per sample, and the weight of the damaged and the undamaged grains in each sample.

During the second round of collecting grain samples (April 2014), data on damage of bags by rodents and insect pests, and management of rodents were also collected. This was done through physical observations of the bags and personal interviews with the farmers. The survey team also captured the farmers' perception on the quality of their maize based on color, aroma, shape, and the taste of food (stiff porridge, locally called *ugali*) made from the stored maize. Farmers were asked if four maize qualities were maintained during the storage period: aroma, color, shape and taste of the stiff maize porridge (*ugali)* made from the stored maize. For each characteristic, they were asked to respond to the question with 0 (strongly disagree), 1 (disagree), 2 (agree) or 3 (strongly agree).

2.4. Analysis

Some control farmers used insecticides (30% at 2 months and 67% at 4 months), but this treatment was not assigned and therefore it is not exogenous: likely, observation of insect pests influences the decision to treat, or to sell, or a combination. Therefore, the differences in outcomes between stores with and without insecticides cannot be attributed to the insecticides alone. Still, the differences are of interest and are therefore presented, but statistical analysis is only performed on treatment vs. control.

Descriptive analysis provided information on the characteristics of the farmers, the damage on the bags, the number of live and dead insects in the samples, and the proportion of damaged grains. To estimate weight loss from stored maize, the count and weigh method was used (Adams & Schulten, 1978) which provides an estimate of the percentage of weight lost. Since the use of hermetic bags was a randomly assigned treatment, the analysis of the RCT mainly involved comparing the means of insects present, grain damage, and weight loss between control and treatment farmers.

Loss abatement analysis was used to establish the amount and value of maize saved by using hermetic bags. Benefit cost analysis was conducted to establish the economic viability of investing in the technology. To calculate the benefits of using the bags, we used the average price of maize in Kenya which is KSh. 40 per kg. To analyze farmer perception on the sensory characteristics of the stored maize, descriptive and ordinal regression analysis were used.

3. Results

3.1. Farmer Characteristics

The control and treatment groups were similar in socio economic and farming characteristics, indicating that our randomization of the households was effective. Most (76%) of the households were male headed with an average household size of five members, which is in line with other studies on household sizes for African families. The household heads were in their fifties with mean years of formal education of seven which is fairly good among farmers in Africa.

The households owned approximately 1.8 acres of land and were cultivating an average of 2.1 acres, including both own and leased land, and most of it (1.8 acres) was put under maize. They were harvesting approximately 18 bags of 90 kg per season.

The participating farmers had maize in their store for home consumption for up to 10 months and bought maize for roughly three months to feed their families. Some were selling either all or some of their maize immediately after they had harvested but most of them started selling their maize on the eighth week (2 months) after harvesting. During this period, from harvest up to two months later, farmers did not earn much from sales because supply was high and demand low, with most families having produced their own food. Farmers sold mostly to grain traders and assemblers who either sold it further or milled and packaged the flour. On average, they earned an annual aggregated income of KSh 129,000 (US$1433). The difference in ownership of cats and use of other rodent control measures such as traps and poisons was not statistically significant between the control and treatment groups

(Table 2)

3.2. Damage of the bags by rodents and insects

Hermetic bags can be damaged by rodents and LGB, which would make them no longer hermetic, becoming ineffective and not reusable. Therefore, farmers were asked if they had observed rodent and LGB damage on the outer as well as the inner bags (the last one for treatment farmers only). Damage by rodents on the outer polypropylene bags was common and was reported by roughly a quarter of the participating farmers, substantially more by the control farmers (35%) than by the treatment farmers (20%). The bags of the households with cats were less damaged by rodents compared to those without cats (Pearson chi-square of 0.059). The bags of the farmers who used rat poisons to control rodents were more damaged by rodents than for those who did not (Pearson chi-square of (0.001). This implies that use of cats is a more effective way of controlling rodent damages on the bags during storage. By the time of the follow-up survey, no farmer had reported rodent damage on the inner lining, so the actual instrument that maintains the hermetic condition in the bag remained intact. However, a few farmers reported rodent damage on the inner lining during our subsequent visit but the percentage is negligible.

LGB damage on the bags was rare: on the outer bags it was only reported by 8% of the farmers in the control group, and by none of the farmers in the treatment group. Further, none of the treatment farmers reported LGB perforations on the inner lining, the actual hermetic bag.

