African Journal of Agricultural Research Vol. 6(10), pp. 2249-2254, 18 May, 2011
Available online at http://www.academicjournals.org/AJAR
ISSN 1991-637X ©2011 Academic Journals

Full Length Research Paper

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*

Tadele Tefera[1]*, Stephen Mugo[1] and Paddy Likhayo[2]

[1]International Maize and Wheat Improvement Center (CIMMYT), ICRAF House, UN Avenue, Gigiri, PO Box 1041, 00621 Village Market, Nairobi, Kenya.
[2]Kenya Agricultural Reserch Institute (KARI), National Agricultural Laboratories, Nairobi, Kenya.

Accepted 8 April, 2011

A study was conducted with the objectives of assessing comparative grain damage and weight loss in maize due *Prostephanus truncatus* and *Sitophilus zeamais* at ten varying population densities (5, 10, 15, 20, 25, 30, 35, 40, 45 and 50 insects per 200 g grain) and three storage durations (30, 60 and 90 days), in a laboratory. The final insect densities, percent grain damage, flour (dust) produced and weight loss due to *P. truncatus* exceeded that of the *S. zeamais*. Mean final insect population density, percent dust production, and weight loss increased over the storage period for *P. truncatus.* However, percent dust production and weight loss did not show significant increase over the storage time for *S. zeamais*. Percent grain damage declined 60 days after grain storage for *P. truncatus*. However, percent grain damage increased sharply over the storage period for *S. zeamais*. A mean weight loss of 67.1 and 6.9% recorded at an initial population density of 50 insects 200 g^{-1} grain, after 90 days for *P. truncatus* and *S. zeamais*, respectively. Flour production by *P. truncatus* (52.8%) was higher than that of *S. zeamais* (1.2%) after 90 days due to extensive tunneling to the grain by the former. In conclusion, *P. truncatus,* caused high grain damage and weight loss, indicating that control measures should be designed at the onset of grain storage if the grain is planned to be stored for more than 30 days. Traditional grain storage facilities may not offer protection against *P. truncatus*, but promotion of the use of metal silos and resistant varieties in Kenya for grain storage is an alternative approach to reduce losses by *P. truncatus*.

Key words: Damage, dust, maize, population density, *Prostepahnus truncatus*; *Sitophilus zeamais*, storage time, weight loss.

INTRODUCTION

Maize is the major staple food in Africa contributing significantly to the agricultural sector. Postharvest maize insect pests are a major constraint to food security and income generation in Sub-Saharan Africa because of significant yield losses and grain quality degradation (Abebe et al., 2009). The most economically important postharvest pests of maize in Africa include the maize weevil (*Sitophilus zeamais*), the larger grain borer (LGB) (*Prostephanus truncatus*), the angoumois grain moth (*Sitotroga cereallela*) and the lesser grain weevil (*Sitophilus oryzae*). *P. truncatus* was incidentally introduced to Africa from Mesoamerica in early 1980s (Boxall, 2002). *P. truncatus* is currently established in almost most parts of Africa threatening maize production due its aggressive nature and the extensive damage it causes within a short period of time. Damaged grain has reduced nutritional value, low percentage germination,

*Corresponding author. E-mail: t.tefera@cgiar.org or tadeletefera@yahoo.com.

and reduced weight and market value.

Farmers in Africa use traditional granaries to store their grains which are not effective against storage pests. The lack of suitable grain storage structures, storage management technologies force maize growers to sell their produce immediately after harvest. Consequently, farmers receive low market prices for any surplus grain they may produce (Kimenju et al., 2009). Post-harvest losses to storage insect pests such as *S. zeamais* have been recognized as an increasingly important problem in Africa (Abebe et al., 2009; Markham et al., 1994). Although postharvest losses in maize due to storage insect pests are generally estimated to range between 20 to 30%, weight losses of up to 34 to 40% and 10 to 20%, for *P. truncatus* and *S. zeamais*, respectively; have been recorded from maize 3 months after storage on the farm (Boxall, 2002). The losses include weight loss, nutritional loss and economic loss such as income foregone as a result of early sale or costs incurred for having to purchase maize (Magrath et al., 1996). Losses due to postharvest insect pests could be influenced by the storage time and population of insects involved in infestation. However, empirical information on the relationship between *P. truncatus* and *S. zeamais* population densities and the extent of damage, dust production and weight loss to maize over a storage period is scanty. Most of the studies on maize grain loss due to insects pests were based on farmers reports during field surveys (Boxall, 2002; Golob and Hodges, 1982; Hodges et al., 1983; Meikle et al., 1998; Magrath et al., 1996). This paper, therefore, reports on comparative grain damage and weight loss in maize due the *P. truncatus* and *S. zeamais* at varying population level and three storage durations.

