Journal of
Entomology

ISSN 1812-5670

Academic
Journals Inc.

www.academicjournals.com

OPEN ACCESS Journal of Entomology

ISSN 1812-5670
DOI: 10.3923/je.2017.136.147

Research Article
Control of the Larger Grain Borer *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) in Different Maize Seed and Grain Storage Methods

[1,3]Egas Nhamucho, [2]Stephen Mugo, [1]Linnet Gohole, [2]Tadele Tefera, [1]Miriam Kinyua and [1,3]Eduardo Mulima

[1]University of Eldoret, Chepkoilel Campus, P.O. Box 1125-30100, Eldoret, Kenya
[2]International Maize and Wheat Improvement Center (CIMMYT), P.O. Box 1041-00621, Nairobi, Kenya
[3]Mozambique Agricultural Research Institute (IIAM), P.O. Box 3658, FPLM Av. N. 2698, Maputo, Mozambique

Abstract
Background and Objective: Maize (*Zea mays* L.) is the primary staple food in many African countries, including Mozambique with seasonal production but continuous consumption. Post-harvest losses have been attributed to storage pests with maize weevil [*Sitophilus zeamais* (Motschulsky)] causing 10-20% losses while the larger grain borer [*Prostephanus truncatus* (Horn)] causes losses of between 30-90%. Seed security is the key to household food security among resource poor farmers in developing countries and seed storage methods play an important role in keeping seed viability and seedling vigour over time in susceptible maize cultivars. New storage methods and technologies have been developed to reduce these post-harvest losses. This study was carried out to evaluate the efficacy of different methods on controlling losses from larger grain borer (LGB) infestation. **Materials and Methods:** Five different maize seed storage methods which included metal silos; Super Grain bag™ inside polypropylene bags; polypropylene bag with pre-fumigated seed with Gastoxin™ (a phosphine fumigant); polypropylene bag with Actellic Super® and polypropylene bag alone were evaluated for preservation of seed quality and control of LGB using a complete randomized design replicated four times through 6 months storage sampling within 2 months. One way ANOVA using GenStat (12th edition) statistical software were applied for analysis using 5% level of significance and four specific orthogonal contrasts were used to separate different storage methods. **Results:** Metal silo had the highest efficacy over the 6 months of storage, showing the lowest seed weight loss of 3.9%, the lowest seed damage of 15.6%, a high seed germination of 77% and high vigour, with a low electric conductivity of less than 3.6 $\mu S\ cm^{-1}\ g^{-1}$. The Super Grain bag™ inside polypropylene bag was second in efficacy. The polypropylene bag alone was the worst, showing high seed weight loss of 28.0%, high seed damage of 88.9%, the lowest germination of <5% and worst vigour and with the highest electric conductivity of more than 6 $\mu S\ cm^{-1}\ g^{-1}$. **Conclusion:** The metal silos demonstrated the best efficacy over other storage methods. If adopted, could reduce the negative impact of larger grain borer and other storage pests that causes post-harvest losses among small-scale.

Key words: Maize storage methods, seed viability, seed electro conductivity, metal silo, super grain bag, larger grain borer

Citation: Egas Nhamucho, Stephen Mugo, Linnet Gohole, Tadele Tefera, Miriam Kinyua and Eduardo Mulima, 2017. Control of the larger grain borer *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) in different maize seed and grain storage methods. J. Entomol., 14: 136-147.

Corresponding Author: Egas Nhamucho, Mozambique Agricultural Research Institute (IIAM), P.O. Box 3658, FPLM Av. N. 2698, Maputo, Mozambique
Tel: +258-829640710

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Maize (*Zea mays* L.) is propagated through seed. In Eastern and Southern Africa, about 70% of farmers use saved grain as seed[1,2]. Seed storage, therefore, plays a major part in ensuring seed quality, seed viability and good seedling vigour, in addition to ensuring stable food supply[2,3]. Storage pests, fluctuations in temperature, relative humidity and prolonged storage in traditional stores result in considerable loss of seed quality[4,5]. Despite significant advances in seed and grain storage methods, many African communities still rely on traditional storage methods[2,6] and the most common being polypropylene bags, gunny bags, fireplace and non-airtight traditional silos (inqolobane)[7,8]. The seed storage method and the length of storage are major determinants of seed quality, seed viability and good seedling vigour[2,3].

On strengthening seed systems for food security, ICARDA[9] writes, ‘‘80-90% of food grains in many developing countries still depend on informal seed systems that consist of recycling older varieties saved during harvest and uncoordinated exchanges of seed among farmers’’. For seed quality per se, recent work challenges the notion that farmer networks only keep subgrade seed in circulation. These studies found few significant differences in quality between seed from farmer and seed from formal sources including seed companies[10,11]. There was no evidence to support the claim that seed recycling negatively affects physical quality as much as it does genetic quality[12].

Maize weevil (*Sitophilus zeamais*) and the larger grain borer (*Prostephanus truncatus* Horn) (LGB) are the major storage insect pests of maize seed[4,8]. The LGB can destroy all the stored maize grain resulting in hunger, food insecurity and reducing future maize production for farmers who use the saved grain as seed. Seed storage problems are partly responsible for farmers’ failure to save seeds[2,13].

Chemicals and traditional materials including use of botanical products are some of the strategies, farmers use to control storage pests. The common chemicals are fumigants, especially phosphine gas and Actellic Super®, an organophosphate insecticide dust[14,15]. The botanicals include smoke and ash from plants with insecticidal properties. However, these methods have low maintenance of viability and seedling vigour[7,16].

The lack of effective storage methods for seed and grain among farmers in many African countries leads to use of traditional methods of controlling storage insect pests or immediate sale of the grain after harvest, to avoid losses due to insect pests[6]. The grain, however, fetches low market prices when sold immediately after harvest, thus low economic gain[14]. Successful seed storage would allow grain to be sold when prices are higher, leading to generation of more income[14].

New and effective grain storage technologies affordable to small-scale farmers have been developed. These storage methods include hermetic technologies-the metal silo and Super Grain bag™-where the depletion of oxygen inside the container suffocates and kills the insect pests before they cause significant damage to the seed[14,17].

The metal silo, is a cylindrical metal container made of galvanized flat iron sheets, which has been used widely in Central America for on-farm grain storage. It has been promoted in various countries in Africa including Kenya, Malawi, Swaziland, Zambia and Zimbabwe by governments and non-governmental organizations[18]. The Super Grain bag™ was developed by GrainPro as a unique solution to rice storage but it is also suitable for storage of other cereals. The Super Grain bag™ fits as a liner inside existing storage bags[19]. Super Grain bags have only been tested and proven for grain storage but not for seed storage.

