Participatory on-farm evaluation of some storage methods and grain protectants on quality characteristics of maize (*Zea mays L*)

Abstract

Aim: The study seeks to improve the livelihoods of farm families by deploying appropriate storage and grain protection methods to reduce on-farm storage losses.

Place and duration of Study: Multi-location experiments were established at 4 communities of the Upper East Region of Ghana from November 2012 to December 2013.

Methodology: For each treatment, 50kg of maize was stored in jute sacs (JS), polypropylene sacs (PS), hermitic triple-layer sacs (HTS) and hermitic poly-tanks (HPT). Both Actellicand phostoxin fumigation were applied at recommended rates. Destructive grain sampling (100g) was done every 2 months for determination of grain characteristics and loss assessment. Scoring for grain quality was done using a 5-point objective scale.

Results: Overall difference was due to the method of storage, influence of the 2 grain protectants was not consistent. Marginal loss of bulk density (9.6 to 14.8%) occurred in HTS and HPT compared to PS and JS (15-17%). Low postharvest losses (2.2-5.8%) was incurredin HTS and HPT compared to PS and JS which showed up to 7.2-31.5% losses. At 12 months after storage, grain stored in the HTS and HPS recorded high quality scores (1.2C to 1.8F), indicating clear grain (C) or few insects (F) which were irregularly distributed and difficult to find by untrained eye.

Conclusion: Although the cost of HPT is high, they are more efficient and can be re-used for several years. Due to differences in varieties and pre-storage operations, storage beyond 6 months in JS or PS will require grain protection and close monitoring.

Key words: Maize, hermitic storage, poly-tanks, grain quality, postharvest losses

Introduction

Maize (*Zea mays* L.) has become an important staple food crop in all parts of Ghana. Currently, maize-based cropping systems have become dominant in drier northern savanna areas where sorghum and millet were the traditional food security crops. Maize is the most cultivated crop in Ghana, occupying up to 1,023,000ha on arable land compared to rice (197,000ha), millet (179,000ha), sorghum (243,000ha), cassava (889,013ha), yam (204,000ha) and plantain (336,000) [1]. However, the country is a net-importer of maize even though it has great potential to be self-sufficient and net-exporter. Per capita consumption of maize is estimated at 44 kg/person/year [2]. After harvest, maize is stored on cob in traditional grain silos or shelled into jute or polypropylene sacs with or without protection. However, stored maize can be damaged by insect pests if they are not properly conditioned and protected. Stored-product arthropods can cause serious postharvest losses, estimated from up to 9% in developed countries to 20% or more in developing countries [3]. Conservative estimates are that close to one-third of the world's food crops is damaged by insects during growth and storage. A host of insect pests are a constraint in maize storage including: Red flour beetle (*Triboliumcastaneum*), larger grain borer (*Prostephanustruncatus),* lesser grain borer(R*hyzoperthadominica*)*,* maize weevil, *Sitophiluszeamais,* granary weevil *(S. granarius)* and*Sitotrogacerealella*) [3-5].

Under many circumstances, the most rapid and economic method of controlling insects is the use of insecticides [3]. However, most of the contact insecticides used in stored product insect pest management are lipophilic and accumulate in areas of high fat content such as the germ and bran of cereals[3, 4]. These toxic residues tend to persist in the treated products which may be detrimental to the consumer, affect non-target insect pests as well as lead to insecticide resistance. Indiscriminate use of common grain protectants such as Actellic (Pirimiphos methyl), bioresmethrin (pyrethroid), phostoxin (Aluminum phosphate) is widespread among small-holder farmers [5]. Most farmers acquire agro-chemicals from non-accredited input dealers without prior training on appropriate use. In addition, phosphine fumigation is widely undertaken in unsealed silos and poor sanitation conditions. As a result, control failures with phosphine have become common and many parcels of grain are repeatedly fumigated. Although the potential of insecticidal dust, plant powders, oils and extracts have been studied [6-9] few farmers resort to these options due to lack of rapid knockdown effect; particularly where infestation already exist. In fact, the repellency or toxicity of neem (*Azadirachtaindica*), black pepper (*Piper nigrum*), chili pepper (*Capsicum annuum*), cinnamon (*Cinnamomumaromaticum*), turmeric (*Curcuma longa*), *Zanthoxylumxanthoxyloides*and *Securidacalongependuncata*among others against stored-product insects have been well established [4, 6-9]. Obviously these products have little environmental hazards and low mammalian toxicity.

