On-Farm Evaluation of Hermetic Technology Against Maize Storage Pests in Kenya

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Abstract

On-farm trial with a total of 32 farmers in eight villages of Naivasha and Nakuru areas of Kenya was conducted between December 2013 and September 2014 to evaluate hermetic grain storage technologies under farmers’ management conditions. The storage technologies evaluated were metal silo and SuperGrain IV-R bag alongside the standard woven polypropylene bag with or without Actellic super dust. Moisture content, insect population, grain discoloration, and weight loss were analyzed 90, 180, and 270 d after storage. Grain moisture content remained stable over the storage period. Both metal silo and SuperGrain IV-R bag suppressed insect population, prevented grain loss and cross-infestation of insects from the surrounding environment. On the contrary, polypropylene bags allowed rapid build up of insect population and re-infestation from the surrounding environment. Grain weight losses were 1.5% in the metal silo and 1.8% in the SuperGrain IV-R bags compared to 32% in the polypropylene bags without Actellic Super dust, 270 d after storage. The present study, therefore, demonstrates that storing grains either in metal silo or SuperGrain IV-R bags would benefit farmers in reducing grain losses and improving quality. The study was of great interest to the farmers, grain storage scientists, and food security experts.

Key words: maize, metal silo, on-farm storage, Prostephanus truncatus, Sitophilus zeamais

Maize (Zea mays) is widely grown in Africa as a staple food and cash crop (McCann 2005, Nuss and Tanumihardjo 2010). The production of maize in Kenya declined from 3.1 to 2.6 million tons in 2011 and 2012, respectively (Karemu et al. 2013). Among the factors that contributed to the decline in maize production include unpredictable rainfall pattern, conversion of land under maize into sugarcane-producing farms following the construction of new sugar factories in western Kenya, and the maize lethal necrosis disease (MoA, 2013). The majority of maize producers are small- to medium-scale farmers. Since maize production is seasonal, storage of the harvested grain for prolonged periods becomes necessary. However, small-scale farmers still experience high postharvest losses due to application of ineffective storage methods.

Postharvest losses in developing countries are high due to, among other factors, poor handling practices and inadequate and ineffective storage structures (World Bank 2011, Affognon et al. 2015). The reuse of contaminated and perforated bags among small-scale farmers predisposes the stored grain to insect infestation (Abass et al. 2014). The on-farm storage losses of maize in Kenya are estimated at 30% (Mutambuki et al. 2011, Karemu et al. 2013). Hodges et al. (2011) estimated maize grain loss at 17.5% for East and Southern Africa. The total postharvest losses of maize in Africa vary from 14 to 36% (Tefera 2012). Whereas developing countries have subsidized farm inputs such as fertilizer to increase productivity, small-scale farmers lack effective storage facilities to store the surplus. The high grain losses during on-farm storage therefore deny the farmers the opportunity to attain food security and increased income. The 2011 World Bank report on “Missing Food” and Villane et al. (2012) showed lack of substantial adoption of improved grain storage technologies in Africa. Among the factors contributing to low adoption include lack of knowledge on the available storage technologies and their effectiveness. Adequate levels of improved storage technologies at household and national levels which reduce losses by maintaining stored grain dry and free from pest attack are important component of food security.

New small-scale technology, based on hermetically sealed high-density polyethylene bag, provides cheap and effective storage alternative for small-scale farmers that would substantially contribute to food security (Obeng-Ofori 2011, De Groote et al. 2013), in particular vulnerable women farmers. The transfer to and adoption of the technologies by the farmers is a function primarily carried out by research institutions in collaboration with extension service providers.
such as the Ministry of Agriculture and NGOs. Kenyan farmers have long used jute and polypropylene bags for grain storage and transition to hermetic bagging would not be perceived as a radical shift. The main difference between these bags is that hermetic bag generates and maintains anaerobic conditions and that insecticide application is not required (Murdock et al. 2003, Baoua et al. 2012).

Hermetic storage has been used to protect grains since ancient time and enable change in gas composition of the storage structure (modified atmosphere). Oxygen gas is drastically reduced through insect respiration and grain itself and these low oxygen levels kill insects by desiccation (Murdock et al. 2014). The on-farm hermetic storage technology offers farmers safe and effective grain storage throughout seasons, opportunity to smooth hunger between crop harvests and for the improved farm income by selling at higher prices when demand outstrips supply (Florkowski and Xi-Ling 1990, Moussa et al. 2014). It is, therefore, crucial that hermetic storage technologies are readily availed to farmers to safely and maintain the quality of their produce (Thamaga-Chitja et al. 2004).