Seed quality is important in crop production, determining germination and consequently the stand count. Good seed storage methods are those that maintain seed quality and particularly so, seed vigour[3]. Seed vigour is the sum total of those properties of the seed that determine the level of activity and performance of the seed during germination and seedling emergence[20]. Direct and indirect tests can be done to assess seed vigour. The direct tests include the cold test where an environmental stress is reproduced in the laboratory and the percentage and/or rate of seedling emergence is recorded. The most used indirect tests are electrical conductivity and the tetrazolium test[20,21].

The objective of this study was to evaluate five maize seed and grain storage methods namely: Metal silos; Super Grain bags inside polypropylene bag; polypropylene bag with pre-fumigated seed with Gastoxin™ (phosphine fumigant); polypropylene bag with Actellic Super® and polypropylene bag alone; to identify suitable methods for farm seed storage based on grain damage and seed viability.

MATERIALS AND METHODS

Seed production: The seed for the experiment was produced under irrigation at the International Maize and Wheat Improvement Center (CIMMYT)/Kenya Agricultural and Livestock Research Organisation (KALRO) Crops Research Station, Kiboko, Makueni County. The Kiboko Station lies 2°15' S and 37°75' E, at altitude of 950 m. The average annual rainfall is 530 mm with temperatures ranging from 14.3-35.1°C and the soils are sand clay. Two seeds were planted/hill in a row of 5 m length and thinned to one seedling/hill 2 weeks after emergence. The row spacing was 75 cm apart and plant-to-plant distance of 25 cm giving a population density of 53,000 plants ha^{-1}. Fertilizers were applied at the rate of 60 kg N and 60 kg P_2O_5 ha^{-1} as recommended for the Kiboko area. Supplemental irrigation was applied when needed. The fields were hand-weeded. The crop was harvested manually. The maize was sun dried for a week, to attain 12-13% moisture content in preparation for evaluation of the different storage methods.

Post-harvest laboratory evaluation: This experiment was set up in November, 2010 at CIMMYT/KALRO post-harvest laboratory. The study evaluated the efficacy of the five storage methods for maize seed storage using two factors: Storage method and sampling time. The sampling time was made a factor to facilitate destructive sampling for each storage method. The storage methods evaluated were: (1) Metal silo, (2) Super Grain bag placed inside a polypropylene bag, (3) Polypropylene bag, (4) Polypropylene bag with seed treated with Actellic Super® and (5) Polypropylene bag with seed fumigated for seven days with Gastoxin™ (phosphine fumigant) to kill any insects or eggs that may have been present on the grain due to natural, random insect attack in the field. Actellic Super® was bought at agro-vet shops in Nairobi, where most of the farmers around buy and it was applied at the recommended rate of 25 g of Actellic Super®/50 kg of seed).

Description of the treatments: Metal silo was an airtight cylindrical metal structure constructed from galvanized iron sheet and hermetically sealed. It was therefore, eliminate oxygen, killing any insect pest in the grain. 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[22-24]. They had been tried and introduced to farmers in central America from early 1990s and in Africa from 2008, showing effectiveness in reducing grain damage and losses from storage pests without any pesticide[17,25].

Super grain bag™ also known as the IRRI super bag is a new storage facility developed by GrainPro® Inc. in the Philippines as a unique solution for storage of agricultural commodities in airtight bags. Most agricultural commodities stored in these bags develop a "Modified atmosphere" of low oxygen and high carbon dioxide content ("Hermetic storage"). This storage method works on the hermitic technology concept (airtight), where the lack of air inside the container suffocates and kills insect pests and reduce the seed damage and weight loss[14]. 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[25].

Actellic super is an organophosphate insecticide which controls a wide range of insect storage pests including, grain weevil (*Sitophilus granarius*), maize weevil (*Sitophilius zeamais*), larger grain borer (*Prostephanus truncatus*) and others. It is a cocktail of 1.6% Pirimiphos-methyl and 0.3% Permethrin and can be used on cereals, oilseed rape, linseed and others[14,15]. It has been promoted as an effective chemical against the stored pests in combination with practices like immediate shelling and treating[26].

Gastonix is a phosphine fumigant. Phosphine is an organophosphorus compounds, used to control the existing pests infestation in airtight stores. The gas moves readily through grain from the point of application and leaks quickly through holes in silos or sheeting. The fumigant must be kept in contact with the insects for at least seven days to kill all the stages of the insect's life cycle that usually exists in stored grains. The major advantage of fumigation with phosphine is that insects can be controlled without moving the grain and fumigation gives no residual protection to stored grain (insects will begin breeding, after the phosphine gas concentration has dropped to low levels)[27].

Description of the experiment: The sampling times were after 2, 4 and 6 months from the date when the experiment was set i.e., January, March and May, 2011, respectively.

Ten kilogram of dry and clean maize grain were placed in each storage type and 200 unsexed and active 20-25 days old adult LGB were picked randomly from a laboratory culture and introduced into the storage container as described by Tefera *et al.*[28]. The storage containers were closed tightly. Oxygen in the metal silo was further depleted by introducing a lit candle inside before closing it tightly- using a rubber band. The polypropylene bag and polypropylene bag with Actellic super® were considered as controls because farmers use them to store maize grain and seed. The storage containers were laid out in a factorial arrangement with 15 treatment combinations (5 storage methods and 3 sampling time) in a completely randomized design (CRD) with each treatment replicated 3 times in a shade enclosed with a wire mesh.

Data collection: Data were collected on germination percentage, seed electrical conductivity, seed weight loss, seed damage, seed moisture and number of alive insects

(LGBs and other species). Baseline data of these parameters was taken in 3 replications when the experiment was set. Since the seed was not treated, assessment of a possible infestation from the field was done in 10 samples of 100$\pm$1 g each of clean and undamaged grains sampled randomly, weighed and placed in clean 250 cm^3 glass jars. The tops of the lids of these jars were cut out, leaving only the screw-top rings with fine wire gauze, to allow air circulation (ventilation) inside the jar. These samples were incubated in a controlled temperature and humidity room at 28$\pm$2°C and 65$\pm$5% RH with 12:12 (light:dark) photoperiod for 40 days. The germination and electrical conductivity were taken using ISTA procedures[20]. On each sampling date, a storage container was opened and their contents mixed by hand to get a homogeneous content for each of the storage container. A sample of 500 g from the homogeneous content was taken and separated into grains, insects and flour using 4.7 and 1.0 mm sieves. The grain and flour were weighed and the number of living and dead LGBs and other insects were recorded. Grain moisture was recorded and a sample of 100 g was taken randomly to record the following parameters; (1) Number and weight of damaged (with holes and/or tunnels) grains, (2) Number and weight of undamaged grains, (3) Seed damage percentage, (4) Seed germination percentage and (5) Electrical conductivity of the seed.

The percentage weight loss was estimated using the Count and Weight method described by Boxall[29], expressed from the formula below:

$$\text{Weight loss (\%)} = \frac{\text{Wu} \times \text{Nd} - \text{Wd} \times \text{Nu}}{\text{Wu} \times (\text{Nd} + \text{Nu})} \times 100 \tag{1}$$

Where:
Wu = Weight of undamaged grains
Wd = Weight of insect damaged grains
Nu = Number of undamaged grains
Nd = Number of insect damaged grains

Moisture content: Two random sub-samples of 50 g were picked, tested for moisture content (MC) using Dickey-John Multi Grain Moisture tester and a mean computed for each sample.