MATERIALS AND METHODS

Insect culture

Adults of *S. zeamais* and *P. truncatus* were obtained from the Kenya Agricultural Research Institute (KARI), Kiboko post harvest insect pest laboratory. Four hundred gram of maize grains was placed in one-liter glass jars and covered with perforated lids. About 200 unsexed adult insects of the two species were separately introduced into the glass jars. After 10 days of oviposition, all adult insects of the insects were removed. Each glass jar where the adult insects oviposited was kept for progeny emergence. Progeny emergence was monitored daily and those emerged on the same day were transferred to fresh grain in glass jars with lids and kept at the experimental conditions until sufficient number of such insects were obtained.

Grain preparation

Grains of the maize hybrid (H513), mostly grown by farmers in Kenya, but susceptible to storage insects at ambient conditions were fumigated with phostoxin tablet (55% Aluminum phosphide, 45.0% inert ingredients) for 7 days to disinfest from any possible sources of infestations. The grains were dried to 12% moisture content by exposing to the sun, sieved to remove any dirt, dust or broken grains. About 200 g grains were kept in a 250 ml capacity glass jar at room temperature for 24 h before introduction of insects.

Determining insect population and storage time on weight loss

Two experiments were separately carried out for *S. zeamais* and *P. truncatus*, with ten varying population levels (treatments), 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50 insects per 200 g grain. Unsexed adults, 7 to 10 days old of the respective species, were introduced into each jar containing 200 g maize grain. The glass jars were covered with a lid made of wire mesh (1 mm) to allow adequate ventilation and prevent escape of the insects. The treatments were arranged in a completely randomized design with four replications, kept on wooden shelves in a laboratory, and incubated for 30, 60 and 90 days. We used 90 days as the maximum duration of the trials, as local farmers in eastern mid-altitude dry ecology of Kenya seldom store maize grain more than 3 months. Separate experiments were concurrently set for each of the 30, 60, and 90 dates. The mean temperature and relative humidity were 28 ± 2°C and 65 ± 5%, respectively.

Data collection and statistical analysis

On each assessment date (30, 60 and 90), the glass jars opened, the content separated into grains, insects and dust using 4.7 and 1.0 mm sieves (Endecotts Limited, UK). The number of live insects, number of dead insects, number of damaged kernels, weight of damaged kernels, weight of undamaged grain, and weight of the dust produced were recorded. The dust or flour produced due the insects feeding and the grains were weighed on a precision electronic scale. Dust weight was expressed as a percentage of the initial grain weight. Grain damage was expressed as a proportion of the total number of grains. Grain weight loss was determined using the count and weight method of Gwinner et al. (1996):

Weight loss (%) = (Wu x Nd) - (Wd x Nu) X 100) / (Wu x (Nd + Nu)

Where, Wu = Weight of undamaged grain, Nu = Number of undamaged grain, Wd = Weight of damaged grain, and Nd = Number of damaged grain.

The number of insects log-transformed ($\log_{10}$), whilst percent grain damage, dust production, and weight loss, angular transformed (arcsine $\sqrt{\text{proportion}}$), in order to stabilize the variance. The transformed data were analyzed using one-way analysis of variance. Significant differences between means were separated using Student Newman Keuls Test (P < 0.05). Back-transformed (original) data are presented here.