(Figure 2)

3.4. Insect pest infestation

The analysis of grain samples collected from both the control and treatment farmers included the counting of both live and dead maize weevils. Samples from control farmers were more infested than those from their treatment counterparts. At two months of storage, live weevils were observed in approximately 60% of both the control and treatment farmers' samples. This was different at four months of storage whereby live weevils were observed in 50% of the control farmers' samples and in 30% of the treatment farmers' samples. Hermetic bags reduced insect infestation, but did not completely control them. It is also possible that a few of the treatment farmers did not strictly follow the recommended process of loading and tying the bags to maintain airtightness. Re-infestation in the hermetic bags was also possible in situations where farmers open their bags to draw grains for consumption and at times leaving them unsealed.

(Figure 3)

For the analysis of insect infestation in treatment and control groups, the latter was divided into farmers who used insecticides and those who did not. The maize for the control group without insecticide was the most infested with approximately 11 weevils per sample (of approximately 500 g or 1500 grains) at two months of storage, and 18 weevils at four months. The insecticides reduced infestation by more than half to approximately five weevils at two months and six weevils at four months. On the other hand, hermetic bags were very effective in reducing weevil infestations. Compared to the control farmers (with and without insecticide combined), the hermetic bags reduced infestation from 10 to four weevils at two months and from 11 to three at four months. There were a few treatment farmers (3% at 2 months and 6% at 4 months) who had used pesticide on their maize.

The trend is similar for the control with and without insecticide where by infestation keeps increasing from baseline to the fourth month. The trend is different for the treatment farmers where infestation increases from baseline to two months but decreases thereafter. This implies that the hermetic bags, if well sealed and taken care of, can reduce infestation even when maize is stored for longer periods.

(Figure 4)

3.5. Grain Damage and Weight Loss

Grain damage (as a % of bored grains in the sample) was compared between treatment and control. Some farmers in the control (30% at 2 months and 67% at 4 months), treated their grain with insecticides which had a marginal effect on grain damage at two months of storage, where both the control with and without pesticides experienced approximately 5% damage. At four months, damage increases significantly for both categories but its higher for the control without pesticide (17%) than for the control with pesticide (13%). Likely, farmers use insecticide when apparent infestation is higher, and insecticides work well for the first two months.

At both two and four months of storage, grain damage is much lower in the hermetic bags than in the polypropylene bags. At two months, grain damage in the hermetic bags reduced to almost zero from 6% and to four percent from 14 percent at four months. The insecticides did not work as well in controlling damage (13%) as the hermetic bags (4%). Although hermetic bags are evidently not perfect, they significantly reduce grain damage by insect pests and therefore preserve the quality of the stored grains.

(Figure 5)

Grain weight loss was significantly higher in the control, with or without insecticide, than in the hermetic bags (Figure 6). At two months of storage, loss in the control was 5%, compared to 2% in the hermetic bags; at four months loss in the control was 12%, compared to 4% in the hermetic bags.

Similar to its effect on grain damage, the pesticides used by farmers in the control group had only a marginal effect on controlling weight loss at two months of storage where both the control with and without pesticide incurred approximately 5% weight loss. At four months of storage, loss in bags with pesticides was 12%, as compared to 14% in those without.

(Figure 6)

3.6. Farmer Perception on the Quality of the Stored Grains

During the second round, (four months) and based on their physical observation and consumption of the stored maize, farmers were asked if they agreed or disagreed if the quality of the grain in storage had been maintained. Approximately 60% of the respondents strongly agreed that the smell, taste, color and shape of the stored maize was maintained, 35% just agreed that the quality was maintained while roughly 5% just disagreed. There was no any treatment farmer who strongly disagreed that the quality of the stored grains was maintained. On the contrary, only less than 10% of the control farmers who strongly agreed that the same quality aspects of the stored maize was maintained, roughly 45% of them just agreed while approximately 50% of them either disagreed or strongly disagreed that the quality of the stored maize was maintained over the storage period.

(Figure 7)

Since the scores are ordered categorical data, we carried out an ordinal regression which is the indicated statistical analysis. The dependent variable for the analysis was the score, for the four characteristics, and the independent variable was a binary variable indicating the treatment (1) or control group (0). From the four attributes assessed by the farmer, the results showed that the quality of the stored maize was significantly better for treatment over control group, for all four criteria. This indicates that farmers consider the hermetic bags to be effective in maintaining grain quality over the storage period.