Seed damage: Seed damage (SD) was recorded as a proportion of damaged seed over the number of seeds sampled and expressed as a percentage count of seed with visible tunnels (damaged) and the undamaged ones.

Seed germination test: Seed germination was measured by conducting the standard germination test as described by International Seed Testing Association(ISTA)[20] but modified on the number of the seed due to lower number of undamaged seed. Twenty five seeds replicated 4 times were picked randomly from the sample and sown between 2 humid filter papers in a petri dish and placed in a room at a temperature of 20-30°C. The seeds were watered two times a day, to maintain the moisture between the filter papers.

The seedlings were separated into normal, abnormal and dead seeds categories. The seed with stunted, retarded, constricted, broken, decayed or missing primary or/and secondary roots were classified as abnormal. The germinated seed were removed from the petri dish each day while the dead seed were removed on the last day. The germination percentage was computed after 7 days, calculated as a proportion of the normal germinated seed over the total seeds sowed and expressed as a percentage[20].

Electrical conductivity test: Electrical conductivity (EC) of the seed was assessed to measure seed vigour. The EC of the maize seed from the storage methods at each sampling time was determined following the ISTA methods[20]. Two samples of 50 seeds each from each storage method at each sampling time were selected randomly, weighed and immersed in 250 mL of distilled water at 20°C for 24 h for rapid imbibition. The electrical conductivity of the distilled water was determined before immersing the seed into the water as a control using PC 510 pH and Electrical conductivity meter (Eutech instruments, Malaysia). After 24 h, the electrical conductivity of solution (distilled water+seeds) after imbibition was determined using the same equipment.

The electrical conductivity per gram of seed in µS cm^{-1} g^{-1} was computed using the Eq. 2:

$$\text{EC} \left(\mu\text{S cm}^{-1}\ \text{g}^{-1}\right) = \frac{\text{ECf} - \text{ECi}}{\text{Wg}} \tag{2}$$

Where:
EC = Electrical conductivity of 1 g of the seed
ECf = Electrical conductivity after 24 h
ECi = Electrical conductivity distilled water before pouring the seed
Wg = Weight of the 50 seeds (grams)

Data analysis: The analysis of variance (one-way ANOVA) was conducted for the following parameters: Seed germination (%), seed electrical conductivity (µS cm^{-1} g^{-1}), seed damage (%), grain weight loss (%), seed moisture content (%), flour weight (g), number of living insects (LGB and others) using GenStat (12th edition) statistical software[30] to assess differences in the parameters among the storage methods using a 5% level of significance. The means of the parameters to determine the efficacy of the storage methods were separated by specific defined statistical orthogonal contrasts also using 5% as level of significance.

The grain weight loss, seed damage and the seed germination were transformed by angular-transformation $\left(\text{Arcsine}\sqrt{\text{proportion}}\right)$ before subjecting them to analysis in order to normalize the data. The number of alive insects (LGB and others) were also transformed before analyses by logarithm transformation base 10, $[\log_{10}(x+1)]$, where x is the observed value, to normalize the data but the final results are presented as means from the original data. The defined contrasts:

Contrast 1: Polypropylene bag (control 1) vs. polypropylene bag with Actellic Super® (control 2)

Contrast 2: Polypropylene bag (control 1) vs. metal silo, Super Grain bag inside a polypropylene bag and polypropylene bag with fumigated seed with Gastoxin.

Contrast 3: Polypropylene bag with Actellic Super® (control 2) vs. metal silo, super grain bag inside a polypropylene bag and polypropylene bag with a seed fumigated seed with Gastoxin

Contrast 4: Metal silo vs. super grain bag inside a polypropylene bag and polypropylene bag with fumigated seed with Gastoxin

For the results presentation and discussion purposes, the polypropylene bag alone and the polypropylene bag with Actellic Super®, were referenced as control 1 and 2, respectively.

RESULTS

Baseline data for possible in field insect infestation: After the 40 days of incubation in a controlled temperature and humidity room at 28±2°C and 65±5% RH (relative humidity) with 12:12 (light:dark), no single insect and damaged seed were found in the 10 samples, meaning that the seed were harvested without any infestation from the field.

Efficacy of the storage methods: There were significant differences ($p<0.05$) among the storage methods in the parameters measured except the number of non-target live insects at the 2 months sampling time the different storage times (Table 1). The seed collected from the metal silo and Super Grain bag performed better compared to the seed collected from the control 1 in all parameters measured over the 6 months (Table 2-4).

Germination percentage: After 2, 4 and 6 months of storage, the germination of the seed collected from the metal silo, Super Grain bag and polypropylene bag with fumigated seed were significantly ($p<0.05$) higher compared to the germination of seed collected from both controls (Table 1). The germination of seed decreased over the 6 months in all storage methods (Fig. 1). The seed stored in metal silo showed lower reduction in germination compared to the seed stored in other storage containers while the seed stored in control 1 showed the highest reduction in quality depicted by the low germination percentage. Super Grain bag reduced lower germination compared to the control 2 after 6 months of storage.

Seed electrical conductivity: Electrical conductivity was used to determine the vigour of the seed stored in different storage methods over a period of 6 months. High electrical conductivity means low seedling vigour. After 2 months of storage, the electrical conductivity of the seed collected from all evaluated storage methods did not show significant differences (Table 1). However, contrasts for specific comparisons showed the seed collected from the metal silo, Super Grain bag and polypropylene bag with fumigated seed being significantly ($p<0.05$) lower compared to the electrical conductivity of the seed collected from the controls. After 4 months of storage, the electrical conductivity of the seed from the metal silo, Super Grain bag and polypropylene bag with fumigated seed was significantly ($p<0.05$) lower compared to the electrical conductivity of the seed collected from control 1 but not significantly different with electrical conductivity from the seed collected from control 2. After 6 months of storage the electrical conductivity of the seed from the metal silo, Super Grain bag and polypropylene bag with fumigated seed was significantly ($p<0.05$) lower compared to the electrical conductivity of the seed collected from controls.