Across Africa, post-harvest losses in maize are estimated around 10-23% in Kenya, 6-14% in Malawi, 10-20% in Rwanda, 20-100% in Tanzania, 4-17% in Uganda and 9-21 in Zambia[10]. Post-harvest losses in sorghum were estimated at 0-37% in Nigeria, 6-20% in Sudan, 0-10% in Zambia and 25% in Zimbabwe http://www.phlosses.net/. Up to 30% destruction of harvested maize due to pests during storage and handling have been reported in Kenya[10]. With the introduction of *Prostephanustruncatus*, average dry weight losses of farm-stored maize in Togo rose from 7 to 30%, for a storage period of 6 months [11, 12]. In Kenya, weight loss of stored maize increased from 4.5 to 30% after the introduction of P. *truncatus*. During 5-12 month storage period of grains in the Sudan and Guinea Savanna of Nigeria, insect damage ranged from 40-60% for unthreshed sorghum and cowpea, to 36-55% for wheat grains [12]. Analysis of on-farm storage losses in Ghana [5] showed that cowpea and bambara nut recorded higher losses of 13.5 and 11.0 % compared to 3.5, 4.8, 6.7, 2.2, 1.7 and 3.1 % in maize, sorghum, millet, rice, soya bean and groundnut, respectively. There is need for commensurate postharvest strategies to contain harvested surpluses. Integration of good pre-harvest operations, pest management and appropriate storage techniques to minimize pest damage should be emphasized. This study seeks to improve the livelihoods of farm families by deploying improved storage methods to reduce postharvest losses in smallholder on-farm storage. The study demonstrates the appropriate use of different storage methods and grain protectants for prolong storage of maize.

Materials and Methods

Study area

The study was conducted in the Upper East Region (UER) of Ghana. The region lies between longitude $1^{0}15^{'}$W to $0^{0}5'$E and stretch from latitude $10^{0}30^{'}$N to $11^{0}8^{'}$N. The region lies in the Sudan savanna agro-ecology, which forms the semi-arid part of Ghana. Annual rainfall ranges from 800-1200 mm and up to 95% of rainfall occurs August and October. There is wide fluctuation in temperature and relative humidity (RH) averaging around 30±5^{o}C, 60-80 %RH from June to October and 33±5^{o}C, 30-55%RH from November to May each year. This study involved technology development and extension; by disseminating improved storage practices to small-holder farmers. Study sites were established at 4 communities: Manga, Tansia, Azum-Sapielga and Tes-Natinga. Selection of communities was based on their level of involvement in maize production and reports of high incidence of postharvest losses. In Tansia and Azum-Sapielga, the experiments were held in community grain warehouses whilst in Manga and Tes-Natinga, the experiments were set out in ordinary sheds.

Description of experiment

Maize grain was bulked from selected farmers during the harvesting season in November-December 2012. For each package, 50kg of maize was stored in polypropylene sacs (PS), jute sacs (JS), Hermitic Triple-layer sacs (HTS) and hermitic poly-tanks (HPT) with and without grain protectants. Two grain protectants, Actellic Super 5 EC and phostoxin, were applied at recommended rates. Actellic Super 5EC is a food-grade chemical containing 80g Pirimiphos-methyl and 15g Permithrin/L. Phostoxin (Aluminum phosphate) is a food-grade fumigant. Jute sacs are made of natural fiber and polypropylene is an artificial fiber. The HTS has 2 inner plastic layers which provides hermitic conditions for the content stored. The poly-tanks are ordinary plastic drums commonly used in household water storage. They have air-tight seals which provide hermitic conditions for grain stored.

Data collection

Destructive grain sampling of 4 replicates of 100g per treatment was done every 2 months for determination of grain physical characteristics, insect count and loss assessment.Data generated include weight loss, number of bored grains, number of live and dead insects and insect species identification. Scoring for grain quality was done using a 5-point objective scale; where score 1= No insect seen in prolonged search, 2= few insects seen, difficult to find and irregularly distributed, 3= insects are obvious to trained eye and occurring regularly, 4= infestation obvious to untrained eye, large crawling insects in grain mass, 5= Heavy infestation, insects can be seen or heard, crawling on floor/walls.

