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Managing storage pests of maize: Farmers' knowledge, perceptions and practices in western Kenya

Charles A.O. Midega [a, *], Alice W. Murage [b], Jimmy O. Pittchar [a], Zeyaur R. Khan [a]

[a] *International Centre of Insect Physiology and Ecology (icipe), P.O. Box 30772-00100, Nairobi, Kenya*
[b] *Kenya Agricultural and Livestock Research Organization (KALRO), P.O. Box 25-20117, Naivasha, Kenya*

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ABSTRACT

Insect pests are a key constraint to effective utilization of cereal crops in sub-Saharan Africa (SSA), with damage caused by these pests in the stores of particular concern. Although a number of approaches have been advanced for control of storage pests of maize, uptake remains a challenge, with effectiveness of some approaches being questionable. We conducted a survey in western Kenya among 330 respondents using face to face interviews and focus group discussions to evaluate farmers' practices, knowledge and perceptions of storage pests of maize, and their current practices in managing such pests as a basis for development of efficient integrated pest management (IPM) approaches for the pests. Majority of the respondents stored maize in traditional granaries, with less than 10% of them using modern improved facilities, mainly due to inability to afford these. Majority of the respondents also cited attack of their stored grains by a number of insect pests, causing about 40% grain losses. The larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae), sawtoothed grain beetle, *Oryzaephilus surinamensis* (L) (Coleoptera: Silvanidae), and maize weevil, *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae), were perceived as the most common and damaging pests. Farmers' perceptions of pests were positively and significantly influenced by level of education and farming experience, indicating that education and experience build farmers' understanding of storage pests. Storing maize in unshelled form seemed to result in less pest attack, although majority of the respondents stored their maize in shelled form. Moreover, local maize varieties were perceived to be resistant to pests. The farmers applied various control methods, with sun-drying being the most popular practice. Usage of pesticides was minimal, mainly due to high costs, lack of information, and unavailability of appropriate and effective products. There were also other cultural methods applied, such as use of smoke and insecticidal plants. The respondents decried lack of training and extension services on storage pests and their management, underscoring the need to develop extension services. The underlying mechanisms of the perceived pest resistance in local varieties of maize and cultural pest management methods need to be established for exploitation in development of effective IPM approaches. There is also need to address the challenges hindering uptake of modern storage and control approaches.

1. Introduction

Cereal crops play a major role in smallholder farmers' livelihoods in sub-Saharan Africa (SSA), with maize, *Zea mays* L., being the most important food and cash crop for millions of rural farm families in the region. In spite of the importance of maize in the region, grain yields are generally <1.0 t/ha, representing some of the lowest in the world (Cairns et al., 2013). This, combined with the high human population growth rates, results in a widening gap between food supply and demand, consequently aggravating the chronic food insecurity in SSA, with one in every four people estimated to be undernourished (FAO, 2013).

Among the key constraints to improving food security in Africa are losses resulting from poor post-harvest management of grains, estimated at 20–30%, amounting to more than US$4 billion annually (FAO, 2010). Some of these losses are caused by insects and fungi, with the speed at which these multiply being influenced by prevailing environmental conditions (Nukenine et al., 2010). Fungi attack on maize, for example, results in both qualitative and

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[*] Corresponding author.
E-mail address: cmidega@icipe.org (C.A.O. Midega).

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quantitative losses, resulting in mycotoxins such as aflatoxin (Tefera, 2012). Insect pests are a key constraint to effective production and utilization of cereal crops in SSA. Indeed, it is estimated that 10–88% of the total maize produced each season in the region is lost due to field and storage pests (Kfir et al., 2002; Ogendo et al., 2004a; Ojo and Omoloye, 2012). While a number of efforts are being implemented to help alleviate ravages caused by field pests (Midega et al., 2015), post-harvest losses resulting from insects remain a huge challenge (Tefera et al., 2010). Directly, these losses result from insect feeding and reproduction. Additionally, stored maize further gets contaminated with the presence and accumulation of excreta, cast skins and cadavers. Indirectly, insect presence and feeding often raises grain temperature and moisture contents, thus creating warm moist spots of increased grain respiration or humidity that stimulate grain deterioration and further fungal activity (Tefera et al., 2010). For many people in SSA, these losses threaten household food security and undermine market returns, driving them to seek options for protecting their grain during storage (Stathers et al., 2008). The favorable tropical climatic conditions and poor storage systems in the region often favor growth and development of these pests, resulting in considerable losses (Bekele et al., 1997). In some instances, farmers are forced to sell their maize grains off cheaply soon after harvesting due to anticipated losses in storage and later buy food at higher prices.