After 4 and 6 months of storage, the electrical conductivity of the seed from control 1 was significantly ($p<0.05$) higher compared to the electrical conductivity of the seed from control 2 while the electrical conductivity of seed collected from metal silo was significantly ($p<0.05$) lower

Table 1: Statistical contrasts for all parameters collected from different storage methods (means squares and statistical significance)

		Time of storage (months)					
		2		4		6	
Variables	Contrasts	MS[p]	CV (%)	MS[p]	CV (%)	MS[p]	CV (%)
Germination (%)	Geral	0.060*	11.1	0.110***	2.8	0.446***	3.5
	PB (Control 1) vs. PB+ACT (Control 2)	0.002[ns]		0.002*		0.626**	
	PB (Control 1) vs. MS, SGB and PB+Fum	0.164**		0.081***		1.397***	
	PB+ACT (Control 2) vs. MS, SGB and PB+Fum	0.0124*		0.050***		0.045***	
	MS vs. SGB and PB+Fum	0.008[ns]		0.325***		0.370***	
Electrical conductivity (µS cm^{-1} g^{-1})	Geral	0.227[ns]	9.2	1.460***	6.9	3.119***	2.9
	PB (Control 1) vs. PB+ACT (Control 2)	0.009[ns]		0.930**		1.650***	
	PB (Control 1) vs. MS, SGB and PB+Fum	0.428*		1.977***		4.560***	
	PB+ACT (Control 2) vs. MS, SGB and PB+Fum	0.596*		0.050[ns]		0.320**	
	MS vs. SGB and PB+Fum	0.051[ns]		3.150***		7.319***	
Seed damage (%)	Geral	0.127***	2.0	0.240***	3.1	0.390***	2.7
	PB (Control 1) vs. PB+ACT (Control 2)	0.000ns		0.141***		0.000[ns]	
	PB (Control 1) vs. MS, SGB and PB+Fum	0.300***		0.485***		0.208***	
	PB+ACT (Control 2) vs. MS, SGB and PB+Fum	0.287***		0.056***		0.197***	
	MS vs. SGB and PB+Fum	0.378***		0.377***		1.230***	
Seed weight loss (%)	Geral	0.006***	5.9	0.041***	12.4	0.053***	3.1
	PB (Control 1) vs. PB+ACT (Control 2)	0.006***		0.040***		0.027***	
	PB (Control 1) vs. MS, SGB and PB+Fum	0.018***		0.097***		0.090***	
	PB+ACT (Control 2) vs. MS, SGB and PB+Fum	0.002***		0.004[ns]		0.009***	
	MS vs. SGB and PB+Fum	0.003***		0.051***		0.112***	
Seed moisture content (%)	Geral	1.542*	4.8	2.612***	3.7	5.503***	4.8
	PB (Control 1) vs. PB+ACT (Control 2)	0.107ns		0.070[ns]		0.042[ns]	
	PB (Control 1) vs. MS, SGB and PB+Fum	1.440ns		2.127**		2.614**	
	PB+ACT (Control 2) vs. MS, SGB and PB+Fum	2.560*		3.180**		1.868*	
	MS vs. SGB and PB+Fum	1.620[ns]		5.894***		18.402***	
Dust weight (g)	Geral	169.413***	6.6	4577.836***	5.4	9666.900***	15.5
	PB (Control 1) vs. PB+ACT (Control 2)	0.380[ns]		3122.233***		1837.500**	
	PB (Control 1) vs. MS, SGB and PB+Fum	396.541***		12022.757***		15361.900***	
	PB+ACT (Control 2) vs. MS, SGB and PB+Fum	427.180***		1698.539***		5104.100***	
	MS vs. SGB and PB+Fum	8.255***		5369.934***		18007.000***	
LGB alive	Geral	0.680***	3.4	1.700***	10.0	1.744***	7.3
	PB (Control 1) vs. PB+ACT (Control 2)	0.032*		0.000[ns]		0.020[ns]	
	PB (Control 1) vs. MS, SGB and PB+Fum	1.497***		0.985***		0.675***	
	PB+ACT (Control 2) vs. MS, SGB and PB+Fum	1.010***		0.951***		0.987***	
	MS vs. SGB and PB+Fum	0.640***		5.242***		5.600***	
Other insects alive	Geral	0.048[ns]	73.3	0.319***	4.5	1.907***	8.1
	PB (Control 1) vs. PB+ACT (Control 2)	0.070[ns]		0.062**		0.237**	
	PB (Control 1) vs. MS, SGB and PB+Fum	0.010[ns]		0.113***		1.710***	
	PB+ACT (Control 2) vs. MS, SGB and PB+Fum	0.181[ns]		0.001ns		0.506***	
	MS vs. SGB and PB+Fum	0.000[ns]		1.153***		5.735***	

PB: Polypropylene bag, MS: Metal silo, PB+ACT: Polypropylene bag+Actelic super, SGB: Super Grain bag, PB+Fum: Polypropylene bag+fumigated seed with Gastoxin, MS: Mean square, [p]Probability, *Significant at 5%, **Significant at 1%, ***Significant at 0.1%, ns: Non significant

Table 2: Means of different parameters after 2 months of storage of the seed collected from different storage methods

Storage system	GP (%)	MC (%)	EC (µS cm^{-1} g^{-1})	SD (%)	WL (%)	DW (g)	Alive LGB[#]	Other insect. alive[#]
Metal silo	89.33	14.60	2.90	3.11	7.41	1.74	12.00	2.00
Super Grain bag in polypropylene bag	84.00	14.10	2.98	8.98	9.18	2.47	35.00	2.00
Polypropylene	63.67	13.20	3.44	35.07	18.92	16.37	191.00	2.00
Polypropylene+Actellic	67.33	12.90	3.52	34.28	12.66	16.88	136.00	2.00
Polypropylene with fumigated seed	85.33	13.20	3.14	10.17	13.59	5.08	56.00	3.00
Mean	77.93	13.60	3.20	18.32	12.35	8.51	86.00	2.00
p-value	0.033	0.043	0.096	<0.001	<0.001	<0.001	<0.001	0.731
CV (%)	11.10	4.80	9.20	2.00	5.90	6.60	3.90	81.72

GP: Germination percentage (%), WL: Weight loss (%), MC: Moisture content (%), DW: Dust weight/flour weight (g), EC: Electro conductivity (µS cm^{-1} g^{-1}), SD: Seed damage (%), Alive LGB[#]: Number of LGB insect alive, Other insect alive[#]: Other insects alive