(Table 5)

3.7. Benefits of hermetic bags and insecticides: abated loss

Farmers using the hermetic bags incurred weight losses of 3.9% after four mounts of storage, which is significantly lower than their control counterparts who incurred weight losses of 12.4%. The abated loss, or loss avoided through the bags, amount to 8.5% which is equivalent to a gain of 7.7kg of grain per 90kg bag per season. Given an average maize value of KSh 40 per kg, this gain is valued at KSh. 307 (US$ 3.6) per bag per season, assuming farmers store for four months only. The value sums up to KSh. 920 (US$ 10.7) per bag in 3 seasons, the minimum period the hermetic bags can be re-used if well taken care of.

Within the control, those who did not use insecticides incurred the highest losses (14.1%), while those who used insecticide incurred 11.5% loss, four months after storage. The insecticide therefore provides a loss abatement of 2.6% or 2.3kg of grain gained per 90kg bag per season, valued at KSh. 93, roughly US$ 1.

(Table 3)

3.7. Cost Benefit Analysis for the Hermetic Bags

Total cost of storage for the control group, assuming they are using insecticides, is KSh 100 per bag of 90kg, comprised of KSh 40 for the bag and KSh 60 for pesticides. The cost for the hermetic bags is KSh 290: KSh 40 for the outer bag and KSh 250 for the inner bag. Therefore, the marginal cost for the hermetic bag, compared for one season is KSh 190 per 90 kg bag. The hermetic bag results to an abated loss of 7.7 kg per bag which leads to a marginal benefit of KSh 307 per season.

With the above conditions, and assuming same average maize value of KSh 40 per kg, and that farmers store only for four months per season, the hermetic bags had a benefit cost ratio of 1.6 which implies that even with one season and storing for four months only, the farmer will have recovered his/her money and made a profit of KSh. 56. This implies that hermetic bags are economically viable even if they were to be used for one season only. The economic viability is expected to increase with increased length of storage, higher grain values, lower costs of the inner lining, and when the bag is re-used for subsequent seasons. For instance, all factors held constant, re-using a hermetic bag for three seasons raises the benefit cost ratio to 4.8, which is a gain of 7.7kg of maize valued at KSh 920 (US$ 10.7) or a profit of KSh 670 (US$7.8). This would imply that farmers need to take care of their bags and ensure they use them for multiple seasons, and that they need to store their surplus longer and sell when the demand is high and supply is low to draw higher prices and hence benefit most from the technology.

(Table 4)

4. Conclusions

The control and treatment farmers were similar in social economic characteristics. Damaging of the polypropylene bags by rodents was common and reported by one quarter of the respondents, but cats were an effective way of controlling rodents during storage. The rodents were not able to reach the inner polyethylene lining for the hermetic bags. Perforation of the polypropylene bags by insect pests was rare, only three percent of the farmers observing them.

No farmer observed insects' perforations on the inner HDPE lining for the hermetic bags. Compared to polypropylene bags (with or without insecticides), the hermetic bags are more effective in controlling postharvest infestation of maize and preserving the quality of the stored maize. Using hermetic bags helped the farmers to avoid post-harvest losses of 8.5 percent which is valued at KSh 307 per season per bags and goes up to KSh 920 if the bag is re-used for three seasons, the minimum period recommended by the manufacturers, if the bags are well taken care of to avoid damage. Investing in hermetic bags is economically viable with a benefit cost ratio of 1.6 for one season and 4.8 for three seasons. From the farmers' perception on the quality of their own stored maize, the hermetic bags scored significantly higher than the control farmers. In addition, results of ordinal regression indicated that the quality of the stored grains was significantly higher among the treatment farmers compared to control farmers.

The results of this study corroborate other on-station findings from West Africa that this is a good storage technology, capable of reducing postharvest loss and therefore improve food security (Baoua et al., 2014, 2012). Unlike previous findings from an on-station trial in Kenya that the hermetic bags can be perforated by postharvest insects (De Groote et al., 2013), the results of this study showed that no inner bag was perforated by insects even after four months of storage. We still speculate that perforation would be possible under high infestation especially from LGB as was the case with the mentioned study where stored maize was artificially infested. We also found that there was reduction of damage on outer bags by rodents and LGB. We speculate the hermetic conditions keep the area around the hermetic bag clean while the inner lining also minimized spillage in the stores. These, in combination with the limited gas exchanges, reduce signals for pests' attraction. Although the hermetic bags do not seem to totally eliminate all insects, their benefits clearly outweigh the costs, even without considering the non-monetary benefits such as safety as users consume chemical free maize and food security due to longer storage. This is the first time RCT is being carried out on hermetic storage. There is need to carry out further studies on the technology particularly on impact assessment on food security and income, farmers willingness to pay for the technology, and farmers behavior change and adoption of the technology.