RESULTS

Significant differences were observed between the initial insect density in the final insect density for *P. truncatus*, after 30 ($F_{9, 30} =$ 0.332; P < 0.01), 60 ($F_{9, 30} =$ 0.223; P < 0.02), and 90 days ($F_{9, 30} =$ 0.528; P < 0.01); and for *S. zeamais*, 30 ($F_{9, 30} =$ 0.388; P < 0.01), 60 ($F_{9, 30} =$ 0.315; P < 0.01), and 90 days after storage ($F_{9, 30} =$ 0.391; P < 0.01) (Table 1). There were no significant differences in the final insect density when the initial insect density applied was ranging from 25 to 50 for *P. truncatus*, 30

Table 1. Effect of the larger grain borer (LGB) and maize weevil (MW) initial population density on final insect density 30, 60 and 90 days after maize grain storage.

Initial insect density 200 g^{-1} grain	Final insect density (LGB) 200 g^{-1} grain			Final insect density (MW) 200 g^{-1} grain		
	30	60	90	30	60	90
5	8 ± 1a	61 ± 28a	155 ±7 5a	6 ± 1a	35 ± 12a	46 ± 13a
10	13 ± 1ab	93 ± 15ab	842 ± 165b	10 ± 1a	45 ± 3ab	84 ± 24ab
15	16 ± 2b	126 ± 36bc	790 ± 103b	15 ± 1b	45 ± 9ab	103 ± 13ab
20	24 ± 4bc	148 ± 31bc	856 ± 215b	20 ± 2bc	113 ± 36bc	119 ± 26ab
25	30 ± 8bcd	174 ± 68cd	726 ± 46b	25 ± 2c	122 ± 16bc	141 ± 34ab
30	43 ± 6cd	178 ± 51cd	714 ± 40b	30 ± 1d	128 ± 27bc	139 ± 15ab
35	41 ± 11cd	217 ± 31d	715 ± 77b	35 ± 2d	134 ± 53bc	181 ± 31ab
40	55 ± 6de	215 ± 46d	729 ± 88b	41 ± 2e	138 ± 29bc	218 ± 43bc
45	46 ± 8cd	236 ± 64d	664 ± 154b	45 ± 1e	145 ± 36c	295 ± 54c
50	56 ± 8de	235 ± 28d	1036 ± 108b	53 ± 1f	174 ± 30c	299 ± 55c

Means followed by the same letter(s) within a column are not significantly different from each other at 5% probability level.