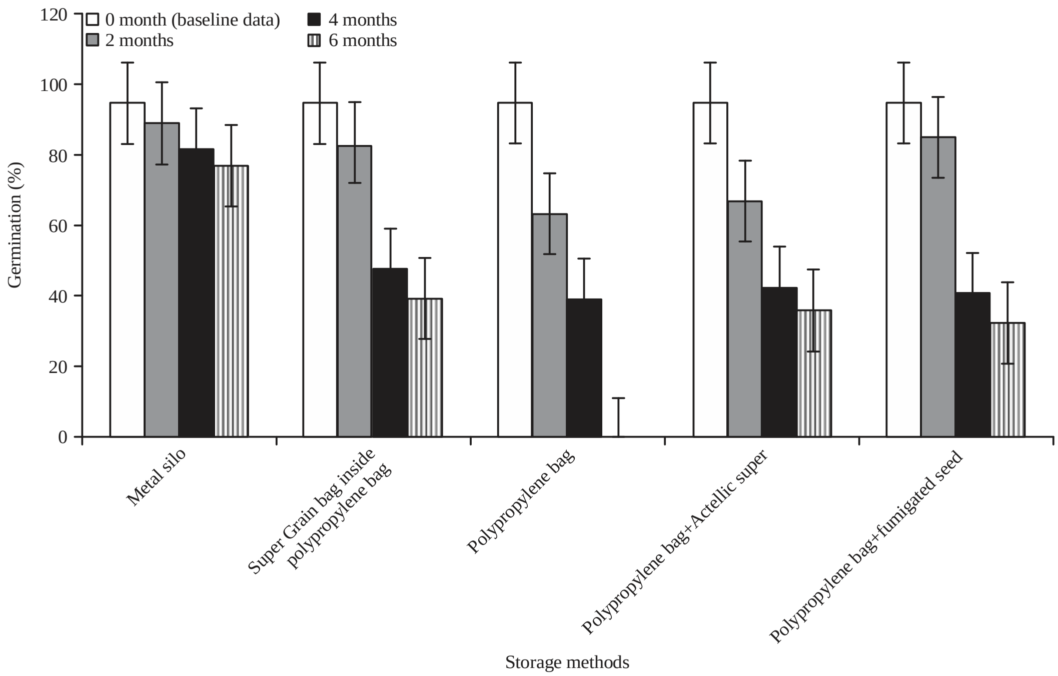

Fig. 1: Germination (%) of the seed collected from different storages methods over time (months)
Error bars represent the Standard Error of Differences (SED)

Table 3: Means of different parameters after 6 months of storage of the seed collected from different storage methods

Storage system	GP (%)	MC (%)	EC ($\mu S\ cm^{-1}\ g^{-1}$)	SD (%)	WL (%)	FW (g)	Alive LGB#	Other insect. alive#
Metal silo	77.33	12.40	3.66	15.61	3.95	10.80	3.00	1.00
Super Grain bag in polypropylene bag	39.62	9.33	5.25	84.04	14.87	81.30	149.00	91.00
Polypropylene	0.00	9.30	6.35	88.90	28.01	156.70	180.00	160.00
Polypropylene+Actellic	36.26	9.47	5.31	88.20	16.81	121.70	225.00	65.00
Polypropylene with fumigated seed	32.69	9.40	5.88	88.45	21.02	130.00	221.00	69.00
Mean	37.18	9.98	5.29	73.04	16.93	100.10	155.00	77.00
p-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CV (%)	3.20	4.8	2.90	2.70	3.10	15.5	7.30	8.10

GP: Germination percentage (%), WL: Weight loss (%), MC: Moisture content (%), DW: Dust weight/flour weight (g), EC: Electro conductivity ($\mu S\ cm^{-1}\ g^{-1}$), SD: Seed damage (%), Alive LGB#: Number of LGB insect alive, Other insect alive#: Other insects alive

Table 4: Means of different parameters after 4 months of storage of the seed collected from different storage methods

Storage system	GP (%)	MC (%)	EC ($\mu S\ cm^{-1}\ g^{-1}$)	SD (%)	WL (%)	FW (g)	Alive LGB#	Other insect. alive#
Metal silo	82.00	12.47	3.12	10.38	1.78	2.52	2.00	12.00
Super Grain bag in polypropylene bag	48.00	10.97	4.04	35.01	5.74	43.41	101.00	74.00
Polypropylene	39.00	10.35	4.90	77.82	18.72	110.16	143.00	64.00
Polypropylene+Actellic	43.00	10.13	4.11	48.81	7.75	64.54	140.00	40.00
Polypropylene with fumigated seed	41.00	10.53	4.72	60.27	11.31	65.25	116.00	64.00
Mean	50.60	10.89	4.18	46.46	9.06	57.18	100.00	51.00
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
CV (%)	2.80	3.7	6.60	3.10	12.40	5.40	10.00	4.50

GP: Germination percentage (%), WL: Weight loss (%), MC: Moisture content (%), DW: Dust weight/flour weight (g), EC: Electro conductivity ($\mu S\ cm^{-1}\ g^{-1}$), SD: Seed damage (%), Alive LGB#: Number of LGB insect alive, Other insect alive#: Other insects alive

compared to the electrical conductivity of seed from Super Grain bag and polypropylene bag with fumigated seed.

The initial electrical conductivity of seed at the storage time was 2.5 $\mu S\ cm^{-1}\ g^{-1}$ and it increased over time, showing the vigour of the seed stored in all storages methods decreased (Fig. 2). The EC of seed stored in metal silo showed the lowest increment after 6 months while the seed stored in control 1 (polypropylene bag) showed the highest increment after the same period of storage.

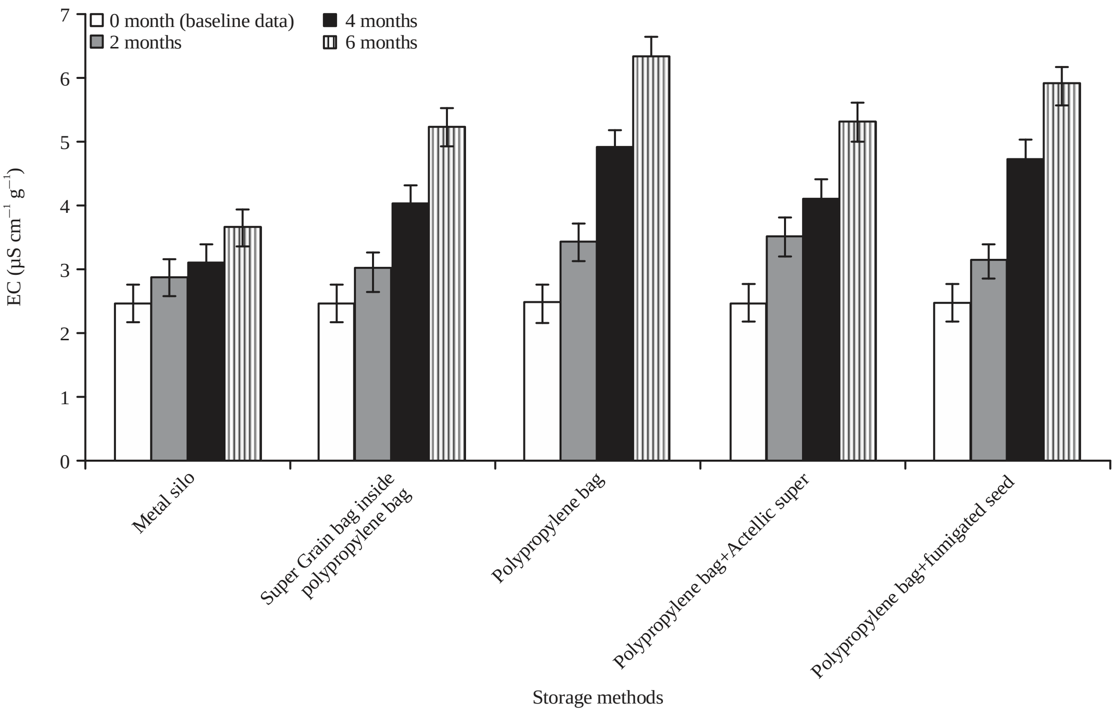

Fig. 2: Electrical conductivity of seed collected from different storages methods over time
Bars represent the Standard Error of Differences (SED)