We recommend that this technology should be promoted among the small scale farmers as its potential to improve their food security and income is high. With more brands in the market and possibly with local production, the technology will reach more farmers and possibly at lower prices. As more farmers demand for the technology and more manufacturers, importers and intermediaries show interest in the business of supplying, there need to be quality control measures in place to ensure that farmers get value for money. There need to be proper training for extension workers, stockiest and farmers to ensure that the bags are being used correctly.

In conclusion, although the hermetic bags evidently not perfect, they are very effective in controlling grain damage and emanating loss hence preserving the quality of the stored grain and increasing the period of on-farm storage by farmers hence improving their food security and farm income. For one to achieve these benefits, it is important that the process of drying, loading the maize in the bags for storage and sealing them is adhered to ensure hermetic conditions are maintained throughout the storage period.

TABLES AND FIGURES

TABLES

Table 1: Number of interviewed households per village

		Grain sampling R1		Grain sampling R2	
District	Village	Control	Treatment	Control	Treatment
Naivasha	Kongoni	5	10	6	6
	Tangi Tatu	12	13	6	12
	Sero	8	14	7	11
	Ngondi	12	11	12	10
Bahati	Mastoo	16	15	13	14
	Mathare	13	8	11	9
	Kamae	14	11	10	15
	Kahuwaini	12	15	15	15
Total		92	97	80	92

Table 2: Characteristics treatment and control farmers, by category

	Control (n = 116)		Treatment (n = 120)		Total (n = 236)	
	Mean	SD	Mean	SD	Mean	SD
Age of head of household	56.0	16.6	53.4	16.0	54.7	16.3
Years of education of head of household	6.5	4.5	6.9	4.3	6.7	4.4
Household size	5.3	2.7	5.0	2.5	5.1	2.6
Land owned (acres)	1.7	1.8	1.9	2.6	1.8	2.2
Total land cultivated - including leased land (acres)	2.2	2.0	2.1	2.1	2.1	2.1
Land under maize (acres)	1.8	1.4	1.8	1.7	1.8	1.6
Maize harvested in normal seasons - 90kg bag	15.5	17.6	19.5	22.8	17.5	20.2
Storage lengths in months	10.1	2.5	10.0	3.1	10.0	2.8
Months bought maize grain	2.7	1.9	3.5	2.9	3.1	2.4
Weeks to first sale	8.2	7.8	8.5	10.4	8.3	9.1
Total annual income (in '000')	110.6	135.2	148.2	389.4	129.4	262.3
Male headed (1 = male, 0 = female)	73.9%		77.3%		75.60%	
Had cats to control rodents	47.6%		52.2%		50.00%	
Used poisons to control rodents	42.0%		38.9%		40.40%	

Table 3: Maize grain loss abated by the hermetic bags and its value

	Control		Total control	Hermetic bags
	No insecticide	Insecticide		
Loss at baseline % (N= 594)	0.1	0.1	0.1	0.1
Loss % at first round (2 months, N=238)	5.4	5.0	5.3	2.0
Loss % at second round (4 months, N=173)	14.1	11.5	12.4	3.9
Abated loss per season (% of grain)		2.6		8.5
Abated loss (kg/bag/season)		2.3		7.7
Benefit (KES/bag/season) - KSh 40 per kg		93.1		306.6
Benefit (KES/bag/3 seasons)		279.3		919.7

Table 4: Cost Benefit Analysis for the hermetic bags

		Total control	Hermetic bags
Cost	Cost outer bag (KSh)	40.0	40.0
	Cost insecticide (KSh per 90kg bag)	60.0	
	Cost inner bag (KSh)		250.0
	Total cost (KSh)	100.0	290.0
	Marginal cost		190.0
Benefit	Weight loss (%) (4 months, N=173)	12.4	3.9
	Grain at 4months of storage (Kg Per 90kg bag)	78.8	86.5
	Grain value at 4 months (KSh) - per 90kg bags	3153.0	3459.6
	Marginal benefit (kg/90kg bag) - at 4 months		7.7
	Marginal benefit (KSh/90kg bag) - one season		306.6
BCA	BC ratio one season		1.6
	Marginal benefit (kg/90kg bag in 3 seasons)		23.0
	Marginal benefit (KSh/90kg bag in 3 seasons)		919.7
	Marginal cost (3 seasons)		190.0
	BC ratio 3 seasons		4.8