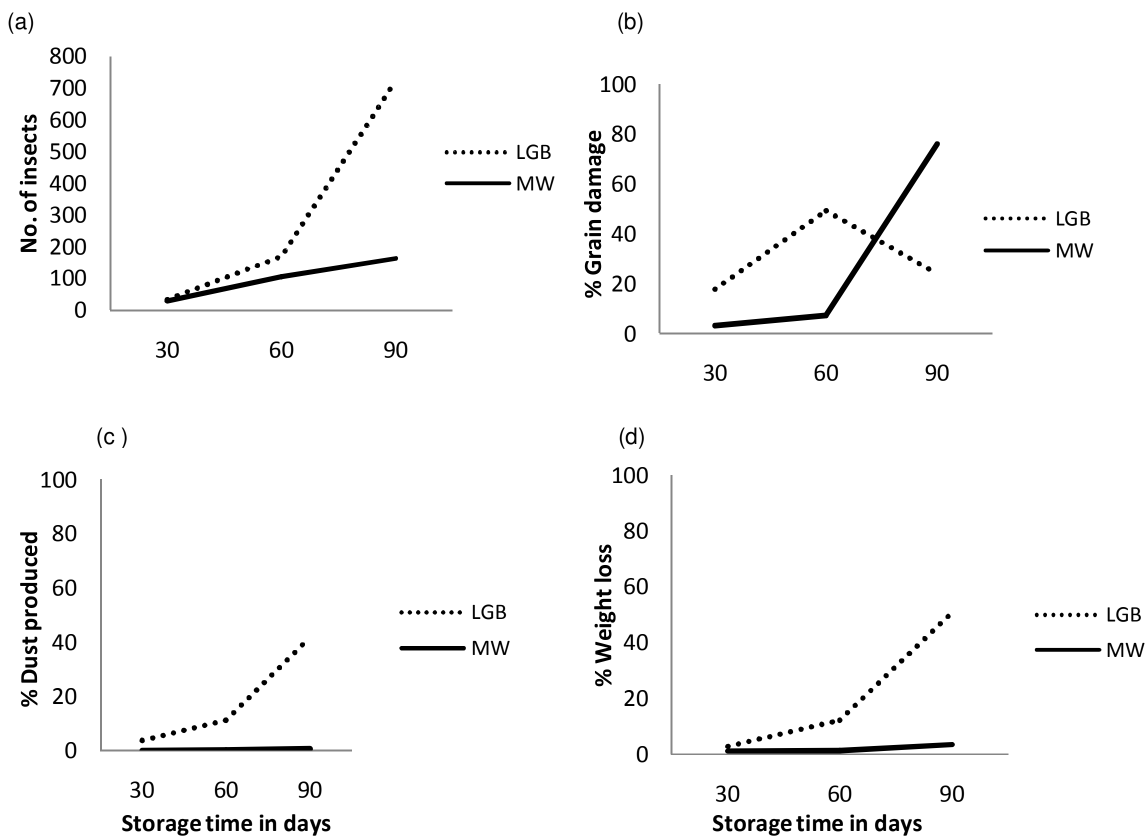

Figure 1. Influence of storage time of larger grain borer (LGB) and maize weevil (MW) pests on (a) number of insects, (b) % grain damage, (c) % dust weight and (d) % weight loss in maize kernels.

and 60 days after storage, and this difference was further significantly reduced when the grain was stored for 90 days, the difference being only at 5 insect 200 g^{-1} grain. For *S. zeamais*, there were significant differences when the initial insect density was applied at 5 insect, and 40, 45 and 50 insect 200 g^{-1} grain 90 days after storage. There was, however, an increasing trend in the final insect density with a corresponding increase in an initial insect density and storage time (Figure 1a).

There were significant differences between the initial

Table 2. Effect of the larger grain borer (LGB) and maize weevil (MW) different population density on percent maize grain damage 30, 60 and 90 days after storage.

Insect density 200 g^{-1} grain	Percent grain damage (LGB) 200 g^{-1} grain			Percent grain damage (MW) 200 g^{-1} grain		
	30	60	90	30	60	90
5	4.6 ± 0.7a	31.3 ± 17a	62.8 ± 12.4b	2.2 ± 0.3a	3.5 ± 0.9a	94.3 ±2 .5cd
10	10.3 ± 1.3ab	41.5 ± 4a	23.4 ± 2.5a	2.6 ± 0.6a	3.9 ± 0.3ab	87.0 ± 2.8cd
15	12.6 ± 2.5ab	49.8 ± 10a	22.6 ± 5.1a	2.6 ± 0.4a	3.5 ± 0.8a	85.7 ± 4.3abc
20	10.7 ± 3.4ab	50.0 ± 12a	21.6 ± 3.5a	2.1 ± 0.8a	5.9 ± 0.9ab	82.9 ± 4.5abc
25	20.3 ± 3.4bc	53.2 ± 8a	18.2 ± 0.9a	2.7 ± 0.1a	7.4 ± 1.4bc	80.1 ± 3.6abc
30	22.3 ± 4.0bc	49.3 ± 13a	19.0 ± 2.4a	3.1 ± 0.1a	8.1 ± 1.0bc	76.5 ± 6.4abc
35	22.3 ± 2.1bc	54.9 ± 8a	15.5 ± 1.2a	3.4 ± 0.1a	9.3 ± 0.8bc	73.8 ± 3.6abc
40	21.6 ± 7.0bc	59.9 ± 5a	17.9 ± 1.6a	3.8 ± 0.1a	9.8 ± 2.6bc	61.1 ± 9.0ab
45	22.9 ± 2.5bc	60.3 ± 4a	20.5 ± 2.3a	3.9 ± 0.2a	9.2 ± 0.5bc	60.8 ± 8.4ab
50	30.4 ± 3.6cd	42.5 ± 5a	18.0 ± 0.9a	4.2 ± 0.2a	11.3 ± 2.2c	57.8 ± 6.2a

Means followed by the same letter within a column are not significantly different from each other at 5% probability level.