Seed damage: There were no insects and no damaged seed at the start of the experiment. Seed damage due to larger grain borer from different storage methods showed significant ($p<0.05$) differences after 2, 4 and 6 months. After 2 and 6 months of storage, there were no significant differences between control 1 and 2 (Table 1). After 4 months of storage, seed damage in control 1 was significantly ($p<0.05$) higher compared to control 2. In all sampling time, seed damage in metal silo, Super Grain bag and polypropylene bag with fumigated seed was significantly ($p<0.05$) lower compared to seed damage in the controls. Over the 6 months, seed damage from metal silo was also significantly ($p<0.05$) lower than that in Super Grain bag and polypropylene bag with fumigated seed. Control 1 showed the highest seed damage while metal silo showed the lowest across the whole sampling period, 2, 4 and 6 months of storage, respectively (Fig. 3).

The percentage of damaged seed due to larger grain borer in all the different storage methods increased over the 6 months. Most of the seed collected from the control 1 were converted to powder.

Seed weight loss: After 2, 4 and 6 months, it was observed that the seed weight loss from control 1 was significantly ($p<0.05$) higher than that from control 2 (Table 1). It was also observed that seed weight loss from metal silo was significantly ($p<0.05$) lower than that from Super Grain bag and polypropylene bag with fumigated seed.

After 2 and 6 months of storage, seed weight loss from the metal silo, Super Grain bag and polypropylene bag with fumigated seed was significantly ($p<0.05$) lower than that from the controls. After 4 months, the only significant ($p<0.05$) difference in seed weight loss was between seed from metal silo, Super Grain bag and polypropylene bag with fumigated seed, which was significantly ($p<0.05$) lower than that from control 1.

The seed weight loss due to LGB in different storage methods increased over the 6 months in all the storage methods (Fig. 4). The seed in control 1 had the highest showed higher increase in seed weight loss compared to the seed stored in other storage methods while the seed stored in metal silo had the lowest increase in seed weight loss compared to seed stored in other storage methods.

Moisture content: The seed moisture content was significantly ($p<0.05$) different among the storage methods in the different sampling times, except from control 1 which did not show significant differences compared to the seed collected from control 2 (Table 1). Grain moisture at the start of the experiment was 13%. The moisture content increased during the first 2 months in the airtight storage methods (metal silo and Super Grain bag) and then decreased as in other storage methods (Table 2). After 6 months the lowest moisture content was recorded on seed from the control 1 and the highest from metal silo (Table 3).

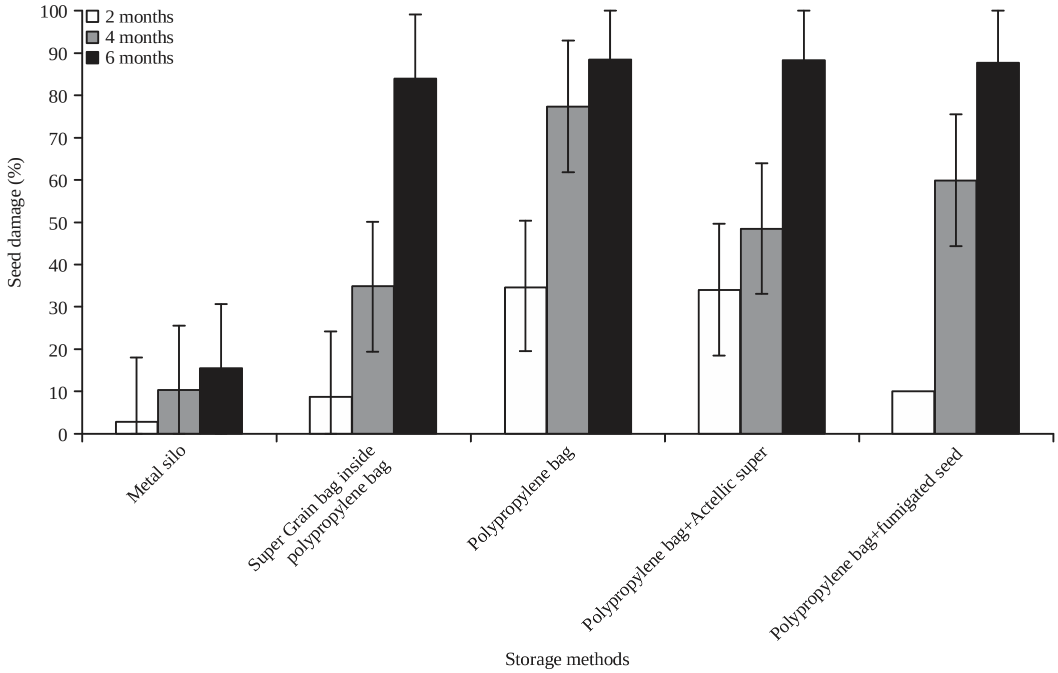

Fig. 3: Seed damage of the seed collected from different storage methods over time (months)
Error bar is the Standard Error of Differences (SED)

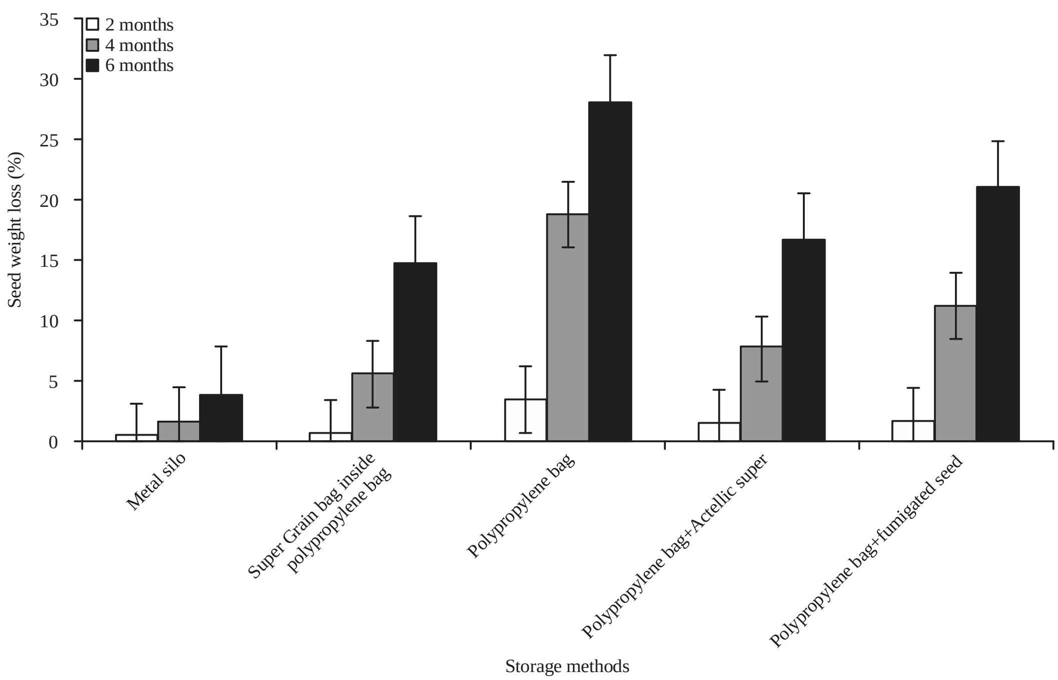

Fig. 4: Seed weight loss of the seed collected from different storages methods over time
Error bars represent the Standard Error of Differences (SED)