Estimation of postharvest losses

Loss assessment was conducted using the standard volume weight and gravimetric methods as recommended by [13].

i. **Standard Volume Weight:** the bulk density of grain (kg/m^3) was determined at the beginning and after 12 months of storage. Differences in bulk density after 12 months of storage was taken as average weight loss over the period.

ii. **The count and weight or gravimetric:** the method involves separating damaged and whole grains and a comparison of their weights calculated as a percentage of the entire sample. Loss assessment due to insects is calculated using the equation below:

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

Where W_u= weight of undamaged grain, N_u= number of undamaged grains, W_d= weight of damaged grain, N_d= number of damaged grains

Data analysis

Data was subjected to analysis of variance (ANOVA) using Genstat (Release 9:2 TE) statistical package. Data was analyzed as a 4x3x4 factorial experiment in a completely randomized design. Factor 1: method of storage; factor 2: method of protection; factor 3: location of storage. Insect count data was transformed using square root transformation.Where significant differences existed, mean separation was by Fisher Least Significant Difference (F-LSD) at $P \leq 0.05$.

Results

Grain Characteristics

Loss of grain weight due to insect feeding and physiological activities was determined using loss of thousand grain weight (TGM) and bulk density (BD) (Table 1). In general, TGW was highly variable across different months of storage, due to widefluctuations in ambientconditions (temperature and relative humidity)(Table 1). Grains held in hermitic conditions gained moisture whiles the much aerated sacsbecame dehydrated since the last sampling was conducted in a much drier month of December 2013. InitialBDranged from 81.1- 85.7 kg/m^3 across treatments (Table 1). At 12 months after storage (MAS), the method of storage showed significant ($P \leq 0.001$) influence on BD but the influence of grain protectants was not consistent. Marginal loss of BD (10%) was noticed in all treatments involving hermitic poly-tanks (HPT) compared to 9.6-14.8% losses in Hermitic Triple-layer sacs (HTS). Higher loss of BD (15-17%) occurred in polypropylene sacs (PS) and jute sacs (JS), and much severe losses were noticed in the standard check. Overall loss of TGW and BD was high at Manga and Tes-Natinga compared to Tansia and Azum-Sapielga.

Severaldescriptorswere employed to assess produce quality at storage. These include: number and weight of whole grain, number and weight of damaged grain, number and weight of mouldy grain, number and weight of bored grain, and count of live and dead insects per sample(Table 2).These indicesdepict the potential damage at any given time so that critical management decisions such as protection or disposal options can be chosen. Overall, the method of storage showed significant ($P \leq 0.001$) influence on all physical characteristics but the influence of grain protectants was not consistent. Significant ($P \leq 0.001$) differencesexisted between the HPT andHTS versus the aeratedPS and JS (Table 2).

Table 1. Effect of method of storage and protection on thousand grain weight and bulk density (12 MAS)

Method of storage	Method of protection	Thousand Grain Weight (g)			Bulk Density (kg/m^3)		
		Initial	Final	% Loss	Initial	Final	% Loss

	Control	259.4	238.8	7.9	83.5	69.0	17.3
Poly-sacs	Actellic Super	255.8	240.8	5.8	84.3	73	13.4
	Phostoxin	266.9	251.8	5.3	85.7	72.7	15.0
Jute sacs	Control	263.8	249.5	5.3	83.0	70.6	15.0
	Actellic Super	269.3	272.1	-1.7	83.5	73.1	12.4
	Phostoxin	272.1	264.0	2.8	84.3	71.2	15.6
Triple-layer sacs	Control	241.1	250.2	-3.7	83.3	75.2	9.6
	Actellic Super	249.6	253.2	-2.5	83.5	71.2	14.8
	Phostoxin	259.6	261.4	-1.1	83.3	73.9	11.3
Hermitic Poly-tanks	Control	246.2	269.1	-9.6	83.1	74.8	10.0
	Actellic Super	275.6	271.1	-1.4	83.9	75.4	10.1
	Phostoxin	264.2	268.7	-2.7	84.6	76.1	10.0
		NS	8.199	5.067	NS	1.512	1.977
		0.2	0.3	97.8	0.3	0.2	1.7