Hermetic bagging is widely practiced in West and Central Africa for the storage of cowpeas (Moussa et al. 2014), and research has been extended to other crops such as maize (Ognakossan et al. 2013, Baoua et al. 2014). However, adoption of hermetic storage technologies in Kenya has been slow. In West Africa where hermetic bagging technology had been promoted for over 20 yr, about 50% of the cowpeas stored on farm are in hermetic containers (Moussa et al. 2011, 2014).

Moussa et al. (2014) found that, depending on the technology, the lack of adoption is due to unavailability of the hermetic storage technologies at the local level when needed, lack of information on their effectiveness, and cost of the technology.

Another hermetic storage technology is the metal silo. Metal silo is made from galvanized plain sheet and as such provide a durable strong barrier against insect pests and rodents and allow for long-term storage. The silo is air-tight and hermeticity is achieved by lit wax candle to deplete oxygen; thus, pests in the grain die of hypoxia. The technology has been promoted in Central America (Bokusheva et al. 2012) and in sub-Saharan Africa, in Kenya (Tefera et al. 2011) and Malawi (Singano et al. 2012) for storing grain. By year 2011, >2,300 metal silos had been fabricated and distributed in Kenya (Gitonga et al. 2013). The International Maize and Wheat Improvement Centre (CIMMYT) in collaboration with national partners have trained several artisans to make silos of various capacities in eastern and southern African countries. Whereas metal silo technology is effective for the control of the major grain storage pests, the adoption by small-scale farmers remain low. The initial cost of the metal silo is prohibitive for the resource poor farmers (Tefera et al. 2011) while that of the hermetic bag is relatively cheaper.

It is hypothesized that participation of group members in the on-farm evaluation of hermetic storage technologies and exposure to usage and handling of the containers will hasten the spread of information on the use and effectiveness of the technology and help the farmers to make an informed decision about the technology. The objective of this study was to evaluate the effectiveness of two hermetic technologies, SuperGrain IV-R bag and metal silo, under farmers’ management practices for long-term protection of maize against storage pests.

Materials and Methods

Study Site

The trial was conducted between December 2013 and September 2014 under natural infestation where the treatments were left to nature at two sites: Naivasha and Nakuru in the escarpment of the Great Rift Valley of Kenya (Fig. 1). Naivasha is located in the southwestern part of Kenya in the Great Rift Valley between 0.7202° S and 36.4285° E, 2,000 m above sea level, on the shore of Lake Naivasha and along the Nairobi-Nakuru highway and Uganda Railway. Nakasha experiences a tropical savannah climate with one distinct and one less distinct rainy period. In between these two periods there still is reasonable amounts of rain. Because of the altitude, temperatures are slightly lower on average. The main industry is agriculture, especially floriculture. Nakuru lies between 0.3000° S and 36.0667° E at 1,850 m above sea level. The region is cool for most part of the year with mean monthly minimum and maximum temperatures of 10°C and 25°C, respectively. Nakuru is slightly warmer than Naivasha. Maize is among the main crops grown and marketed in the two study sites.

Selection of Farmers for On-Farm Experiment

Farmers groups were identified by the CARITAS Agriculture Programme of the Catholic Diocese of Nakuru based on the differences in agro-ecological zones. The groups in Naivasha and Nakuru subcounties were sensitized on the study in a chosen central place. The members were then allowed to select among themselves those that would participate in the study based on the amount of the maize harvested and the duration they store their grains. Four groups and four farmers from each group were selected per sub-county to participate in the study. A total of 32 farmers participated in the on-farm trial of which 18 were female and 14 male. The total number of farmers was determined by willingness of the farmers to participate in the on-farm trial.

Description of Storage Containers

Three storage containers were used: the metal silo, SuperGrain IV-R bag, and standard woven polypropylene bag. The metal silo was of one standard design, cylindrical structure, fabricated by trained local tinsmith from galvanized iron sheet (gauge No.24) with a top loading inlet and a lateral unloading spout at the bottom (Bravo 2009) and hermetically sealed with rubber band. The SuperGrain IV-R bag, produced by GrainPro Inc., is a bag made of tougher polyethylene (PE) inner liner, 78 µm thick, with good gas and water barrier properties (Villers et al. 2008, Garcia-Lara et al. 2013). It does not come with a polypropylene woven bag and users buy the woven bag separately. However, for this study the polypropylene bags were provided by GrainPro.