Flour weight: The flour weight produced by the seed was significantly ($p<0.05$) different among the storage methods over sampling times (Table 1). Flour weight in the different storage methods due to LGB attack, increased over time (Table 2-4). The increase rate was lowest in the metal silo and highest in control 1 (Table 3).

Number of living LGB and other insects: The number of living LGB and other insects increased from the 2-6 months of sampling in all storage methods except for the metal silo (Table 2-4) and control 1 (only for LGB). The polypropylene bag with Actellic Super® and with fumigated seed showed high increase and the highest number of living LGB while the metal silo showed the lowest number of living LGB. The controls did not show significant difference in number of living LGB after 2 months of storage (Table 1). The non-airtight storage methods had the highest number of live LGB and other insects (non-target ones) (Table 2-4). The most common non-target insects observed were *Sitophilus zeamais* and *Sitotroga cerealella*.

DISCUSSION

Seed germination, seed vigour, seed weight loss and seed damage are key parameters to determine the efficacy of a storage method for seed quality. Seed quality will eventually deteriorate under ambient temperatures, but the rate of deterioration is much reduced under low temperatures and low relative humidity conditions best found in coldrooms and germplasm banks. The best storage method for small-scale farmers is the one that results in slower rate of reduction of seed quality and seed weight loss.

Metal silos showed less seed damage, less seed weight loss, high germination and good seedling vigour and very low insect development over the 6 months. The storage methods that did not allow high insect development were the most efficient as they showed slower rate of reduction of seed weight and seed quality over time. The polypropylene bag that is commonly used by small-scale farmers, performed worst compared to the other storage methods for all parameters over the 6 months: Seed damage over 85%, seed weight loss over 16%, germination less than 5% and low seedling vigour (EC over 5 $\mu S\ cm^{-1}\ g^{-1}$). Polypropylene bag, therefore, is not a good method of storing maize seed and grain. This is in line with previous studies[2,7,31] which showed that traditional storage methods including sacks or polypropylene bag are not efficient in grain storage over time. Polypropylene bag is not airtight and is made of polythene material that allows entry of insect pests in and out of the bag, thus allowing their un-inhibited feeding and reproduction. The non-efficacy of this for germination and vigour is mostly caused by damage to the embryo and endosperm. Storage insect pests develop faster when located between the endosperm and the embryo and hence feed alternately on the germ and the endosperm and thus obtain both proteins and carbohydrates from these tissue. The embryo in maize seed is the most preferred tissue by maize weevil and LGB, most likely because of their high nutritional values[32].

The polypropylene bag with Actellic Super® did not have the expected efficacy in controlling seed damage due to storage insect pests as documented. The results were surprising knowing that Actellic Super® is a well-known chemical most commonly used pesticide for the management of stored product pests in Africa. Actellic Super® has been extensively promoted for long as the alternative method for management of the storage pests among small-scale farmers. The non-effective control of LGB by Actellic Super® was also reported by Kimenju and De Groote[14] who found higher weight loss in grain and seed in the metal silo with Actellic Super® than metal silo without a Actellic Super®. The likely causes are either resistance by LGB as kind of “New pest” to Actellic Super®[33] or to poor quality of the used Actellic Super®, as the sale of “fake” or adulterated pesticides in Kenya has been reported[34].

The Gastoxin™ (phosphine fumigant) showed significant ($p<0.05$) effect only within first 2 months of storage. After this period, seed damage, weight loss and electrical conductivity increased leading to decreased vigour and germination percentage. This can be attributed to the fact that this fumigant is designed to protect grain against the existing infestation from field and not for later infestation. With time, the effect of the gas ceases and new insects can attack and damage the seed. The low damage during the first 2 months could be attributed to the lag phase as the population of the insects build up in the respective storage containers.

The metal silos showed efficacy through the 6 months period due to its airtight property and the material which it’s made of. Similar results about the metal silo were reported by Kimenju and De Groote[14], where after 6 months of storage the grain collected from the it showed a grain weight loss of 1.4% without the application of any insecticide.

Larger grain borer is a wood pest, which can destroy plastic and polythene storages but it can ´ t destroy the galvanized iron sheet. The metal silo is, thus, a very promising storage method for seed and grain and can have a great impact among the small scale-farmers.

An economic analysis on the use of the metal silo concluded that the metal silo prices differ from country to country due to the price of the galvanized iron but are still affordable to the small scale farmers in Africa[14]. The economic gain from use of the metal silo is higher than the loss that could be caused by the insects, if the farmers were using the common storage methods. Metal silos are cheap in the long run, easy to maintain, keeps seed or grains for long with no damage, saves space and are easy to load and offload[17]. Farmers would have great benefits if they use the metal silos to store their maize seed or grain.

CONCLUSIONS

There was variability in the efficacy of the storage methods. The metal silo is the best option for seed storage as it maintains high seed quality: Weight loss less of 4%, damage less of 16%, germination percentage over 75% and good seeding vigour (EC>4 µS cm^{-1} g^{-1}) after 6 months of storage. The use of Super Grain bag requires special attention particularly in areas where there is high infestation of LGB. Its efficiency is compromised because LGB can damage the bag from outside. Results from Actellic Super® were surprising knowing that actellic is the known chemical used for management of stored product pests in Africa with good results.

SIGNIFICANCE STATEMENT

This study showed that use of metal silos and super grain bag for grain and seed storage by small scale farmers can be beneficial for seed and food security. This study further showed that hermetic conditions for storage are an alternative to chemical control for storage pests that has been the main recommendation for small scale farmers.

ACKNOWLEDGMENTS

Authors are gratefully acknowledge the Alliance for Green Revolution in Africa (AGRA -2009 PASS 030) for funding this project. The authors are also grateful to the Syngenta Foundation for Sustainable Agriculture for supporting this work through the Insect Resistant Maize for Africa (IRMA) project (SFSA-CIM-003) and the Africa Productivity Program for Southern Africa (APPSA-IDA 52040) for the financial support to publishing this paper. Authors also thank the CIMMYT Kiboko team for their assistance during experimental set-up and data collection.