Table 2: Influence of method of storage and protection on grain characteristics in relation to insect damage (12 MAS)

Method of storage	Method of protection	Whole grain		Damaged grain		Bored grains		Insect count	
		Number per sample	Weight per sample (g)	Number per sample	Weight per sample (g)	Number per sample	Weight per sample (g)	Dead insects in sample	Live insects in sample
	Control	279.8^{b}	65.4^{d}	75.0^{b}	13.1^{b}	13.1^{b}	5.9^{b}	2.3^{b}	2.4^{bc}
Poly-sacs	Actellic Super	311.6^{ab}	72.1^{c}	43.9^{d}	8.2^{c}	3.9^{e}	2.1^{d}	1.6^{c}	1.8^{bc}
	Phostoxin	278.7^{b}	70.8^{c}	56.3^{c}	10.3^{bc}	9.9^{c}	4.8^{c}	2.3^{b}	2.6^{b}
Jute sacs	Control	212.6^{c}	58.6^{e}	93.5^{a}	18.6^{a}	17.3^{a}	8.0^{a}	3.4^{a}	3.0^{a}
	Actellic Super	267.3^{b}	74.8^{b}	32.8^{e}	6.2^{c}	4.5^{e}	2.6^{d}	1.7^{c}	2.1^{c}
	Phostoxin	288.2^{b}	71.6^{c}	46.2^{d}	11.5^{bc}	8.2^{d}	5.0^{bc}	1.9^{c}	2.1^{c}
Triple-layer sacs	Control	366.0^{a}	79.3^{a}	18.6^{f}	2.5^{d}	1.8^{fg}	1.3^{e}	1.4^{d}	1.3^{d}
	Actellic Super	322.1^{ab}	76.7^{b}	24.2^{ef}	4.9^{cd}	2.2^{f}	1.3^{e}	1.4^{d}	1.5^{cd}
	Phostoxin	326.0^{ab}	76.6^{b}	22.1^{f}	3.8^{d}	2.2^{f}	1.4^{de}	1.5^{cd}	1.5^{d}
Hermitic Poly-tanks	Control	298.7^{b}	80.2^{a}	16.6^{f}	2.2^{d}	1.3^{g}	1.2^{e}	1.4^{d}	1.2^{d}
	Actellic Super	307.5^{b}	80.6^{a}	15.6^{f}	2.8^{d}	1.4^{fg}	1.3^{e}	1.3^{d}	1.3^{d}
	Phostoxin	325.5^{ab}	80.4^{a}	15.0^{f}	1.9^{d}	1.4^{fg}	1.4^{e}	1.3^{d}	1.2^{d}
	CV (%)	3.7	1.6	12.1	10.5	3.3	3.5	3.2	7.2

Data on number and weight of bored grain, and Insect count data was transformed using square root transformation

Loss assessment due to Insects

The species identified were larger grain borer(*Prostephanustruncatus*),lesser grain borer(R*hyzoperthadominica*), maize weevil *(Sitophiluszeamais),* granary weevil *(S. granarius)* and*Tribolium spp*. Only nominal insect count (dead and live) was conducted. The influence of the 2 grain protectants was not consistent, particularly using JS and PS. Initial pest infestation was minimal, but the number of bored grains across treatments shows a latent pest infestation; high infestation levels could show up when favourable conditions exist. Initial infestation begun at irregular spots and spread to entire grain mass in August to October. Overall, similar trends were noticed with infestation and subsequent damage. Critical differences was due to method of storage.Differences in insect count was consistently lower in treated grain compared to the standard check for grain stored in JS or PS.

Similar pattern was noticed in postharvest losses with respect to the method of storage and use of grain protectants (Table 4). Low losses (2.2-5.8%) were incurred in all treatments held in the HTS and HPT compared to those stored in JS and PS which showed up to 7.2-21.1% losses at 12 MAS. Consistently higher losses were noticed in Manga and Tes-Natinga compared to Tansia and Azum-Sapielga. Although these range of losses may look inconsequential at the individual farmer level their cumulative effect on the national food balance sheet is huge. The damage caused by insects was mainly by boring into and feeding on the grain biomass. The frass produced from insect feeding activities often form complexes which promote imbibition of moisture which aggravate secondary pests and mouldgrowth. Under severe infestation, this leads to loss of sensory appeal (colour, aroma and taste) as well as increases in grain temperature, moisture and other microbial activities.