Polypropylene, the farmers’ common storage bags, were procured from local vendors. The bags are made from woven synthetic fibre and deteriorate faster when exposed to sun rays (ACDI/VOCA-Kenya, 2007). The containers were of holding capacity of 90 kg each.

Grain Preparation

The grain which was used in the study had been purchased from the farmers participating in the demonstration. The popular maize cultivar grown in the region was hybrid variety H614. The grains were sun-dried and cleaned by sieving to remove chaff, broken and rotten kernels before storing. No disinfestations of the grains were applied to simulate farmers’ local practice.

Treatments and Experimental Design

The trial comprised four treatments: Metal silos (MS), SuperGrain IV-R bag (SGB), polypropylene bag with grain protectant commonly used by the farmer (PPB + A), and polypropylene bag without grain...
protectant (PPB). PPB + A and PPB were used as positive and negative control, respectively. Actellic Super dust (1.6% Pirimiphos-methyl + 0.3% Permethrin), used as the grain protectant against insect pests, was purchased from local agrovet shops in Naivasha or Nakuru. The experimental design was a completely randomized block design (RCBD) with 32 replications (total number of farmers). Each farmer had all the four treatments.

Experimental Set-up

The metal silos were filled with 90 kg maize grains and a lit wax candle was placed at the center of the grains to remove oxygen in the entrapped air. The lids of the silos were secured with rubber bands (obtained from the used inner tubes of bicycle tyres) re-enforced with wind tape to ensure air-tightness was maintained. Use of lit wax candle and rubber bands are standard recommendations that are widely practiced to ensure hermetic conditions in the metal silos (Tefera et al. 2011). As recommended, the SuperGrain IV-R bags were placed inside polypropylene bags to provide support and handling convenience. After loading with grains (90 kg), the entrapped air was squeezed out and then secured tightly with rubber straps. For positive control, farmers themselves admixed grains with the protectant before filling into the polypropylene bags. The farmers were instructed on how to admix the protectant with maize grain during sensitization sessions. The polypropylene bags were filled with 90 kg treated grains and sealed with sisal strings. Equivalent grains with no insecticide were prepared and filled into polypropylene bags to serve as negative control. All the treatments were kept

Fig. 1. Map of Kenya showing demonstration villages in Naivasha and Nakuru.
on wooden pallet at ambient condition in farmer houses or stores. To prevent the bags from rodent damage, storm (warfarin) blocks were placed strategically in the farmer houses or stores.

Sampling Procedure
Grains were sampled using vertical sampling spear with special care taken not to pierce the bags. At each sampling time, the containers were unsealed and 100 g maize grain drawn from each of the five sampling points (one at the center and four cardinal points near the side) per treatment. After every sampling, the entrapped air was removed as described in the experimental set-up before sealing the containers. Grains from the five points were bulked and the whole lot (500 g) used as a working sample. The duration of the experiment was 270 d with nondestructive sampling every 90 d.

Determination of Moisture Content
Moisture content of the maize grains was determined by Dickey-John Multi-Grain moisture tester (Dickey-John Corporation, Auburn, IL) (wet basis). Moisture content was measured at the beginning of experiment and at every sampling time. Three readings of each sample were taken and the average recorded. At the onset of the storage, the moisture content of maize grain at Naivasha was 13.6 ± 0.0 and Nakuru 13.4 ± 0.1%.

Grain Analysis
Collected samples were separated into grains, insects, and dust (flour generated by feeding activities of insects) by sieving across a set of 4.7- and 1.0-mm aperture screens. The number of live and dead insects was counted and recorded as the total number of insects present. A subsample (a quarter) of grains was obtained by use of a riffle divider. The grains of the subsample were sorted into undamaged, damaged, and discolored fractions. The number of kernels and the weight of each fraction was recorded. The grains were weighed on a precision electronic scale. Discolored grains were expressed as a percentage of the total number of grains. A grain was regarded discolored or rotten when its surface darkened with presence or absence of associated off-odor. Grain weight loss was determined by count and weight method (Boxall 1986):

\[
\text{Discolored grain} \% = \frac{\text{Number of discolored grain}}{\text{Total number of grain}} \times 100
\]

\[
\text{Weight loss} \% = \frac{[(W_u \times N_d) - (W_d \times N_u)]}{W_u \times (N_u + N_d)} \times 100
\]

Where \(W_u\) = Weight of undamaged grain; \(N_u\) = Number of undamaged grain; \(W_d\) = Weight of damaged grain, and \(N_d\) = Number of damaged grain.