Table 3. Effect of larger grain borer (LGB) and maize weevil (MW) population density on percent dust produced 30, 60 and 90 days after maize grain storage.

Insect density 200 g^{-1} grain	Dust production (%) (LGB) 200 g^{-1} grain			Dust production (%) (MW) 200 g^{-1} grain		
	30	60	90	30	60	90
5	1.3 ± 0.9a	2.5 ± 0.7 a	10.4 ± 8.0a	0.03 ± 0.1a	0.19 ± 0.1a	0.18 ± 0.1a
10	1.7 ± 0.2a	7.5 ±1.2 ab	38.4 ± 5.2b	0.05 ± 0.1a	0.18 ± 0.1a	0.39 ± 0.1ab
15	2.0 ± 0.3a	8.9 ± 2.4 ab	41.0 ± 15.4b	0.08 ± 0.1a	0.18 ± 0.3a	0.38 ± 0.1ab
20	2.2 ± 0.4a	9.7 ± 2.2 ab	44.4 ± 7.1b	0.08 ± 0.1a	0.30 ± 0.1ab	0.45 ± 0.1ab
25	3.9 ± 0.8ab	10.7 ± 3.3 ab	46.9 ± 2.3b	0.08 ± 0.1a	0.26 ± 0.1ab	0.65 ± 0.1bc
30	4.6 ± 1.0ab	11.9 ± 3.2 b	47.5 ± 6.2b	0.08 ± 0.1a	0.29 ± 0.1ab	0.64 ± 0.1bc
35	4.5 ± 0.7ab	13.2 ± 1.8 bc	46.6 ± 3.8b	0.09 ± 0.1a	0.34 ± 0.1ab	0.76 ± 0.1bc
40	4.8 ± 0.8ab	15.0 ± 1.9 c	43.6 ± 4.9b	0.11 ± 0.1a	0.32 ± 0.1ab	0.87 ± 0.1bc
45	5.9 ± 1.0ab	13.6 ± 1.8 c	45.7 ± 15.6b	0.12 ± 0.1a	0.37 ± 0.1ab	1.0 ± 0.1bc
50	7.5 ± 0.3b	17.8 ± 1.5 c	52.8 ± 3.2b	0.13 ± 0.1a	0.39 ± 0.1c	1.2 ± 0.1c

Means followed by the same letter within a column are not significantly different from each other at 5% probability level.

insect densities in percent grain damage for *P. truncatus*, 30 ($F_{9, 30} =$ 4.98; P < 0.01) and 90 days ($F_{9, 30} =$ 7.33; P < 0.01), and for *S. zeamais*, 60 ($F_{9, 30} =$ 4.41; P < 0.01), and 90 ($F_{9, 30} =$ 5.46; P < 0.01) days after grain storage (Table 2). The least and the highest percent grain damage was recorded at 5 and 50 insect density 200 g^{-1} grain respectively, for *P. truncatus* 30 days after grain storage. However, grain damage was substantially reduced 60 days after storage (Figure 1b); the highest percent grain damage was observed in the least insect density, 5 insects 200 g^{-1} grain, after 90 days (Table 2). On the contrary, percent grain damage increased for *S. zeamais*, 60 days after storage (Figure 1b); the least and the highest percent damage recorded at 50 and 5 insect density 200 g^{-1} grain, respectively, after 90 days (Table 2).