Considering the dual necessity to achieve food security and food safety, especially in developing economies, there is need for simple and effective pest management approaches for smallholder farmers who form the bulk of grain producers in SSA. For that, a number of approaches ranging from cultural to use of pesticides have been advanced for management of post-harvest pests. Reports indicate that judicious use of synthetic insecticides could provide effective pest control (Ogendo et al., 2004b). However, there is growing concern about insect-related food quality problems among consumers, with awareness of the potential hazards from chemical pesticides being on the increase. Furthermore, problems associated with pesticides, and the possibility of misuse of pesticides, and the accompanying undesired effects, demand a vigorous search for alternative pest control practices. There is thus a need to develop integrated pest management (IPM) packages that are suitable and cost-effective for the smallholder farmers' conditions in the region.

In spite of the ravages caused by storage pests, there exists very little information on farmers' perceptions of the pests and their management practices in the region. One of the major constraints upon establishing effective pest management approaches for smallholder farmers is the lack of adequate information about farmers' knowledge, perceptions and practices in pest management (Morse and Buhler, 1997). Indeed, the need to understand farmer knowledge systems has been recognized as a basis for development of pest management technologies that are adapted to local farmers' situations (Van Huis and Meerman, 1997; Norton et al., 1999) and meet their aspirations, as a key condition to adoption of new innovations (Chitere and Omolo, 1993). Moreover, understanding these could significantly strengthen the practical basis for exploring the potential approaches of intervention for more IPM-oriented storage pest management for smallholder farmers in SSA. The current survey was conducted to identify potential points for intervention in the development of IPM strategies for storage pests of maize that are appropriate to the needs and circumstances of low-income, smallholder farmers in western Kenya. Specifically, the study sought to (1) evaluate farmers' knowledge and perceptions of storage pests of maize; (2) examine farmers' current practices in managing storage pests of maize; and to (3) identify pest management challenges and intervention opportunities as a basis for development of efficient IPM approaches that would contribute to attainment of food security and improved incomes by effectively addressing losses attributable to post harvest insect pests in western Kenya.

2. Materials and methods

2.1. Study site

The survey was conducted between August and October 2014 in six sub-counties in western Kenya covering the key maize growing areas in the region. These were Homabay (0° 40′ to 0° S, 0° to 34° 50′ E), Vihiga (0° to 0° 15′ S, 34° 30′ to 35° 0′ E), Busia (0° 1′ to 0° 46′ S, 33° 54′ to 34° 26′ E), Siaya (0° 26′ to 0° 18′ S, 33° 58′ to 34° 33′ E), Bondo (0° 25′ to 0° 2′ S, 34° 0′ to 34° 33′ E) and Migori (0° 40′ to 0° S, 34° 50′ E). These areas are characterized by a bi-modal rainfall pattern, with the main cropping season running from March to August and the short cropping season from October to January. The region is also considered of high potential for agriculture, with medium elevation (1000–1700 m above sea level). The main farming systems comprise cereal crops intercropped with food legumes and integrated with livestock.

2.2. Data collection

In order to elicit a comprehensive understanding of the emic (insider, in this case farmer) perspectives (Sileshi et al., 2008) of maize storage and its constraints, particularly insect pests in western Kenya, we used a combination of farm-level cross-sectional data collected through surveys involving individual semi-structured questionnaire interviews and focused group discussions using methodologies described by Midega et al. (2012). In each area, farmers for the interviews were randomly selected using sampling lists provided by the Kenya Ministry of Agriculture and Agricultural Extension officials in each sub-county. This list was derived from master roll, of the main person involved in farming in the households, maintained by the officials. A total of 330 farmers were interviewed, 55 farmers from each sub-county. The semi-structured questionnaire once drawn up was pre-tested and administered by trained enumerators recruited from the target sub-counties with good knowledge of the areas of study. Each interview began with the enumerators confirming the interviewee was the person responsible for maize handling and storage in the household and explaining the aims of the study. Most of the survey questions were ‘open’, in order to avoid limiting farmers' responses. When a farmer scheduled for interview was away from home, the enumerators rescheduled the interviews to coincide with their time of availability. Information sought included (i) farmers' socio-economic profiles, such as age, gender, education and farming experience; (ii) farm characteristics, i.e. farm size, farm area under maize, maize varieties grown, and yields; and (iii) storage of maize and its constraints, e.g. insect pests and pest control methods. In addition to these, information was sought on training on pest control and ranking of severity of pest attack on stored maize, with each interview taking an average of 30 min. Focused group discussions were conducted through organized community meetings (Midega et al., 2012), where guiding questions were asked to stimulate discussion and generate information on the key aspects of maize storage and its constraints, principally insect pests, their management and challenges the respondents faced. Each meeting took approximately 2 h.