Table 3: Effect of methods of storage and protection on total insect count (12 MAS)

Method of storage	Method of protection	Location of storage				Overall insect count
		Manga	Azum-Sapielga	Tansia	Tes-Natinga	
	Control	6.65^{ab}	2.65^{ef}	2.75^{ef}	7.02^{a}	4.77^{b}
Poly-sacs	Actellic Super	3.52^{de}	2.98^{ef}	3.28^{de}	3.84^{de}	3.41^{c}
	Phostoxin	3.86^{de}	4.84^{dc}	3.90^{de}	7.05^{a}	4.91^{b}
Jute sacs	Control	5.83^{bc}	5.43^{c}	6.62^{ab}	7.57^{a}	6.37^{a}
	Actellic Super	4.06^{d}	3.52^{de}	3.52^{e}	4.05^{d}	3.79^{c}
	Phostoxin	4.40^{d}	2.41^{ef}	3.38^{e}	5.43^{c}	3.91^{c}
Triple-layer sacs	Control	2.76^{ef}	2.62^{ef}	2.94^{ef}	2.41^{ef}	2.68^{d}
	Actellic Super	2.65^{ef}	2.65^{ef}	3.76^{de}	2.65^{ef}	2.93^{d}
	Phostoxin	2.61^{ef}	2.98^{ef}	3.85^{de}	2.41^{ef}	2.97^{d}
Hermitic Poly-tanks	Control	2.41^{ef}	2.41^{ef}	3.16^{de}	2.41^{ef}	2.60^{d}
	Actellic Super	2.51^{ef}	2.41^{ef}	2.94^{ef}	2.41^{ef}	2.57^{d}
	Phostoxin	2.51^{ef}	2.41^{ef}	2.51^{ef}	2.41^{ef}	2.46^{d}
		P≤0.001, LSD= 0.8671, CV(%)= 2.3				

1. Insect count data was transformed using square root transformation 2. Data values along columns with same letters are not significantly different

Table 4: Influence of methods of storage and protection on postharvest losses (12 MAS)

Method of storage	Method of protection	Location of storage				Overall Postharvest Losses (%)
		Manga	Azum-Sapielga	Tansia	Tes-Natinga	
	Control	26.10	3.58	3.73	31.50	16.2^{b}
Poly-sacs	Actellic Super	11.09	10.32	8.89	9.01	9.8^{c}
	Phostoxin	8.10	11.21	7.89	21.11	12.1bc
Jute sacs	Control	25.24	7.59	32.80	21.18	21.7a
	Actellic Super	11.87	5.67	4.21	7.08	7.2^{c}
	Phostoxin	10.10	3.49	30.39	9.67	13.4^{b}
Triple-layer sacs	Control	2.58	2.14	5.43	1.79	3.0^{cd}
	Actellic Super	5.79	7.46	6.25	3.68	5.8^{cd}
	Phostoxin	4.74	3.79	6.10	3.59	4.6^{cd}
Hermitic Poly-tanks	Control	2.67	2.26	3.15	1.94	2.5^{d}
	Actellic Super	5.86	2.79	2.84	1.39	3.2^{cd}

	Phostoxin	3.46	2.79	0.97	1.70	2.2^{d}
		P≤0.001, $LSD_{(0.05)}$= 9.11, cv (%)=18.1				

Table 5: Effect of method of storage and protection on Grain Quality at 4 communities (12 MAS)