Significant differences were observed among the *P. truncatus* densities in percent dust produced 30 ($F_{9, 30} =$ 3.94; P < 0.01), 60 ($F_{9, 30} =$ 3.68; P < 0.01) and 90 ($F_{9, 30} =$ 8.13; P < 0.01) days after grain storage for *P. truncatus* (Table 3). The least percent dust (10.4%) was produced by *P. truncatus* at 5 insects 200 g^{-1} grain, as opposed to the highest dust produced (38.4 to 52.8%) by the remaining insect densities, 90 days after storage. There were significant differences among the densities of *S. zeamais* in percent dust produced 60 ($F_{9, 30} =$ 3.28; P < 0.01) and 90 ($F_{9, 30} =$ 5.46; P < 0.01) days after grain storage. Although dust production was quite low in the *S. zeamais* compared to the *P. truncatus*, the highest percent dust (0.39 to 1.2%) was produced at the highest *S. zeamais* population density, 50 insect 200 g^{-1}, 60 and 90 days after storage. Percent dust produced increased with an increase in an initial insect population density (Table 3) and storage time for *P. truncatus* (Figure 1c).

There were significant differences among the initial

Table 4. Effect of larger grain borer (LGB) and maize weevil (MW) density on percent weight loss 30, 60 and 90 days after storage.

Insect density 200 g^{-1} grain	Weight loss (%) (LGB)200 g^{-1} grain			Weight loss (%) (MW)200 g^{-1} grain		
	30	60	90	30	60	90
5	0.6 ± 0.3a	1.5 ± 0.6 a	11.8 ± 1.4a	0.1 ± 0.1a	1.1±0.1a	1.2 ± 0.2a
10	0.6 ± 0.1a	5.3 ± 1.7a	38.4 ± 14.1bc	1.2 ± 0.9a	1.3 ± 0.1a	1.8 ± 0.1ab
15	0.8 ± 0.2a	7.6 ± 3.2ab	48.2 ± 7.6bc	1.2 ± 0.1a	1.2±0.6a	1.8 ± 0.1ab
20	1.1 ± 0.3ab	10.2 ± 2.6bc	51.8 ± 20.6bc	1.4 ± 0.9a	1.6±0.1a	1.7 ± 0.2ab
25	3.1 ± 1.1bc	11.7 ± 4.3bc	54.6 ± 6.2bc	1.6 ± 0.2a	1.6 ± 0.2a	3.5 ± 1.3ab
30	3.1 ± 1.2bc	15.9 ± 4.1cd	59.1 ± 7.2bc	1.6 ± 0.3a	1.6 ± 0.1a	3.6 ± 1.1ab
35	3.1 ± 0.8bc	15.8 ± 2.6cd	59.2 ± 5.1bc	1.4 ± 0.1a	1.5 ± 0.2a	3.9 ± 0.7ab
40	3.9 ± 1.1bc	15.9 ± 6.2cd	58.5 ± 5.2bc	1.3 ± 0.3a	1.5 ± 0.2a	4.9 ± 1.8ab
45	5.6 ± 1.1cd	15.4 ± 3.4cd	58.9 ± 19.8bc	1.5 ± 0.4a	1.7 ± 0.2a	6.3 ± 1.6b
50	7.3 ± 0.4d	23.5 ± 1.9d	67.1 ± 5.0cd	1.4 ± 0.3a	1.5 ± 0.2a	6.9 ± 1.8b

Means followed by the same letter within a column are not significantly different from each other at 5% probability level.

insect density in affecting grain weight losses, 30 ($F_{9, 30} =$ 11.88; P < 0.01), 60 ($F_{9, 30} =$ 13.65; P < 0.01) and 90 ($F_{9, 30}$ $=$ 5.52; P < 0.01) days after storage for *P. truncatus* (Table 4). The weight loss ranged from 0.3 to 7.3%, 1.5 to 23.5%, and 11.8 to 67.1%, after 30-, 60- and 90- days of storage, respectively. Significant differences ($F_{9, 30} =$ 17.89; P < 0.01) in weight loss were observed 90 days after storage for *S. zeamais* (Table 4). *S. zeamais* caused the least grain weight loss (6.9%) compared to the highest loss (67.1%) caused by *P. truncatus.* Grain weight loss decreased with an increasing storage time (Figure 1d).