2.3. Data analysis

Survey data were summarized and descriptive data analysis conducted using means, frequencies and proportions using SPSS version 21 (SPSS, 2012). A content analysis for the focused group discussion was done, identifying common themes which were later post-coded and analyzed together with the survey data. Chi-square and one-way analysis of variance (ANOVA) were conducted to assess any differences with regard to farmers' perceptions on pests and their management practices. Significance level was set at 0.05 and means were separated by Tukey HSD test.

To understand the perceived severity of storage pest attacks on maize, farmers were asked to identify the different pests, using pictures provided by the enumerators, with farmers identifying them in their local names, observed in their stored maize and rate the severity of attack by each pest using a 3-point likert scale; 1 = Not severe, 2 = Moderately severe, and 3 = Very severe. Nine different maize storage pests were identified and their severity of attack rated as indicated in Table 3. The severity ratings were summed across sub-counties to generate a total severity score for the pests mentioned by each respondent. This sum of scores which reflects a ranking of severity index for observed maize storage pests ranged from 0 to 15. The continuum of the generated severity score was then recoded into 4-point likert rating, such that 0 = Not severe (for scores between 0 and 3), 1 = Moderately severe (for scores between 4 and 7), 3 = Severe (for scores between 8 and 11) and 4 = Very severe (for scores between 12 and 15). With these 4 ordered rating for Y (severity levels), a categorical ordered response model was required. We therefore used the ordered logit to explain the association between this severity index and other socio-economic, farm and ecological factors (Uematsu and Mishra, 2011). Ordinal logit model was built around a latent regression represented as;

$$Y^* = \beta' X_i + \varepsilon$$

The observed ordinal severity index Y is a function of Y^* which is an underlying continuous unmeasured latent variable that indexes the level of contribution of selected variables to the respondents' decision making on perception. β is parameter vector to be estimated, X represents the demographics, farm and ecological characteristics, and ε is the random error term.

Y^* exhibits itself in ordinal categories with various thresholds and is assumed to follow the following mapping:

$$Y = 0 \text{ if } Y^* \le 0, \text{ Not severe}$$

$$Y = 1 \text{ if } 0 < Y^* \le \mu_1, \text{ Moderately severe}$$

$$Y = 2 \text{ if } \mu_1 < Y^* \le \mu_2, \text{ Severe}$$

$$Y = 3 \text{ if } Y^* \ge \mu_3, \text{ Very severe}$$

If the pest attack is ‘not severe’ for example, $Y^* \le 0$ but the observed $Y = 0$. The μ's are unknown threshold parameters that are estimated with the β's in the model. By using the ordered logit model, we describe the probability of a responses falling in any of the 4 categories. In this case,

$$\text{Prob }(Y = 0) = \varphi\left(-\beta' X\right)$$

$$\text{Prob }(Y = 1) = \varphi\left(\mu_1 - \beta' X\right) - \varphi\left(-\beta' X\right)$$

$$\text{Prob }(Y = 2) = \varphi\left(\mu_2 - \beta' X\right) - \varphi\left(\mu_1 - \beta' X\right)$$

$$\text{Prob }(Y = 3) = 1 - \varphi\left(\mu_3 - \beta' X\right)$$

where Φ is the logistic distribution function.

3. Results and discussion

3.1. Socio-economic and farm characteristics of the respondents

Majority of the respondents were female (59.4%, Table 1). This was also the case in all the sub-counties, except for Homabay where male farmers dominated (61.8%). There is a general observation in SSA that women constitute majority of smallholder farmers, providing most of the labour and managing a large part of the farming activities (Admire and Tinashe, 2014). Over half of farmers had attained primary level of education (57.7%), and a third (30.4%) had secondary level of education, with only 5.6% of the respondents not having gone through formal education, indicating the sampled population had a relatively high literacy level. The respondents were of middle age, average of 48.3 years, with an average farming

Table 1
Characteristics of the respondents in western Kenya.