Statistical Analysis
The number of insects was \(\log_{10}(\text{count} + 1)\) transformed, while percent discolored grain and weight loss data were square root transformed, in order to stabilize the variances. The transformed data were first analyzed using one-way repeated measures ANOVA (SPSS version 20, IBM Corporation 2011) to compare grain moisture content, insect numbers, percent discolored grain, and weight loss at each storage time among the treatment as the response variable and treatment as the main effect. Storage time represented the repeated factor. Afterwards and separately, each response variable was analyzed using General Linear Model procedure of SPSS, with treatment as main effect. Significant differences between the means were separated by Student Newman–Keuls (SNK) test at \(P < 0.05\). However, for ease of understanding untransformed means are presented.

Results
Changes in Grain Moisture Content With Storage Period
The grain moisture content at Naivasha did not differ significantly within treatments \((F_{3,60} = 2.27; P = 0.09)\) and storage period \((F_{149, 93.08} = 21.24; P = 0.32)\) and no interaction \((P = 0.34)\) was detected. Although no significant differences were observed, the moisture content at Naivasha increased marginally for grain stored in polypropylene bags between 90 and 270 d of storage. The grains stored in polypropylene bag treated with Actellic Super dust and metal silo recorded the lowest (12.8%) and highest (13.0%) moisture contents after 270 d of storage, respectively (Table 1a). In Nakuru, no significant differences were noted with storage time \((F_{3,120} = 2.30; P = 0.11)\). However, the grain moisture content increased marginally between 90 and 180 d of storage. The treatment effect on grain moisture was significant \((F_{3,60} = 2.81; P = 0.05)\) but there was no interaction with storage time \((F_{6,120} = 2.17, P = 0.051)\). The grains stored in polypropylene bag treated with Actellic Super dust and SuperGrain IV-R bag recorded the lowest (12.3%) and the highest (13.3%) moisture contents after 270 d of storage, respectively (Table 1b). Overall, the moisture content of the grains stored in the metal silo and SuperGrain IV-R bags at Naivasha and Nakuru was the same. In general, however, the grain moisture content remained below the maximum recommended moisture content of 13.5% for safe storage of maize grain in jute bags in warehouses.

Effect of Treatments on the Total Number of Adult \(P.\ truncatus\) and \(S.\ zeamais\)
The baseline data at the onset of the trial confirmed the presence of live adult forms of \(P.\ truncatus\) and \(S.\ zeamais\). Of the 16 baseline grain samples taken from Naivasha, two had \(P.\ truncatus\) (1 adult/sample) and nine had \(S.\ zeamais\) (4 adults/sample) while at Nakuru two had \(P.\ truncatus\) (1 adult/sample) and five had \(S.\ zeamais\) (1 adult/sample). The mean difference of the total number of adult insects differed significantly with storage time \((F_{2,120} = 18.45; P < 0.05)\).

Table 1. Mean percent grain moisture content at Naivasha (a) and Nakuru (b)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Storage time (d)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>90</td>
<td>180</td>
</tr>
<tr>
<td>a) Naivasha</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polypropylene bag</td>
<td>12.6 ± 0.2a</td>
<td>13.0 ± 0.1a</td>
</tr>
<tr>
<td>Polypropylene bag + Actellic dust</td>
<td>12.2 ± 0.2a</td>
<td>12.9 ± 0.1a</td>
</tr>
<tr>
<td>Metal silo</td>
<td>13.1 ± 0.3a</td>
<td>12.9 ± 0.1a</td>
</tr>
<tr>
<td>SuperGrain IV-R bag</td>
<td>13.0 ± 0.4a</td>
<td>12.8 ± 0.1a</td>
</tr>
<tr>
<td>b) Nakuru</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polypropylene bag</td>
<td>12.7 ± 0.1a</td>
<td>12.9 ± 0.0a</td>
</tr>
<tr>
<td>Polypropylene bag + Actellic dust</td>
<td>12.5 ± 0.1a</td>
<td>12.9 ± 0.1a</td>
</tr>
<tr>
<td>Metal silo</td>
<td>12.7 ± 0.2a</td>
<td>13.0 ± 0.2a</td>
</tr>
<tr>
<td>SuperGrain IV-R bag</td>
<td>12.6 ± 0.2a</td>
<td>12.8 ± 0.3a</td>
</tr>
</tbody>
</table>