DISCUSSION

This study demonstrated the comparative maize grain damage, dust produced, weight loss and final insect density increase for *P. truncatus* and *S. zeamais* over a storage duration of 90 days. The final insect densities, grain damage, dust produced and weight loss for the *P. truncatus* exceeded that of the *S. zeamais*. *P. truncatus* and *S. zeamais* final densities were relatively low until 60 days of storage. However, as the storage time progressed, no differences were observed between the final insect densities except at the smallest initial insect density (5 insects 200g^{-1} grain). This indicates that population build up is fast for the two insects, particularly for *P. truncatus*, therefore, can cause significant damage and losses. Adda et al. (2002) reported that estimated pest densities based on the analysis in the laboratory were always higher than those obtained from the on-farm assessments. However, on-farm assessment is less accurate than the assessment in the laboratory, but is quicker and may be also convincing to the farmers. The current study revealed that smallest initial density (5 insects 200g^{-1} grain) of *P. truncatus* caused high grain damage and weight loss. This indicates that small initial population of the *P. truncatus* in stores at the beginning of the season suffices to cause high infestation levels at the end of the storage period.

Percent grain damage declined 60 days after storage for *P. truncatus*; however, it sharply increased over the storage period for *S. zeamais*. It was observed during the laboratory analysis that grain kernels were actually lost or destroyed as opposed to damaged grain (holed) due to severe infestation by *P. truncatus*, 60 days after storage. When infestation is severe such missing grains were not taken into account, hence the percent grain damage is likely to underestimate grain damage as reported by Compton et al. (1998).

Flour production by *P. truncatus* (52.8%) was higher than that of S. *zeamais* (1.2%) after 90 days due to extensive tunneling to the grain by the former. The extensive tunneling in maize grain by *P. truncatus* adults characteristics allows it to convert grain into flour within a very short time. The flour produced during the insects feeding consists of the insect eggs, excreta and exuvia; hence, neither fit for animal nor human consumption in Kenya due to its unattractive taste. However, blending flour from damaged maize with cassava flour for consumption or by blending damaged maize with top quality maize for immediate sale in Ghana was reported (Magrath et al., 1996).

In the present study, mean weight losses of 6.9 and 67.1% recorded after 90 days for *S. zeamais* and *P. truncatus*, respectively. This implies that in the absence of control measures, post-harvest losses due to the P. truncatus during storage can be severe. Although not experimentally tested individual farmers reportedly suffering high losses of up to 34% dry weight and in extreme cases, 70 to 80% of the maize grains were damaged. The commodity was totally unfit for consumption (Golob and Hodges, 1982; Hodges et al., 1983). It was found that losses averaged 9% over the relatively short storage period of six months (Hodges et al., 1983) whereas weight losses in farm-stored grain caused by indigenous pest complexes are usually of the order of 5% (Tyler and Boxall, 1984). Reports from Tanzania showed that farmers growing improved maize varieties, susceptible to pest attack, suffered storage losses averaging 17.9% after six months and 41.2% after eight months (Keil, 1988). Surveys in Togo, West Africa, showed a mean rise in maize storage losses from 7 to over 30% during 6 to 9 month period (Pantenius, 1988). The weight loss reported in the present study for *P. truncatus* is much higher than earlier reported. This could be attributed to the susceptibility of the hybrid used and conducive climatic conditions (28°C and 65% RH). Losses in maize due to *P. truncatus* were consistently higher than those due to indigenous pest species (Magrath et al., 1996).

Although no published report is available regarding financial losses incurred due to postharvest pests of maize in Kenya, it is apparent that small holder farmers experiences huge losses since the introduction of *P. truncatus* in early 1980's. Magrath et al. (1996) reported that in the Volta Region of Ghana individual farmers could lose up to 50% of the value of their maize to *P. truncatus* attack. Losses in the market value of maize infested by only *Sitophuilus* spp. were 5 to 10% while value losses ranged 15 to 45% for maize damaged by *P. truncatus*. The resulting level of financial loss was equivalent to about 5% of average total household income (Magrath et al., 1996, 1997).