	Homabay	Vihiga	Busia	Siaya	Bondo	Migori	Overall sample	F-test	χ^2
	N = 55	N = 56	N = 54	N = 54	N = 55	N = 55	N = 329		
Gender (%)									
Male	61.8	42.9	33.3	34.5	23.6	47.3	40.6		19.982***
Female	38.2	57.1	66.7	65.5	76.4	52.7	59.4		
Level of education (%)									
None	16.4	0.0	0.0	1.9	7.5	8.0	5.6		32.178***
Primary	58.2	69.6	52.9	48.1	60.4	56.0	57.7		
Secondary	16.4	25.0	41.2	42.9	28.3	30.0	30.4		
College	9.1	5.4	5.9	7.4	3.8	6.0	6.3		
Age of the farmer (years)	51.58	51.30	43.19	49.96	48.96	44.73	48.31	3.28***	
	(2.00)	(2.11)	(1.93)	(1.72)	(1.96)	(1.88)	(0.81)		
Farming experience (years)	17.80	20.89	18.04	25.20	20.80	17.05	19.97	2.46**	
	(1.69)	(2.09)	(2.00)	(2.02)	(1.97)	(1.77)	(0.80)		
Land size (hectares)	3.04	0.754	0.9	1.21	1.19	1.25	1.40	27.69***	
	(0.32)	(0.08)	(0.09)	(0.13)	(0.06)	(0.09)	(0.08)		
Area of farm land under cereal crops (hectares)	1.38	0.40	0.48	0.69	0.68	0.95	0.76	30.70***	
	(0.11)	(0.04)	(0.04)	(0.03)	(0.04)	(0.08)	(0.03)		
Quantity of maize harvested (SR, 2014)	620.89	197.48	260.09	168.08	97.00	381.28	294.52	8.22***	
	(118.40)	(19.96)	(24.03)	(9.69)	(22.36)	(92.82)	(28.48)		

Figure in parenthesis are Standard errors.
SR 2014 Short Rainy Seaon 2014.
***Significant at 1% and ** 5%.

experience of 20 years. The average land size was 1.4 ha of which 0.76 ha were committed to cereal farming, indicating that these were largely smallholder farmers.

Majority of the farmers planted both hybrid and open pollinated varieties (OPVs) of maize (41.5%), with the latter dominating most farms (Fig. 1). In Homabay and Bondo sub-counties, majority (60% and 65.5% respectively) planted OPVs. Only 17.6% of the respondents planted hybrid maize alone in the whole sample. Highest use of hybrid maize alone was observed in Busia and Migori sub-counties where 35.2% and 39.5% of the farmers, respectively, indicated that they planted hybrid maize. This could be attributed to cross-border influence where farmers would prefer to plant hybrid maize which is viewed as higher yielding, and therefore likely to provide surplus grains for sale. Although use of hybrid maize varieties has potential to improve household food security and incomes, emerging evidence indicates that uptake of such varieties remains low (Smale and Olwande, 2014), with majority of smallholder farmers in most parts of SSA still relying on OPVs for their plantings. Such OPVs are locally grown and are a result of farmer selection and management over many generations (Midega et al., 2016), with the choice being partly influenced by the length of growing season, taste and storability. Additionally, a number of the OPVs have local adaptation to key constraints affecting maize production in the region, including cereal stemborers (Tamiru et al., 2012) and the parasitic weed, *Striga hermothica* (Delile) Benth. (Orobanchaceae) (Midega et al., 2016).

3.2. Post-harvest handling and storage of maize

Table 2 presents results on post-harvest handling of maize and incidences of attack by storage pests. These results indicate that respondents produced maize which required storage for future use, including for sale. Apart from Siaya and Migori, respondents in the other sub-counties indicated that they stored maize following harvest, with significant variations among sub-counties. The type of storage used significantly varied among sub-counties, with majority indicating they stored the grains in sacks in residential houses (94.6% in Vihiga, 83.3% in Busia, 92.7% in Siaya, 85.5% in Bondo and 78.2% in Migori), except in Homabay where most respondents (74.5%) stored their grains in traditional granaries. Across the sub-counties, less than 10% of the respondents used other storage facilities, including modern granaries and metal bins, except in Busia and Bondo where 11.1% and 12.7% of respondents indicated they stored their grains in such facilities. While traditional granaries take various forms, they are largely made of wooden walls and grass thatched roofs, while modern granaries often have concrete platforms, brick walls and asbestos or iron-roofed tops (Admire and Tinashe, 2014). Modern granaries are thus perceived to be expensive and unaffordable for a majority of smallholder farmers in the region and are therefore not commonly used. These results thus corroborate those that have reported relatively low usage of modern granaries (e.g. Admire and Tinashe, 2014), with traditional granaries being more commonly used to store maize in most of rural Africa. These results were corroborated during the focused group discussions where participants decried