Means within a column followed by the same letter are not significantly different (SNK test, \(P > 0.05)\).
Effect of Treatments on Percentage Discolored Grain

Prior to storage, the percentage of discolored maize grains was 5.4 ± 1.1% for Naivasha and 6.4 ± 1.1% for Nakuru. In Naivasha, the percentage of discolored grains varied significantly with treatment ($F_{3,60} = 13.24; P < 0.005$; coefficient of variation = 0.33) and storage period ($F_{2,120} = 11.62; P = 0.005$; coefficient of variation = 0.16). Although the interaction between these factors was also significant ($F_{6,120} = 2.71; P = 0.01$) the effect was not large to be important (coefficient of variation = 0.13). The percentage of discolored grains stored in polypropylene bags with or without the protectant reduced significantly with storage time (Table 3a). Polypropylene bag (1.2%) and SuperGrain IV-R bag (10.1%) recorded the lowest and highest percentage discolored grain after 270 d of storage duration.

At Nakuru, the percentage of the discolored grains varied significantly with treatment ($F_{3,60} = 9.88; P < 0.001$; coefficient of variation = 0.39) but not with the storage period ($F_{2,120} = 0.81; P = 0.446$). However, the interaction between these two factors was observed ($F_{6,120} = 2.93; P = 0.01$, coefficient of variation = 0.13). Polypropylene bag (2.3%) and SuperGrain IV-R bag (12.8%) recorded the lowest and highest percentage discolored grain after 270 d of storage duration (Table 3b). SuperGrain IV-R bag and metal silo had the highest percentage discolored grain compared to polypropylene bag with or without Actellic Super dust in the two sites (Table 3). The percentage of discolored grain in SuperGrain IV-R bag and metal silo did not differ significantly in the two sites.

Table 2. Mean number of adult P. truncatus and S. zeamaïs insects combined (both live and dead) at Naivasha (a) and Nakuru (b) per grain sample

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Storage time (d)</th>
<th>Naivasha</th>
<th>Nakuru</th>
<th>Naivasha</th>
<th>Nakuru</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Naivasha</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polypropylene bag</td>
<td>39 ± 1.3c</td>
<td>107 ± 2.3c</td>
<td>385 ± 9.2d</td>
<td>12 ± 0.4a</td>
<td>1.2 ± 0.4a</td>
</tr>
<tr>
<td>Polypropylene bag +</td>
<td>16 ± 7b</td>
<td>121 ± 6.2b</td>
<td>337 ± 11.9c</td>
<td>4.2 ± 1.0a</td>
<td>4.1 ± 1.2b</td>
</tr>
<tr>
<td>Acetillic Super dust</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metal silo</td>
<td>8 ± 2a</td>
<td>12 ± 4b</td>
<td>24 ± 7b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SuperGrain IV-R bag</td>
<td>2 ± 1a</td>
<td>3 ± 2a</td>
<td>10 ± 7a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) Nakuru</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polypropylene bag</td>
<td>35 ± 1.3b</td>
<td>58 ± 10d</td>
<td>454 ± 142d</td>
<td>6.5 ± 1.7a</td>
<td>2.3 ± 0.7a</td>
</tr>
<tr>
<td>Polypropylene bag +</td>
<td>28 ± 8b</td>
<td>41 ± 2.3c</td>
<td>258 ± 98c</td>
<td>8.2 ± 1.5ab</td>
<td>10.5 ± 2.8ab</td>
</tr>
<tr>
<td>Acetillic Super dust</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metal silo</td>
<td>7 ± 2a</td>
<td>13 ± 4b</td>
<td>33 ± 11b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SuperGrain IV-R bag</td>
<td>1 ± 2a</td>
<td>3 ± 1a</td>
<td>12 ± 6a</td>
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</tbody>
</table>

Means within a column followed by the same letter are not significantly different (SNK test, $P > 0.05$).