In conclusion, *P. truncatus,* caused high grain damage and weight loss, indicating that control measures should be designed at the onset of grain storage if the grain is planned to be stored for more than 30 days. Traditional grain storage facilities may not offer protection against *P. truncatus*. However, the current promotion of the use of resistant varieties and metal silos in Kenya by the International maize and wheat improvement center, for grain storage is an alternative approach to reduce losses by *P. truncatus.*

ACKNOWLEDGEMENTS

The authors thank Christine Waviyna, for her assistance during experimental setup and data collection. This paper contributes to the Insect Resistant Maize for Africa Project (IRMA-III-Conv), funded by the Syngenta Foundation for Sustainable Agriculture.

REFERENCES

Abebe F, Tefera T, Mugo S, Beyene Y, Vidal S (2009). Resistance of maize varieties to the maize weevil *Sitophilus zeamais* (Motsch.) (Coleoptera:Curculionidae). Afri. J. Biotechnol., 8: 5937-5943.

Adda C, Borgemeister C, Biliwa A, Meikle WG, Markham RH, Poehling HM (2002). Integrated pest management in postharvest maize: a case study from Republic of Togo. Agric. Ecosyst. Environ., 93: 305-321.

Boxall RA (2002). Damage and loss caused by the larger grain borer *Prostephanus truncatus*. Integr. Pest Manage. Rev., 7: 105-121.

Compton JAF, Floyd S, Ofusu A, Agbo B (1998). The modified count and weigh method: An improved procedure for assessing weight loss in stored maize cobs. J. Stored Product Res., 34: 277-85.

Golob P, Hodges RJ (1982). Study of an outbreak of *Prostephanus truncatus* (Horn) in Tanzania. Report G164. Slough: Tropical Products Institute, U.K.

Gwinner J, Harnisch R, Muck O (1996). Manual on the prevention of post harvest seed losses, post harvest project, GTZ, D-2000, Hamburg, FRG, p. 294.

Hodges RJ, Dunstan WR, Magazini I, Golob P (1983). An outbreak of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) in East Africa. Prot. Erotol., 5: 183-94.

Keil H (1988). Losses caused by the Larger Grain Borer in farm-stored maize. In G.G.M. Schulten and A.J. Toet (eds) *Technical Papers. Workshop on the Containment and Control of the Larger Grain Borer,* 16–21 May1988, Arusha, Tanzania, pp. 28-52.

Kimenju SC, De Groote H, Hellin H (2009). Preliminary Economic Analysis: Cost effectiveness of the use of improved storage methods by small scale farmers in east and southern Africa countries. International Maize and Wheat Improvement Center (CIMMYT), p. 17.

Magrath, P, Compton J, Ofusu A, Motte F (1997). Cost benefit analysis of client participation in agricultural research: A case study from Ghana. Overseas Development Institute Agricultural and Extension Network Paper, 74b: 19-39.

Magrath PA, Compton JAF, Motte FF, Awuku M (1996). Coping with a new storage insect pest: The impact of the larger grain borer in eastern Ghana. Chatham: Natural Resources Institute, UK.

Markham RH, Bosque-Perez NA, Borgemeister C, Meikle WG (1994). Developing pest management strategies for the maize weevil, *Sitophilus zeamais*, and the larger grain borer, *Prostephanus truncatus*, in the humid and sub-humid tropics. FAO Plant Prot. Bull., 42: 97-116.

Meikle WG, Holst N, Scholz D, Markham RH (1998). Simulation model of *Prostephanus truncatus* (Coleoptera: Bostrichidae) in rural maize stores in the Republic of Benin. Environ. Entomol., 27: 59-69.

Pantenius CU (1988) Storage losses in traditional maize granaries in Togo. Insect Sci. Appl., 9: 725-35.

Tyler PS, Boxall RA (1984). Post-harvest loss reduction programmes: a decade of activities; what consequences? Trop. Stored Prod. Inf., 50: 4-13.