Table 5: Farmer perception on the quality of the stored grain

Codes: 0 =strongly disagree, 1 = disagree, 2 = agree, 3 = strongly agree	Ordered regression			
	Coefficient	Std. error	Sig	Cox and snell
The aroma of the grain was maintained during the storage period	-3.57	0.39	0.000	0.43
The color of the grain was maintained during the storage period	-3.28	0.40	0.000	0.36
The shape of the grain was maintained during the storage period	-4.02	0.49	0.000	0.45
Fresh taste of food from the grain was maintained during the storage period	-2.86	0.32	0.000	0.35

FIGURES

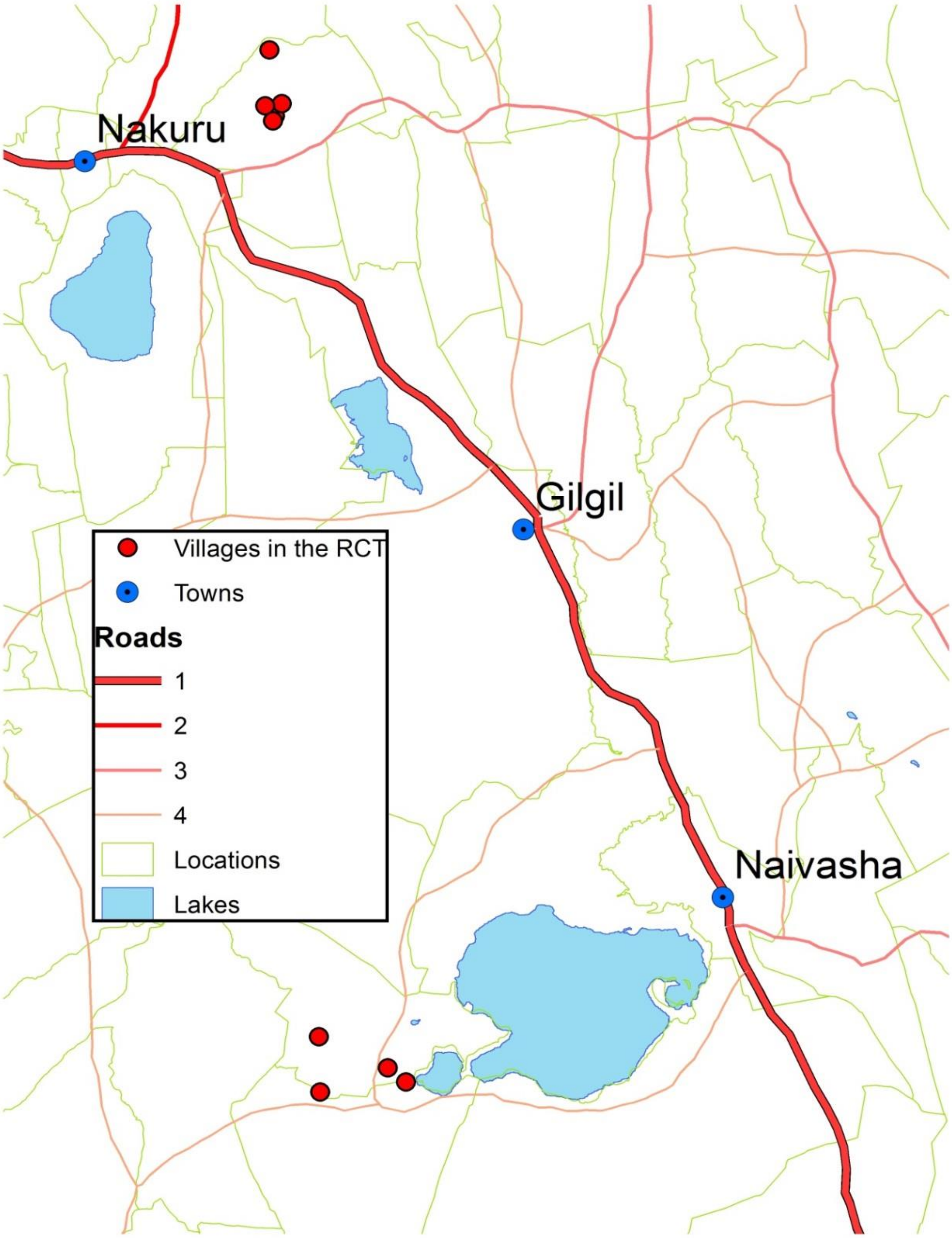

Figure 1: Map of the study area and the selected villages

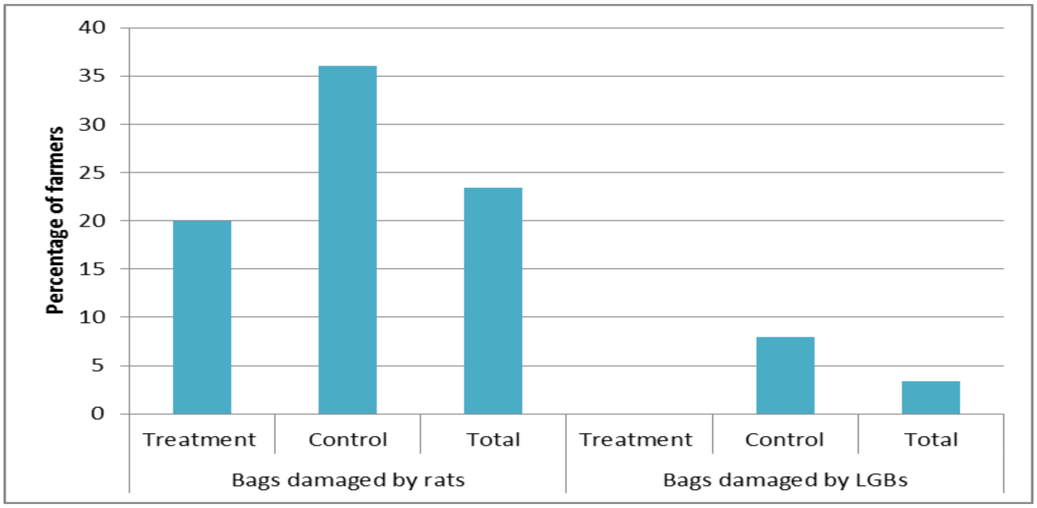

Figure 2. Bag damage from rodents and larger grain borers, as reported by farmers

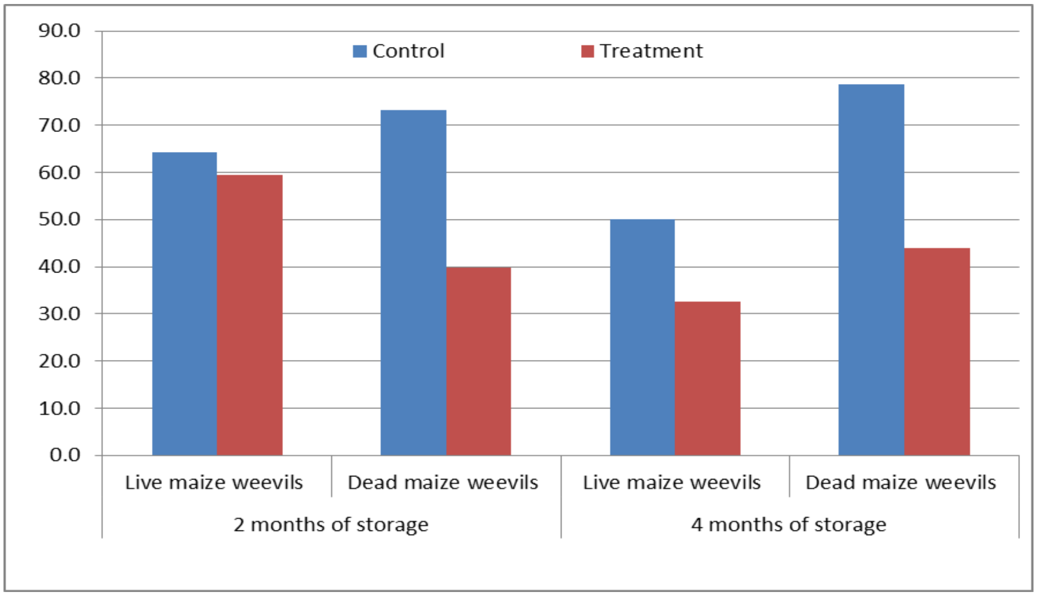

Figure 3: Farmers from whose samples weevils were observed.