Effect of Treatments on Grain Weight Loss

There were significant mean differences in percentage weight loss with storage time ($F_{1,85,111.19} = 21.41; P < 0.005$; coefficient of variation = 0.3) and treatment ($F_{3,60} = 33.83; P < 0.005$; coefficient of variation = 0.6) in Naivasha and Nakuru, storage time ($F_{2,120} = 25.24; P < 0.005$; coefficient of variation = 0.3) and treatment ($F_{3,60} = 53.39; P < 0.005$; coefficient of variation = 0.7). The time by treatment interaction was also significant ($P < 0.005$) at the two sites. The results showed significantly increasing trend in grain weight loss over the storage time and treatment in both Naivasha and Nakuru. The grains stored in the metal silo and SuperGrain IV-R bag had the least mean weight loss (0.5 and 1.1%, respectively) compared to grains stored in polypropylene bag (32.1%) in Naivasha 270 d after storage (Table 4a). Over the same storage period, metal silo and SuperGrain IV-R bag recorded weight loss of 1.5 and 1.8%, respectively compared to polypropylene bag (30.0%) in Nakuru (Table 4b). Overall, the efficacy of SuperGrain IV-R bag in preventing grain weight loss was comparable to that of metal silo across the two sites.

Table 3. Mean percentage discolored grain in the samples at Naivasha (a) and Nakuru (b)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Storage time (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Naivasha</td>
<td></td>
</tr>
<tr>
<td>Polypropylene bag</td>
<td>7.0 ± 1.2a</td>
</tr>
<tr>
<td>Polypropylene bag +</td>
<td>8.3 ± 1.1a</td>
</tr>
<tr>
<td>Acetillic Super dust</td>
<td></td>
</tr>
<tr>
<td>Metal silo</td>
<td>10.0 ± 1.7a</td>
</tr>
<tr>
<td>SuperGrain IV-R bag</td>
<td>10.5 ± 2.1a</td>
</tr>
<tr>
<td>b) Nakuru</td>
<td></td>
</tr>
<tr>
<td>Polypropylene bag</td>
<td>7.0 ± 0.6a</td>
</tr>
<tr>
<td>Polypropylene bag +</td>
<td>5.1 ± 0.9a</td>
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<tr>
<td>Acetillic Super dust</td>
<td></td>
</tr>
<tr>
<td>Metal silo</td>
<td>7.9 ± 1.8a</td>
</tr>
<tr>
<td>SuperGrain IV-R bag</td>
<td>9.4 ± 2.7a</td>
</tr>
</tbody>
</table>

Means within a column followed by the same letter are not significantly different (SNK test, $P > 0.05$).

Table 4. Mean percentage weight loss of the grain samples at Naivasha (a) and Nakuru (b)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Storage time (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Naivasha</td>
<td></td>
</tr>
<tr>
<td>Polypropylene bag</td>
<td>2.8 ± 1.1b</td>
</tr>
<tr>
<td>Polypropylene bag +</td>
<td>0.6 ± 0.4a</td>
</tr>
<tr>
<td>Acetillic Super dust</td>
<td></td>
</tr>
<tr>
<td>Metal silo</td>
<td>0.1 ± 0.0a</td>
</tr>
<tr>
<td>SuperGrain IV-R bag</td>
<td>0.2 ± 0.1a</td>
</tr>
<tr>
<td>b) Nakuru</td>
<td></td>
</tr>
<tr>
<td>Polypropylene bag</td>
<td>2.6 ± 1.4a</td>
</tr>
<tr>
<td>Polypropylene bag +</td>
<td>3.4 ± 2.2a</td>
</tr>
<tr>
<td>Acetillic Super dust</td>
<td></td>
</tr>
<tr>
<td>Metal silo</td>
<td>0.2 ± 0.1a</td>
</tr>
<tr>
<td>SuperGrain IV-R bag</td>
<td>0.3 ± 0.2a</td>
</tr>
</tbody>
</table>

Means within a column followed by the same letter are not significantly different (SNK test, $P > 0.05$).
Discussion

The temperature profile of the study areas was high enough to permit insect development and the observed differences in insect population may be attributed to the effect of the treatment. Temperature and grain moisture content influence reproduction rate and life span of insect pests of stored grain. Most storage insects require temperatures higher than 21°C to develop to damaging populations (Storey et al. 1979).