Method of storage	Method of protection	Location of storage				Overall quality score
		Manga	Azum-Sapielga	Tansia	Tes-Natinga	
	Control	5.0^{a} (VH)	1.3^{de} (C)	1.7^{d} (F)	5.0^{a} (VH)	3.3 (M)^{b}
Poly-sacs	Actellic Super	2.3^{cd} (F)	2.0^{c} (F)	2.0^{d} (F)	3.0^{bc} (M)	2.3(F)^{d}
	Phostoxin	2.0^{d} (F)	2.7^{bc} (M)	2.0^{d} (F)	5.0^{a} (VH)	2.9(M)^{c}
Jute sacs	Control	5.0^{a} (VH)	3.0^{bc} (M)	5.0^{a} (VH)	5.0^{a} (VH)	4.5(VH)^{a}
	Actellic Super	2.3^{cd} (F)	2.3^{cd} (F)	2.0^{d} (F)	3.7^{b} (H)	2.6(M)^{c}
	Phostoxin	3.0b^{c} (M)	1.0^{e} (C)	2.0^{d} (F)	4.0^{b} (H)	2.5(M)^{cd}
PICS sacs	Control	1.0^{e} (C)	1.0^{e} (C)	2.0^{d} (F)	1.0^{e} (C)	1.3(C)^{f}
	Actellic Super	2.0^{d} (F)	1.3^{de} (C)	2.0^{d} (F)	2.0^{d} (D)	1.8(F)^{e}
	Phostoxin	2.0^{d} (F)	2.0^{d} (F)	1.7^{d} (F)	1.0^{e} (C)	1.7(F)^{ef}
Hermitic poly-tanks	Control	1.0^{e} (C)	1.0^{e} (C)	2.0^{d} (F)	1.0^{e} (C)	1.3(C)^{f}
	Actellic Super	1.3^{de} (C)	1.0^{e} (C)	1.7^{d} (F)	1.0^{e} (C)	1.3(C)^{f}
	Phostoxin	1.3^{de} (C)	1.0^{e} (C)	1.3^{de} (C)	1.0^{e} (C)	1.2(c)^{f}

Where score 1= No insect seen in prolonged storage, 2= few insects seen, difficult to find and irregularly distributed, 3= insects obvious to trained eye and occurring regularly, 4= infestation obvious to untrained eye, large crawling in grain mass, 5= Heavy infestation, insects can be seen or heard, crawling on floor/walls. 2. Letters in parenthesis are quality grade; where C= Clear grain, F= Few insects seen, Medium= Medium infestation, H= heavy infestation, VH= Very heavy infestation. 3. Data values along columns with same letters are not significantly different

Quality Scoring

Quality scoring at 12 MAS showed that differences was mainly due to method of storage, the influence of the grain protectants was marginal and not consistent (Table 5). Across locations, minimal loss of marketable quality (Score of 1.2F to 1.8M) was noticed in grains stored in HTS and HPT. Grain stored in the HTS and HPS ± grain protection recorded high quality scores (1.2C to 1.8F), indicating clear grain (C) or few insects (F) which were irregularly distributed and difficult to find by untrained eye (Table 5). Under local grain markets in Ghana, all treatments showing clear (C), few (F) or medium infestation (M) can be marketed without significant loss of price; but should be consumed immediately. Treatments showing high (H) or very high (VH) infestation are often winnowed and sold immediately in Ghana, albeit at less premium price.

Discussion

Grain storage is a major component in the production chain [5, 14]).Invariably, the value of storage to a market-oriented farmer is a function of price seasonalityand loss prevention. The value of any surplus grain appreciates during storage provided it is maintained at premium quality [5, 15]. However, high losses during storage is a critical limitation in developing countriesbecause most on-farm storage methods offer little protection against biological, physical and environmental hazards. Such losses are unacceptable since economic resources would have been expended. A study in Ghana identified the main causes of loss as insect pest (69.2%), rodents (16.2%) grain moulds (6.7%), weight loss (5.7%) and loss of flavor/nutrition

(1.7%). Close to 44.2% of respondents noticed pest infestation within 1-4 months, 33.3% within 5-8months, whiles 12.5% noticed no pest incidence [15]. However, some programmes were initiated by the Ministry of Food and Agriculture (MoFA) to develop long term programmes to assist farmers to reduce storage losses through dissemination of improved postharvest technologies. Albeit very slow progress has been achieved in this regard. For instance, the use of improved mud-silo and community grain banks which were promoted by MoFA have received low adoption so far. General strategies starting from clean farm operations to use of improved storage technologies are still required.Knowledge of farmers and warehouse managers about the factors influencing grain infestation is critical and should be integral in overall strategies to reduce on-farm storage losses.