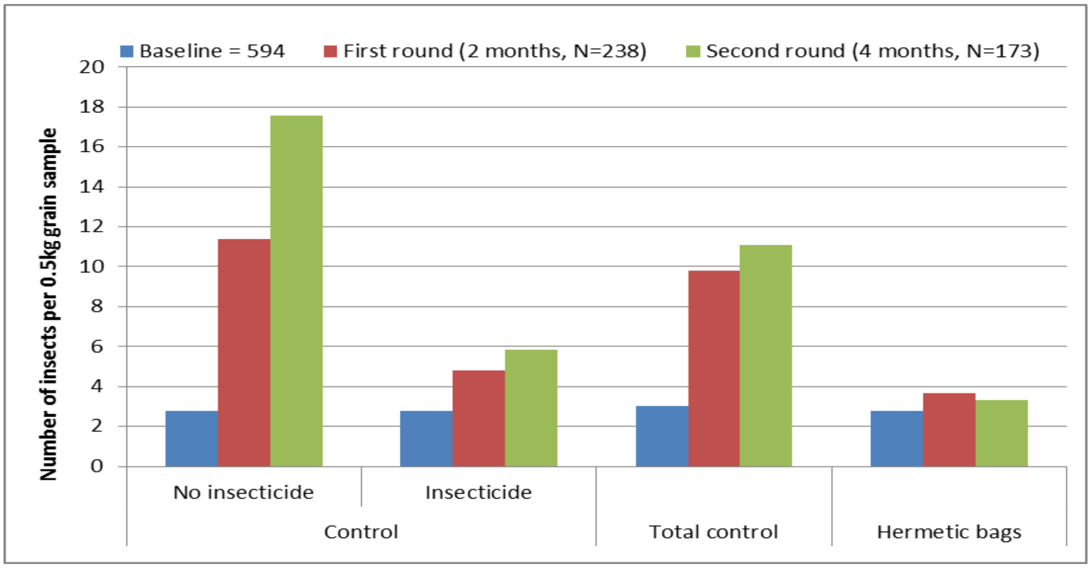

Fig 4: Postharvest pest infestation for treatment and control farmers

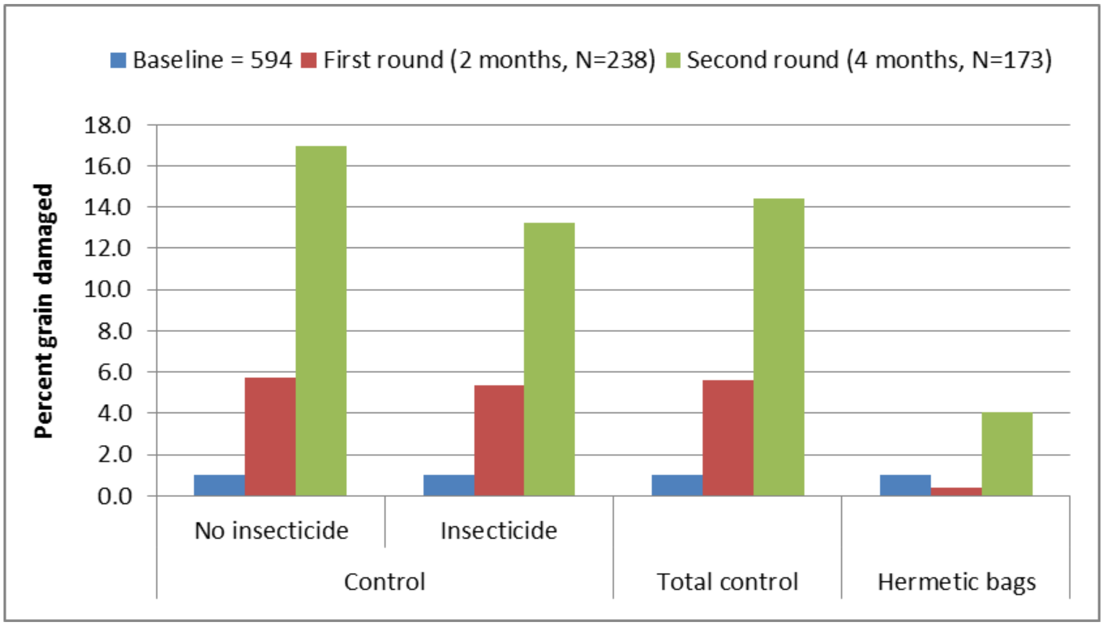

Fig 5: Comparing percentage grain damage between treatment and control farmers.