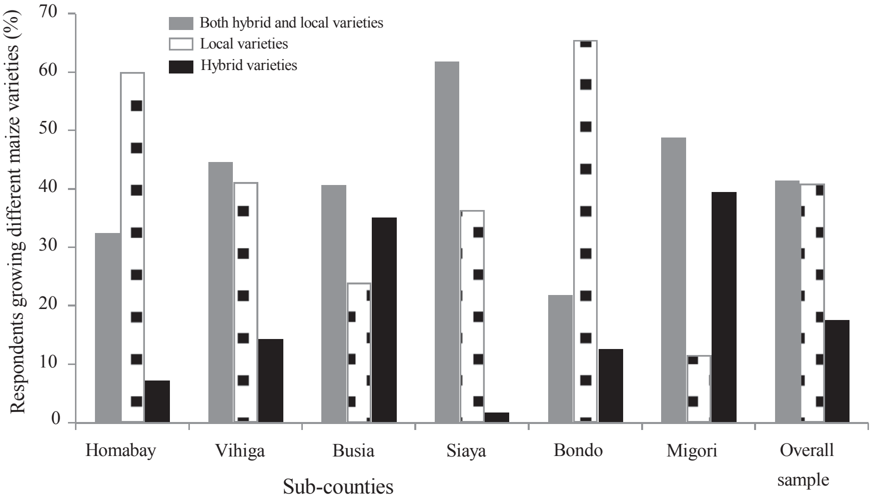

Fig. 1. Types of maize varieties grown in different sub-counties in western Kenya.

Table 2
Methods used to store maize, storage forms and experiences of storage pest attacks in different sub-counties in western Kenya.

Parameter	Homabay	Vihiga	Busia	Siaya	Bondo	Migori	Overall sample	χ^2
Where maize is stored (%)								
Traditional granaries	74.5	1.8	3.7	1.8	1.8	21.8	17.6	180.298[b]
Modern granaries	3.6	0.0	1.9	0.0	0.0	0.0	0.9	
Sacks in residential houses	21.8	94.6	83.3	92.7	85.5	78.2	76.1	
Other[a]	0.0	3.6	11.1	5.5	12.7	0.0	5.5	
Form of maize storage (%)								
Shelled	63.6	94.6	98.1	100	92.7	92.7	90.3	56.31[b]
Unshelled	36.4	5.4	1.9	0.0	7.3	7.3	9.7	
Experience storage pest attack (%) (Yes)	100	100	100	94.5	100	74.1	94.8	59.26[b]

[a] Mainly metal bins and plastic bags.
[b] Significant at 1%.

the poor state of the traditional granaries, and attributed this to a lack of construction materials and income to purchase them. Additionally, they indicated that although they were aware of existence of improved granaries and modern storage facilities, the costs were prohibitive and thus they could not afford these. Previous studies have indicated prohibitive costs as some of the challenges hindering adoption of improved technologies in the region (Mutangadura and Norton, 1999). The form of storage significantly varied among sub-counties, with over 90% of the respondents reporting they stored their maize in shelled form, except in Homabay sub-county with 36.4% of the respondents storing their maize in unshelled form.

3.3. Insect pests of stored maize and their management

Pest attack on stored maize was reported in all the sub-counties, with over 90% of the respondents citing attack of their stored grains by a number of insect pests. All respondents in Homabay, Vihiga, Busia and Bondo sub-counties indicated that they experienced pest damages in their stored maize; Migori and Siaya sub-counties on the other hand recorded 74.1% and 94.5% of the respondents respectively. Overall, the larger grain borer *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae), Sawtoothed grain beetle *Oryzaephilus surinamensis* (L) (Coleoptera: Silvanidae) and maize weevil *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) were perceived as the most common (Table 3). In total, respondents identified and ranked nine major pests that attacked their stored maize. Attack of stored maize by larger grain borer was rated as very severe by 84% of the sample population. This was followed by sawtoothed grain beetle (80%), maize weevil (67.3%) and flat grain beetle *Cryptolestes pusillus* (Schönherr) (Coleoptera: Laemophloeidae (50%). Other pests that were rated as moderately severe included termites (by 67.7% of the respondents), angoumois grain moth *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelichiidae) (54.8% of the respondents), lesser grain borer *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae) (53.3% of the respondents), and Indian meal moth *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae) (51.9% of the respondents). Estimation of the proportion of grains damaged by storage pests significantly varied across sub-counties, ranging from 26% to 75% as reported by over 40% of the respondents in Homabay, Vihiga, Bondo and Migori (Table 4).

These results were confirmed during the focus group discussions where insect pests were mentioned as the main constraint affecting stored products in the region, with the larger grain borer and maize weevils being considered the most serious pests of stored maize in western Kenya. These pests are considered most destructive to stored cereal grains in tropical and sub-tropical regions (Kossou et al., 1993; Mendesil et al., 2007), with a more recent study by Abass et al. (2014) reporting the larger grain borer, maize weevil and lesser grain borer as major pests of stored maize in Tanzania. The damage levels reported in the current study coincide with those observed by other workers who reported that these pests caused significant yield losses >30% for weevils and >50% for the large grain borers (Abass et al., 2014). Larger grain borer in particular is reported to cause damage not only to the stored cereal grains but also to other stored commodities including cassava and wood in Africa (Hodges, 2002).