In the two study sites, maize crop is grown once a year and is harvested in October during the onset of the short rains. Unseasonal rains due to climate change may dampen the grains when stooked in the field for drying, a cultural method widely practiced in this region. As small-scale farmers depend on the sun for drying the grains before storage, it is likely that moist grains could be stored in the hermetic containers during unfavourable weather conditions. However, the grain moisture content remained below the maximum recommended moisture content of 13.5% for safe storage of maize grain in jute bags in conventional warehouses. The insects of stored grain obtain water from the grain itself (Hall 1970). When the grain moisture content is below 10%, fewer insects survive (Storey et al. 1979). The grain moisture levels and ambient temperatures in the current study were high enough to allow insect development. The significant reduction in the extent of insect numbers in the metal silo and SuperGrain IV-R bags may be attributed to hermeticity within the containers.

Baseline grain samples prior to storage confirmed the presence of live adult P. truncatus and S. zeamais. These two pests infest maize while the crop is still in the field (Golob and Hanks 1990) and infestations continue during storage (Hodges et al. 1998). On-farm storage study in Bungoma (Western Kenya) by Ngatia and Kimondo (2011) reported the absence of P. truncatus and existence of S. zeamais. In this study, P. truncatus was recorded during the baseline and sampling that followed probably due to its sporadic nature of outbreak. The higher insect population in polypropylene bags alone could have been favored by the commonly grown dent hybrid maize (H614) variety grown in the two study areas and the grain moisture content which was not below 10%, at which development and reproduction of insects stops.

The present results show that Actellic Super dust did not prevent the increase in insect population at Naivasha. This demonstrates that where re-infestation and cross-infestations are likely to occur, repeat application of the insecticide would be required. Moreover, many farmers apply insecticides when infestation has already started (live insects detected) (Golob 1991), which may not be appropriate for the control of P. truncatus, as it would be embedded in the grain and not in contact with insecticide. Grain damage by this pest will therefore persist where long-term storage period is anticipated thus necessitating a repeat application of Actellic Super dust, which is uneconomical practice and predisposes the consumer to health hazard. The insecticidal potency of Actellic Super dust has been shown to reduce with time (Denloye et al. 2008). The insecticide which was used in the study was one month old since the manufacturing date and loss of potency could not be attributed to inadequate control of the insects. A probable reason for this could have been the application method of the insecticide. Farmers sprinkled the insecticide dust to the grains in the polypropylene bags for admixture which probably resulted in a few pockets of uneven treatment. Also the grains in Naivasha were slightly above the recommended moisture content (13.5% wet basis) for safe storage at the start of the study and that might have contributed to the loss of potency of the insecticide. It is known that moist grain can cause a dilution effect and hasten residue degradation of the insecticide (Samson et al. 1988, Arthur et al. 1992).

There was very slow increase in insect population in the SuperGrain IV-R bags than in the metal silo. Before the setup of the experiments, the hermetic bags and metal silos were tested for air-tightness by checking for leakages of squeezed sampled air in the bags and white smoke from smouldering paper in the silos. The observed low insect population might have been caused by very low rate of adult emergence as a result of fewer eggs which were laid during storage in the SuperGrain IV-R bags. Since the containers were opened every 30 d with great care to avoid changes in air composition, fairly hermetic conditions were maintained. The opening of the bags for sampling was therefore not expected to greatly affect hermeticity and the performance of the containers under such conditions. Nevertheless, the unsealing and rescaling of the metal silo might have affected the hermetic conditions that favoured the already laid eggs and/or larvae to develop slowly. Immature stages of many insects have been reported to show higher tolerance than adults in hermetic conditions (Annis 1986, Donahaye 1990). Recently, Kimani (2014) reported emergence of P. truncatus F1 progeny after incubating maize grain stored in the metal silo for five weeks at room temperature.

Upon termination of the trial, inspection showed that six out of 32 SuperGrain IV-R bags were physically damaged (perforated by LGB and rats). SuperGrain IV-R bag is made of tougher polyethylene (PE), 78 μm thick, with good gas and water barrier properties. Therefore, grain volatiles would not be released to the outside to elicit movement of insects into the bag looking for food. Although the holes were evident to the naked eye, their examination by use of hand-held magnifying glass showed that the scratch and tear were less marked around the holes on the side from which the insects perforated the liner, an indication of exit holes (Riudavets et al. 2007). The holes might have been made by LGB attempting to escape the bags when exposed to oxygen-depleted environment. LGB has the ability to bore through hard materials such as a 35-mm-thick plastic (Li 1988). The holes were made near the bottom of the bags. The holed bags therefore failed to attain air-tight conditions resulting in ineffective control of the storage pests. The observation is consistent with that made by Ognakossan et al. (2013) when maize was stored for 150 d. Cowpea bruchid Callosobruchus maculatus F. (Coleoptera: Bruchidae) was found to bore PICS bags during storage in Niger (Baoua et al. 2012) but the hermetic conditions were not completely lost because of the imperforated second liner. Since SuperGrain IV-R bag is a single liner, the integrity of holed bag was lost and consequently could not be re-used.