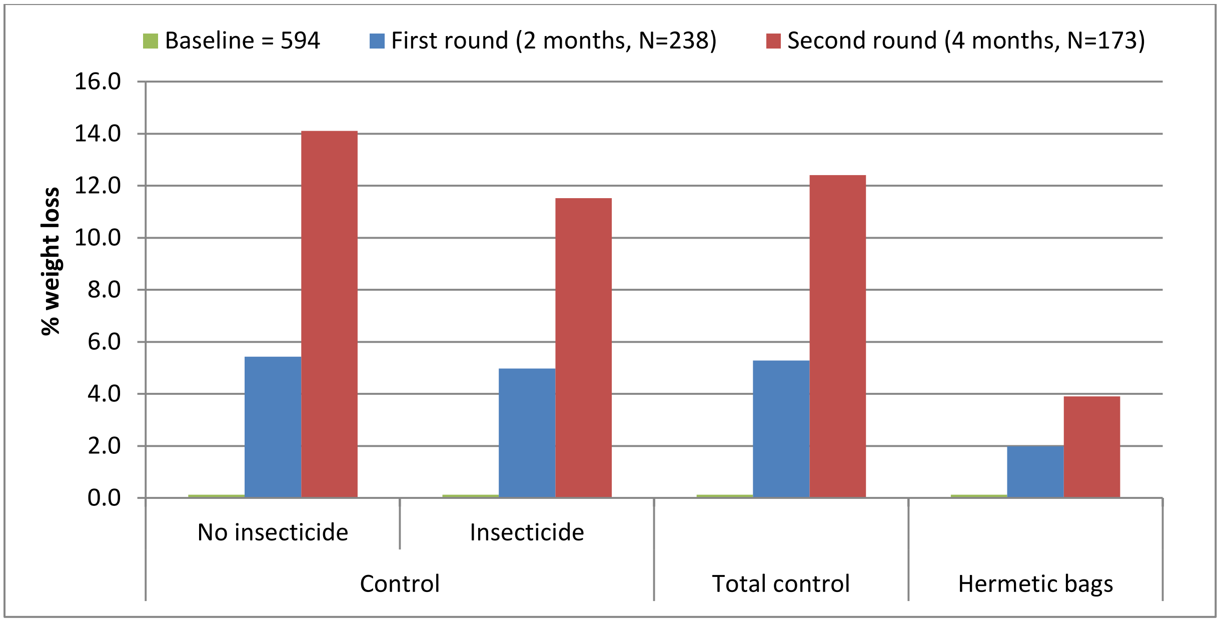

Figure 6: Weight loss in storage after 2 and 4 months, treatment (hermetic bags) vs. control (polypropylene bags with our without insecticide)

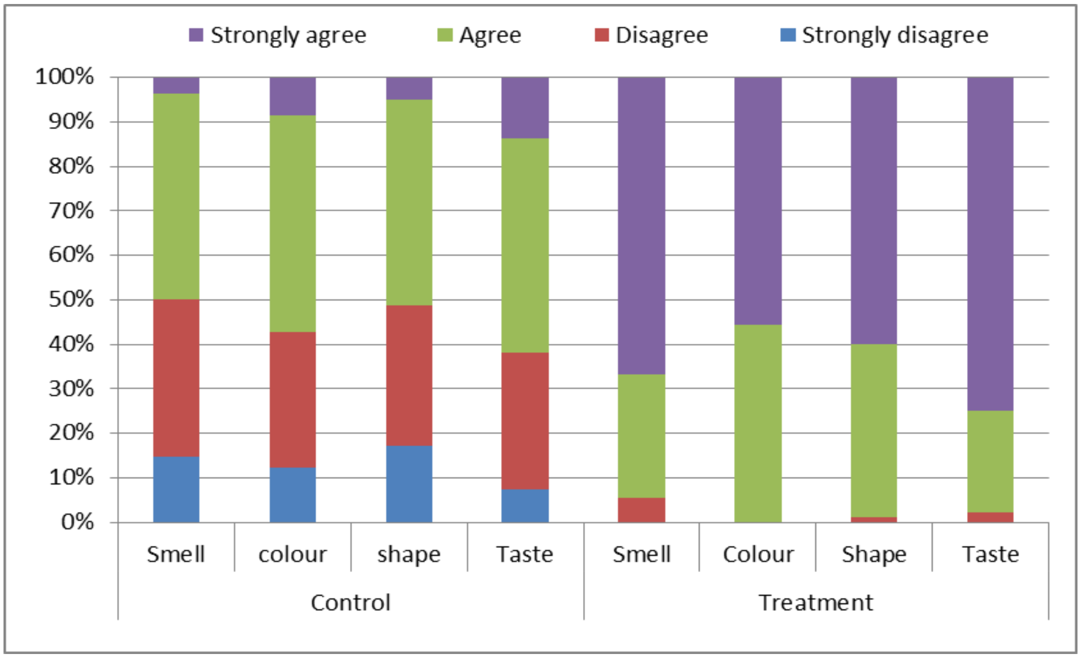

Figure 7: Farmer perception on the quality of the stored grain

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