3.4. Determinants of farmers' knowledge and perceptions of storage pests

The results on coefficient and marginal effects (ME) for the factors influencing farmers' perception on the severity of storage pest attack are presented in Table 5. The model was significant at 1% (Prob > chi^2 = 0.000). The variables representing farmers who had attained college level of education and the one for farming experience had positive coefficients (0.881 and 0.027 respectively), signifying that they perceived storage pest attacks in stored maize as “very severe”. The ME for college education was −0.020 (significant at 5%) for ‘not severe’ rank, implying that this category of farmers were less likely to rank the attack as not severe. Thus, it appears that education equips the farmers with the ability to understand and effectively interpret storage pests and their impact on stored maize. Moreover, the ME for farming experience was 0.004

Table 3
Severity of attack on stored maize by each pest in western Kenya.

Name of the storage pest	Percentage response			
	Not severe	Moderately severe	Very severe	χ^2
Angoumois moth	10.6	54.8	34.6	256.094[a]
Flat beetle	0.0	50.0	50.0	
Indian meal moth	5.2	51.9	42.9	
Larger Grain Borer	2.7	13.3	84.0	
Lesser Grain Borer	13.3	53.3	33.3	
Rust red flour beetle	4.2	50.0	45.8	
Sawtooth beetle	0.0	20.0	80.0	
Termite	17.7	67.7	14.6	
Weevils	2.4	30.3	67.3	

[a] Significant at 1%.

Table 4
Proportion of crop damage by storage pests in western Kenya.

	Homabay	Vihiga	Busia	Siaya	Bondo	Migori	Overall sample	χ^2
Proportion of maize damaged								
0-25%	0.0	5.4	64.8	98.1	1.8	58.2	37.7	277.04***
26-50%	27.3	32.1	35.2	1.9	30.9	40.0	28.0	
51-75%	45.5	60.7	0.0	0.0	54.5	1.8	27.4	
>75%	27.3	1.8	0.0	0.0	12.7	0.0	7.0	
Farmer trained on storage pest control and management								
Yes	16.4	3.6	9.3	10.9	18.2	3.6	10.3	11.36**
No	83.6	96.4	90.7	89.1	81.8	96.4	89.7	

***Significant at 1% and ** 5%.

Table 5
Determinants of perception on severity of storage pest attack on maize in western Kenya.

Variables	Coefficient		Marginal effects[a]					
			Not severe		Severe		Very severe	
	Coef.	Std. Err.	dy/dx	Std. Err.	dy/dx	Std. Err.	dy/dx	Std. Err.
Gender (0 = Female, 1 = Male)	0.059	0.263	−0.001	0.009	0.003	0.023	0.005	0.039
Age (years)	−0.016	0.016	0.001	0.001	−0.001	0.001	−0.002	0.002
[b]No education (1 = Yes 0 = No)	−0.293	0.683	0.011	0.029	−0.031	0.084	−0.040	0.084
Secondary education level (1 = Yes 0 = No)	0.292	0.296	−0.008	0.009	0.019	0.021	0.038	0.047
College education level (1 = Yes 0 = No)	0.881*	0.525	−0.020**	0.010	0.021	0.028	0.154	0.112
Farming experience (years)	0.027*	0.016	−0.001	0.001	0.002	0.002	0.004*	0.002
Land size (hectares)	−0.066	0.043	0.002	0.002	−0.006	0.004	−0.010	0.006
[c]Store in traditional granaries (1 = Yes 0 = No)	−0.344	0.456	0.012	0.019	−0.034	0.055	−0.046	0.061
Store in modern granaries (1 = Yes 0 = No)	−2.161**	1.165	0.207	0.211	−0.314*	0.130	−0.160***	0.035
Store in metal bins (1 = Yes 0 = No)	0.164	0.642	−0.004	0.019	0.010	0.043	0.021	0.102
Store in sacs (1 = Yes 0 = No)	−1.075**	0.553	0.053	0.041	−0.141	0.088	−0.120***	0.047
Form stored (1 = shelled 0 = unshelled)	−0.911**	0.464	0.022***	0.010	−0.022	0.028	−0.168*	0.101
Preservation before storage(1 = Yes 0 = No)	−0.001**	0.001	0.000**	0.000	0.000*	0.000	0.000**	0.000
Variety (1 = hybrid, 0 = Local)	0.519**	0.284	−0.001	0.002	0.003	0.004	0.005	0.007
[d]Homabay (1 = Yes 0 = No)	1.078**	0.592	−0.016**	0.009	0.037**	0.019	0.082*	0.048
Busia (1 = Yes 0 = No)	−2.489***	0.434	−0.027**	0.013	0.029	0.032	0.199	0.127
Siaya (1 = Yes 0 = No)	−1.753***	0.555	0.195***	0.067	−0.319***	0.056	−0.228***	0.032
Bondo (1 = Yes 0 = No)	−0.226	0.402	0.109*	0.060	−0.236***	0.082	−0.173***	0.038
Migori (1 = Yes 0 = No)	−1.084***	0.485	0.007	0.015	−0.021	0.043	−0.030	0.054
/cut1	−5.274	0.847	0.048	0.035	−0.129	0.079	−0.117	0.046
/cut2	−2.405	0.801						
/cut3	−0.380	0.786						