The majority of farmers in the study area do not clean and sort rotten grains before storing. Maintaining un-discolored or unrotten grains is important since part of the stored produce is used for food and also for sale. Depending on storage period and conditions, hermetic storage may increase the percentage of discolored grains caused by fungal infection such as Aspergillus spp. High storage moisture and temperature are among factors that trigger elevated respiration in grains resulting in discoloration or rotting (Dillahunty et al. 2000). In addition, complex changes caused by localised heating and high humidity due to intense respiration when insect population reach an extremely high level may severely affect discolored or rotten grains in air-tight containers for long periods (Weinberg et al. 2008). Ingestion of such food grains, which may be laden with mycotoxins pose serious health hazard. The present storage trial revealed that the metal silo and SuperGrain IV-R bag recorded marginal increase in the percentage discolored or rotten grains. The grain used in the study was prepared according to the farmers
practice. Farmers do not sort grains to separate discolored or rotten grains before storage. This coupled with the initial grain moisture content (13.6% in Naivasha and 13.4% in Nakuru) might have contributed to the marginal increase in percentage discolored grain stored in the metal silo and SuperGrain IV-R bags and not the hermetic technology itself. Anaerobic condition does not increase the percentage of discolored grains and this study suggests that hermetic conditions were not sufficiently attained. Bokusheva et al. (2012) reported that the grain moisture content of maize before filling the silo must not exceed 13% in order to avoid moulds. Based on grain discoloration, farmers require training on proper postharvest handling procedures and management in order to avoid grain discoloration.

In the present study, grain weight loss of 30% (Nakuru) and 32.1% (Naivasha) was recorded after 270 days storage in the traditional polypropylene bag. Grain weight loss increased with storage duration, reflecting increases in insect population. Kim and Kossou (2003) reported a strong positive correlation between grain weight loss and increase in weevil population. Henckes (1994) reported that weight loss of 3% in stored maize exceeded the economic threshold and that such a level would require control action. Further, grain damage of more than 6% has been reported to cause economic losses (Compton et al. 1998). This study has demonstrated that storage of maize grains in polypropylene bags with or without protectants for more than 180 days could result in significant economic losses at both Naivasha and Nakuru. SuperGrain IV-R bags and metal silo protected maize grains against insect attack and have great potential to reduce weight loss to less than 2% from 30% due to such pests without pesticide. This would improve food security at household level. In addition, the hermetic storage containers safeguard human health and environment since the use of grain protectants is not required. The novelty of this study is the effectiveness of the bio-generated modified atmosphere in maintaining grain quality and use of farmer demonstration as an extension to introduce the technology and guide farmers on the handling and use of hermetic containers. On the overall, the present study confirms earlier estimation of on-farm storage losses of maize in Kenya at 30% (Mutumbuki et al. 2011, Karemu et al. 2013). The finding of the work would be of great use by agricultural policy makers and monitoring of loss reduction activities along maize crop value chain.

In conclusion, the on-farm trial with farmer groups enabled a good number of farmers to become aware of the hermetic storage technology. Hermetic technology using SuperGrain IV-R bag effectively preserved maize grain quality and prevented economic loss from maize weevil and larger grain borer damage. The bags suppressed insect population, grain weight loss and prevented insect cross-infestation from the surrounding. Grain weight loss was significantly low in both metal silo and SuperGrain IVR bags (<2%) compared to the controls. Untreated grains stored in polypropylene bags incurred much higher weight loss (30-32%) over 270 days storage duration. Field observations show that some live insects were still present in the hermetic bags and in the metal silo. While the presence of live insects could be partly due to lack of air-tightness, the assumption that insects will never develop resistance to modified atmosphere need to be tested. In the study area, maize is harvested during short rainy season in October–November. Consequently, drying maize to safe moisture level for storage is difficult to achieve. An effective, affordable, and readily available drying technology need to be evaluated and promoted with the farmers. In addition, further studies on cost benefit analysis and farmers perception about the technologies are required.

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**Reference**