In general, several factors from pre-to postharvest such as variety, time of harvesting and storage type are known to influence grain quality at storage. The extent of damage may be aggravated by storage environment, grain moisture and method of protection. For instance, a high yielding improved variety (Obatanpa) was more susceptible to *Prostephanustruncatus*and *S. zeamais*compared to Kamang-kpong; they showed mean weight loss of 16.75% and 11.09 % respectively [16]. Kernel hardness in grains has been associated with tolerance or resistance to stored-product insects; progeny production decreases as kernel hardness increases [17]. Maize stored in triple-layer hermetic bags recorded low weight loss of 2.94% compared to jute and polypropylene bags which recorded higher mean values of 19.55% and 23.65% respectively [16]. They noticed that *Prostephanustruncatus*caused the highest mean weight loss of 17.19% while *S. zeamais*caused 10.57%.In another study, kernel weight loss was less than 5% in various treatments involving maize stored in tin containers with fumigation except with local white and yellow maize stored without fumigation which showed kernel weight loss of more than 10% and seed damage of between 40 and 100% [14]. They recommended that storing susceptible local maize varieties in tin, plastic and earthen potswithout fumigation should be discouraged. Harvested rice with more cracks and splits in the hull provided pathway for entry of neonate *R. dominica,* and eventual emergence of adults was greater inrice with cracks and splits compared to those with larger proportion of intact grain [18, 19].

Similar to this study, several reports confirm the success of the hermitic triple-layer sacs or "PICS bags" in the control of *Callosobruchusmaculatus*,*Acanthoscelidesobtectus*and *Zabrotessubfasciatus*on stored cowpea, *P. truncatus, S.Zeamais* on maize, and *P. truncatus*and *Dinoderus*spp. on stored cassava chips [14, 20-22].Dissemination of the PICS bags was expected to reach 28,000 villages in Niger, Benin, Burkina Faso, Cameroon, Ghana, Mali, Nigeria, Senegal, Chad, and Togo by 2011 with support from the Bill & Melinda Gates Foundation [www.nourishingtheplanet.org]. Some critical limitations however, include high initial cost,poor accessibility,and the sacs cannot be re-used as they are not puncture resistant. In this study, the use of hermitic poly-tanks offers an alternative to more endowed farmers since the poly-tanks can be re-used for several years, and are sturdy for handling. A modified poly-tank can store up to 1 ton of grain, equivalent to storage volumes of most smallholder farming households.Although there are wide variationsin pre-harvest farm hygiene, varieties and drying operations among farmers, recommendations of this study addresses such factors. The trend of infestation showed that for up to 6 months of storage, use of any grain protectants may be avoided given the low infestation range. Apparently severe dry conditions exist in the first 5 months succeeding harvest, which favour further grain drying. In all cases, the grain must be cleaned and dried to approximately 12-14% moisture. For storage beyond 6 months in JS or PS, the use of grain protection and close monitoring is required; infestation build-up by 8 MAS could be very rapid. Consistent low infestation was noticed at Tansia and Azum-Sapielga, since the experiment was set out in well-developed grain warehouses compared to Manga and Tes-Natinga. However, the potential of these warehouses was woefully underutilized due to a myriad of socio-cultural to policy limitations.

Conclusion

This study reveals the potential hermitic storage methods using triple-layer sacs and poly-tanks for maize storage. Although the initial cost of these methods is high, the overall efficiency is high and could provide for the storage requirement of emerging medium-scale 'well endowed' farmers. Grain stored in these packages, even without protection, were still clear (C) or with few insect (F) after 1 year of storage. The less sensitive response of the two grain protectants in jute and poly-sacs explains the high postharvest losses often incurred in on-farm storage. This response may have link with insect resistance to insecticide which has become a threat in recent times due to non-adherence to safe use of agro-chemicals in rural areas. The initial grain quality analysis showed some extent of latent infestation; requiring strategies to reduce pre-storage infestation such as prompt harvesting and adequate drying.There is need to bridge the knowledge gap in communities in aspects of early detection and appropriate use of grain protectants.This will require active involvement of the Unified Extension Service of the Ministry of Food and Agriculture to achieve reasonable outcomes.

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