N = 270, LR $chi^2(19) = 99.83$, Prob > $chi^2 = 0.000$, Pseudo $R^2 = 0.148$.
***Significant at 1%, ** 5% and *10%.

[a] 'Moderately severe' option used as the base category for comparison purposes.
[b] Primary education used as reference variable.
[c] Storage in sacks used as the reference variable.
[d] Vihiga used as the reference variable.

(significant at 10%) for 'very severe' rank, implying that farmers who had more farming experience were likely to rate the severity of pest attack on stored maize grain as 'very severe', possibly due to the experience farmers gain over time as they store the crop. These results coincide with those of Midega et al. (2012) who reported positive and significant effects of education and farming experience on farmers' knowledge of cotton pests in western Kenya.

The types of storage facility also determined the severity of pest attack. Compared to respondents who stored their grains in sacks in their residential areas, those who stored maize in modern granaries perceived the pest attack as 'not severe' (coefficient −2.161), although the proportion of respondents who used these granaries was low. The corresponding significant MEs were −0.314 (for 'severe' rank) and −0.160 (for 'very severe' rank) for the modern granary storage. During the focus group discussion, farmers decried the sorry state of their traditional granaries and perceived this to be responsible for the high pest attack rates in these facilities. Any storage facility needs to maintain air tightness in order to eliminate insect pests in storage (Abass et al., 2014). The younger farmers expressed tendencies to abandon the use of traditional granaries for lack of knowledge on how to construct them, and existence of better facilities such as metal silos (Gitonga et al., 2013), an observation supported by an earlier report by World Bank (2011) that use of these facilities was on the decline in rural Africa.

Although majority of the respondents stored their grains in shelled form, those that stored their grains in unshelled form perceived the attack as not severe (Coefficient = −0.911; ME = 0.022 for not severe rank and −0.168 for very severe rank). This supports observations of earlier work by Kossou et al. (1993) who reported reduced susceptibility of maize to maize weevil when stored in dehusked unshelled form. This is partly explained by the fact that in the dehusked maize ears there is less suitable endosperm diet for first instar larvae which hatch from eggs laid on or near the kernel's crown, accompanied by the difficulty of finding a site on the kernel where adults can emerge (Kossou et al., 1992, 1993). However, this is only applicable in management of storage pests other than the larger grain borer, a pest whose rates of growth and development are reduced on shelled maize (Addo et al., 2002; Boxall, 2002; Hodges, 2002). Preservation of grains before storage resulted in less severity of pest attack as perceived by the respondents (coefficient = −0.001 and ME = 0.000 for not severe rank). Hybrid maize varieties were perceived to be more susceptible to severe pest attacks (Coefficient = 0.519). Similar perceptions have been reported in Ethiopia where farmers indicated 'resistance' of local sorghum varieties to storage pests (Mendesil et al., 2007). Chitio et al. (2004) recently confirmed existence of resistance to maize weevil among sorghum genotypes. Additionally, Kossou et al. (1993) had reported relatively lower susceptibility of local maize genotypes to storage pests in Benin. However, Gudrups et al. (2001) reported relatively higher susceptibility of local maize varieties to the maize weevil. Studies are therefore needed to screen maize genotypes grown in western Kenya against the key storage pests and establish any sources of resistance for utilization as components of IPM strategies.

The locality variables were significant, with the results showing a probability of higher severity of attack in Homabay (Coefficient = 1.078), and less severity in Busia (coefficient = −2.489), Siaya (Coefficient = −1.753) and Migori (Coefficient = −1.084) sub-counties compared to Vihiga, which was the reference sub-county. This corresponds to the low damage rating reported by the respondents in these sub-counties.

3.5. Storage pest control methods

In spite of the perceived significant losses to maize by the storage pests, less than 20% of the respondents had received some training on management of storage pests (Data not shown). Nonetheless, our study showed that farmers applied various

Table 6
Farmers' responses on control practices used for storage pests in different sub-counties, western Kenya.