REFERENCES

1. Pingali, P. and S. Pandey, 2001. Meeting World Maize Needs: Technology Opportunities and Priorities for the Private Sector. In: CIMMYT 1999-2000 World Maize Facts and Trends. Meeting World Maize Needs: Technology Opportunities and Priorities for the Private Sector, Pingali, P. (Ed.)., CIMMYT., Mexico City, Mexico.
2. 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. Consumer Sci., 32: 8-15.
3. Abba, E.J. and A. Lovato, 1999. Effect of seed storage temperature and relative humidity on maize (*Zea mays* L.) seed viability and vigour. Seed Sci. Technol., 27: 101-114.
4. Jayas, D.S. and N.D.G. White, 2003. Storage and drying of grain in Canada: Low cost approaches. Food Control, 14: 255-261.
5. Shah, W.H., T. Kausar and A. Hussain, 2002. Storage of wheat with ears. Pak. J. Agric. Res., 17: 206-209.
6. Olakojo, S.A. and T.A. Akinlosotu, 2004. Comparative study of storage methods of maize grains in South Western Nigeria. Afr. J. Biotechnol., 3: 362-365.
7. Wambugu, P.W., P.W. Mathenge, E.O. Auma and H.A. van Rheenen, 2009. Efficacy of traditional maize (*Zea mays* L.) seed storage methods in western Kenya. Afr. J. Food Agric. Nutr. Dev., 9: 1110-1128.
8. Bett, C. and R. Nguyo, 2007. Post-harvest storage practices and techniques used by farmers in semi-arid eastern and central Kenya. Proceedings of the 8th African Crop Science Society Conference, October 27-31, 2007, El-Minia, Egypt, pp: 1023-1227.
9. ICARDA., 2013. Strengthening seed systems for robust food security. International Center for Agricultural Research in the Dry Areas, October 8, 2013.
10. Bishaw, Z., P.C. Struik and A.J.G. Van Gastel, 2012. Farmers' seed sources and seed quality: 1. Physical and physiological quality. J. Crop Improv., 26: 655-692.
11. Bishaw, Z., P.C. Struik and A.J.G. Van Gastel, 2013. Farmer's seed sources and seed quality: 2. Seed health. Int. J. Plant Prod., 7: 637-657.
12. Biemond, P.C., O. Oguntade, T.J. Stomph, P.L. Kumar, A.J. Termorshuizen and P.C. Struik, 2013. Health of farmer-saved maize seed in North-East Nigeria. Eur. J. Plant Pathol., 137: 563-572.
13. Delouche, J., 1982. Seed quality guidelines for the small farmer. Proceedings of the Improved Seed for the Small Farmer Conference, August 19-13, 1982, CIAT (Centro Internacional de Agricultura Tropical), Cali, Colombia, pp: 26-29.
14. Kimenju, S. and H. de Groote, 2010. Economic analysis of alternative maize storage technologies in Kenya. Proceedings of the 3rd International Conference of the African Association of Agricultural Economists (AAAE). September 19-23, 2010, Cape Town, South Africa.
15. Syngenta, 2005. Actellic® an effective, broad spectrum insectide for control of public health pests. SPH/BEAM/4969/01.05, Switzerland, pp: 1-8.

16. Pats, P., 1985. A survey on maize and potato storage in Kenya, with particular reference to post-harvest losses caused by insects. Examensarbeten-Sveriges Lantbruksuniversitet, Institutionen foer Vaext-och Skogsskydd, Sweden.
17. Tefera, T., F. Kanampiu, H. de Groote, J. Hellin and S. Mugo *et al.*, 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: 24-245.
18. FAO., 2008. Household metal silos: Key allies in FAO's fight against hunger. Agricultural and Food Engineering Technologies Service, FAO., Rome, Italy.
19. Grain Pro, 2010. GrainPro SuperGrainbags^{TM}: The ultimate solution for quality preservation of agricultural commodities in bags. GRAIN PRO., Inc., October 20, 2010.
20. ISTA., 2006. International rules for seed testing. Seed science and technology. International Seed Testing Association (ISTA), Basserdorf, Switzerland.
21. Powel, A., 2009. ISTA: The importance of quality seed in agriculture. Proceedings of the ISTA 2nd World Seed Conference, September 8-10, 2009, ISTA., Italy.
22. CIMMYT., 2010. Effective grain storage for better livelihoods of African farmers project. CIMMYT., Kenya, November 20, 2009.
23. CIMMYT., 2009. Annual report: Effective grain storage for better livelihoods of African farmers project. CIMMYT, Nairobi, Kenya, pp: 3-27.
24. FAO., 2008. Agricultural and food engineering technologies service: Household metal metal silo. Key allies in FAO's fight against hunger. FAO., Rome, Italy.
25. De Groote, H., S.C. Kimenju, P. Likhayo, F. Kanampiu, T. Tefera and J. Hellin, 2013. Effectiveness of hermetic systems in controlling maize storage pests in Kenya. J. Stored Prod. Res., 53: 27-36.
26. Farrell, G. and G.G.M. Schulten, 2002. Larger grain borer in Africa: A history of efforts to limit its impact. Integrated Pest Manage. Rev., 7: 67-84.
27. Kaley, K.B. and C. Salocks, 2003. *Ephedrine* and *Pseudoephedrine*: Technical support document. Toxicology Clandestine Drug Labs, Methamphetamine, pp: 1-2.
28. Tefera, T., S. Mugo and P. Likhayo, 2011. Effects of insect population density and storage time on grain damage and weight loss in maize due to the maize weevil *Sitophilus zeamais* and the larger grain borer *Prostephanus truncatus*. Afr. J. Agric. Res., 6: 2249-2254.
29. Boxall, R., 1986. A critical review of the methodology for assessing farm level grain losses after harvest. Report of the Tropical Development and Research Institute, Great Britain, TDR G191, pp: 1-139.
30. VSN., 2010. Reference Manual Release 12: Genstat Procedure Library PL20. 12th Edn., VSN. International Ltd., Oxford, UK.
31. Meikle, W.G., R.H. Markham, C. Nansen, N. Holst, P. Degbey, K. Azoma and S. Korie, 2002. Pest management in traditional maize stores in West Africa: A farmer's perspective. J. Econ. Entomol., 95: 1079-1088.
32. Schoonhoven, A.V., R.B. Mills and E. Horber, 1974. Development of *Sitophilus zeamais* Motschulsky, in maize kernels and pellets made from maize kernel fractions. J. Stored Prod. Res., 10: 73-80.
33. Perez-Mendoza, J., 1999. Survey of insecticide resistance in Mexican populations of maize weevil, *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae). J. Stored Prod. Res., 35: 107-115.
34. Panapress, 2002. Fake pesticides feared to affect Kenyan harvest 2002. Islamic Development Bank, Nirobi, Kenya.