	Homabay	Vihiga	Busia	Siaya	Bondo	Migori	Overall sample	χ^2
Aeration/sun drying (Yes)	74.5	76.8	100	87.3	100	90.9	88.2	31.837[b]
Sorting out affected grain (Yes)	1.8	30.4	0.0	45.5	29.1	20.0	21.2	51.151[b]
Pesticide use (Yes)	21.8	26.8	0.0	10.9	0.0	36.4	16.1	44.886[b]
Fumigate store (Yes)	0.0	21.4	0.0	7.3	0.0	3.6	5.5	37.875[b]
Doing nothing (Yes)	5.5	0.0	0.0	0.0	0.0	0.0	0.9	15.138[b]
Other[a] (Yes)	0.0	0.0	0.0	1.8	0.0	0.0	0.3	5.015

[a] Wood ash and insecticidal plants.
[b] Significant at 1%.

methods to mitigate the ravages caused by the storage pests, with aeration/sun-drying being the most popular practice in the sub-counties, with an average of 88.8% of the respondents applying it (Table 6). Overall, sorting/removal of the affected grains was used by 21.2% of the respondents, mainly in Siaya where 45.5% of the respondents applied it. These observations were confirmed during the focus group discussions where participants decried shortage of learning opportunities on storage pests and their management. Challenges of pesticide use ranged from lack of information on appropriate and effective products for target storage pests, to lack of resources to acquire pesticides as they were expensive to buy. Only 16.1% of the respondents used synthetic chemicals to control storage pests of maize, with most participants at the focus group discussions mentioning high costs and unavailability of chemical pesticides as the main reasons for not applying them against pests of stored maize. These results coincide with those of Mendesil et al. (2007) who reported similar reasons for limited use of chemical pesticides against storage pests of sorghum in Ethiopia.

Farmers indicated use of plants as grain protectants and mentioned *Lantana camara* L. (Verbenaceae) and *Tephrosia vogelli* Hook (Fabaceae) as being effective against the maize weevil. Previous studies had confirmed effectiveness of ground powder derived from these plants in control of maize weevil in western Kenya (Ogendo, 2004a,b). These powders caused high mortality rates on the immature stages of the pests and repelled the adult weevils. Plant products play an important role in traditional methods of protection against crop pests in Africa (Golob et al., 2002), underscoring the critical role of plant-derived products in post-harvest protection of grains in developing countries. Although farmers expressed reservations in use of some of the plant-derived products since they left an undesirable smell on the grains, this knowledge is important in development of an IPM for storage pests of maize. Moreover, farmers' indigenous pest management knowledge is site-specific and should be the basis for developing IPM techniques (Abate et al., 2000; Abass et al., 2014). Also mentioned was use of cultural practices including storage hygiene and treatment of maize with wood ash. Other farmers kept maize cobs over fires, especially those meant to be stored for longer periods of time such as seed for the following cropping season, a cultural grain preservation method common in eastern Africa (Abate et al., 2000).

In conclusion, planting of local maize varieties was dominant among majority of the respondents, partly due to their adaptation to the farming conditions in the region, which supports the emerging evidence of low uptake of hybrid varieties in western Kenya. Majority of the respondents stored maize in traditional granaries, with less than 10% of them using modern improved facilities, mainly due to inability to afford these. There is therefore a need to explore ways to reduce costs and improve affordability. Majority of the respondents (>90%) cited attack of their stored grains by a number of insect pests, with over 25% of the respondents in all sub-counties, except Siaya, reporting at least 26% grain losses. The larger grain borer, sawtoothed grain beetle and maize weevil were perceived as the most common and damaging pests. Farmers' perceptions of pests was positively and significantly influenced by level of education and farming experience, indicating that education and experience farmers' understanding of storage pests. However, the respondents decried lack of training and extension services on storage pests and their management, underscoring the need to address the challenge of extension service in order to build farmers' capacity on storage pests and their management. Storing maize in unshelled form seemed to result in less pest attack (other than larger grain borer), although majority of the respondents stored their maize in shelled form. Moreover, hybrid maize varieties were perceived to be more susceptible to severe pest attacks. The underlying mechanisms need to be established for exploitation in development of effective IPM approaches for the pests. The farmers applied various methods to mitigate the ravages caused by the storage pests, with sun-drying being the most popular practice. Usage of pesticides (by 16.1% of the respondents) was minimal, mainly due to shortage of information, and unavailability of appropriate and effective products and their costs being prohibitive. There are also other cultural methods (such as use of smoke) and insecticidal plants, but these seem to leave a bad smell and taste on the grain. These need to be explored, and any mechanisms involved elucidated to allow their use as components of an IPM approach, development of which needs to involve participation of the farmers. There is also need to address the challenges hindering uptake of modern storage approaches, and those hindering judicious use of pesticides, all within the context of an integrated management approach.

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