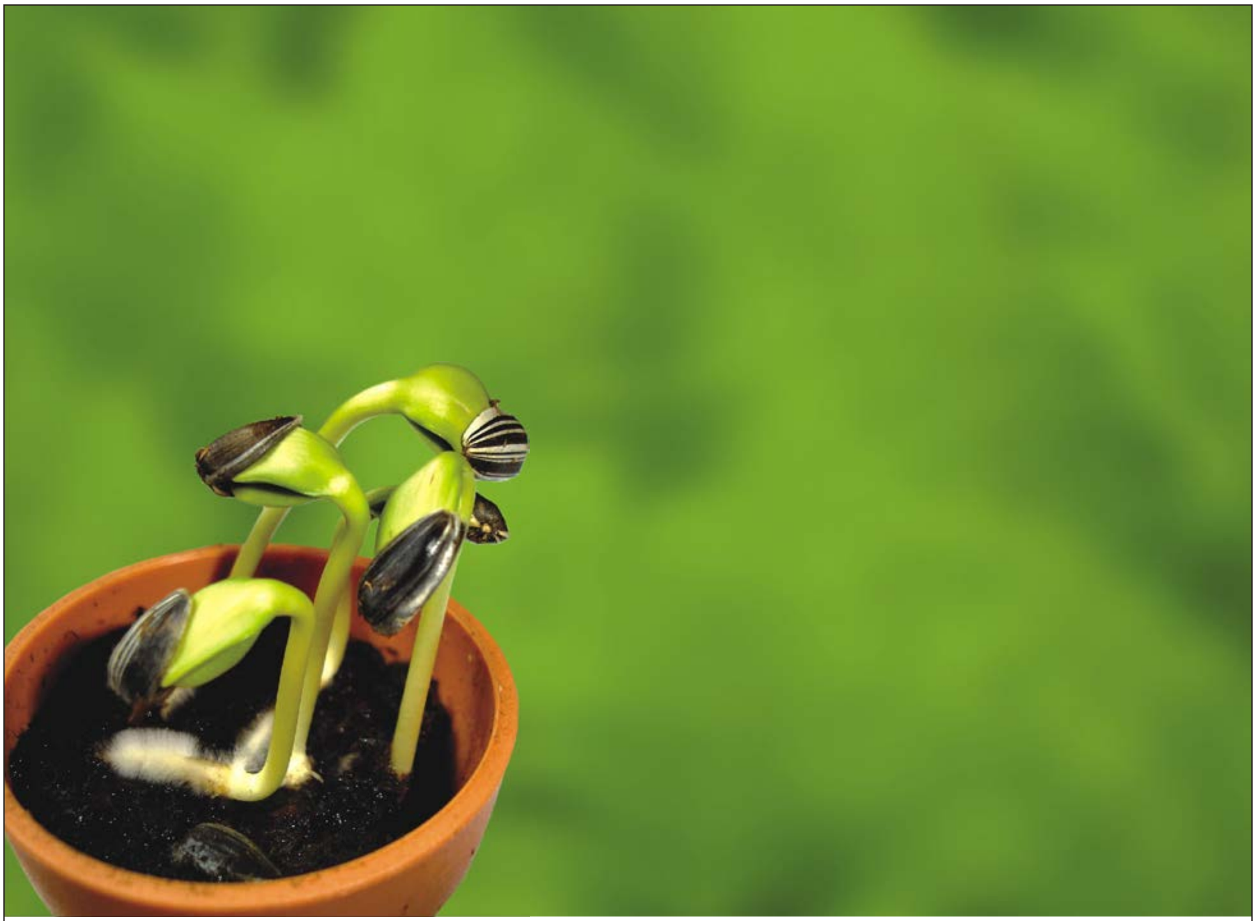

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Postharvest Insect Pest and Foliar Disease Resistance and Agronomic Performance of New Maize Hybrids in East Africa

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ABSTRACT

A study was carried out with the objectives to evaluate maize hybrids for grain yield, agronomic performance and reaction to foliar diseases. Twenty seven experimental maize hybrids with varying level of resistance to two postharvest insect pests: the Larger Grain Borer (LGB) and Maize Weevil (MW), tested in nine environments in Kenya and Ethiopia. The performances of the hybrids were not consistent across environments for all traits tested as evident from the significant genotype×environment interactions. The contribution of the environment main effect was 46.1% for grain yield, 84.9% for days to anthesis, 26.9% for ears per plant, 63.3% for anthesis-silking interval, 76.5% for plant height and 74.7% for ear height. The mean yield performance of the hybrids across locations was 4.8 t ha^{-1}. The hybrids yielded high at Kiboko (6.13 t ha^{-1}) followed by Mpeketoni (5.66 t ha^{-1}) and Bako (5.47 t ha^{-1}). The hybrids had similar days to anthesis (65-68 days), relatively taller plant (183 to 227 cm) and ear height (88-116 cm) compared to the commercial check (plant height 204 cm and ear height 98 cm). The hybrids were all resistant to rust and gray leaf spot diseases and moderately resistant to *Turcicum* leaf blight. However, they were susceptible to maize streak virus Two hybrids, CKPH08009 (4.9 t ha^{-1}) and CKPH08025 (5.0 t ha^{-1}) had high yield performance and resistance to both the LGB and MW compared to the commercial check, WH505 (5.1 t ha^{-1}) which is susceptible. These results indicate that selection for insect resistant did not result in yield penalty. Therefore, the two resistant hybrids can be recommended for release and commercialization in eastern Africa where MW and LGB are the major storage pests.

Key words: Maize, postharvest insects, *Prostephanus truncatus*, *Sitophilus zeamais*, yield performance

INTRODUCTION

Postharvest insect pests including the maize weevil *Sitophilus zeamais* and the larger grain borer, *Prostephanus truncatus*, are the two most destructive pests of stored maize in Africa (Tefera *et al*., 2011a; Boxall, 2002). Grain losses in maize caused by MW are 12-20 and 9-45% for LGB depending on periods of storage (Tefera *et al*., 2011b; Gueye *et al*., 2008; Markham *et al*., 1991; Panthenius, 1988; Law-Ogbomo and Enobakhare, 2006; Abdullahi *et al.*, 2011; Iloba and Ekrakene, 2006). Insect damage results directly in reduced kernel weight which also may reduce future maize production for farmers who plant saved kernel as seed that represent 70% of all maize planted in eastern and southern Africa (Boxall, 2002). There is also health risk associated with consumption of infested maize kernel, as it has been reported to have relatively higher levels of aflatoxin contamination than non-infested maize kernels (Kankolongo *et al.*, 2009; Golob, 2002; Dhliwayo and Pixley, 2003).

Developing high yielding maize varieties with resistance to LGB and MW has been regarded as an option to minimize storage losses in maize. The International Maize and Wheat Improvement Centre (CIMMYT) in collaboration with the Kenya Agricultural Research Institute (KARI) developed and deployed resistant, high yielding and adaptable maize hybrids (Mugo *et al.*, 2001).

Previous research suggests that selection of superior genotypes for grain yield and agronomic traits in maize hybrid performance trials is affected by genotype by environment (G×E) interaction (Beyene *et al.*, 2011; Butron *et al.*, 2004; Lee *et al.*, 2003; Pixley and Bjarnason, 2002; Iqbal *et al.*, 2007; Selvaraj and Nagarajan, 2011). Newly developed maize hybrids need to be tested in multi-locations to determine the performance of the hybrid before commercial release. Selection based on insect resistance only may not always be adequate for new maize hybrids. Disease and yield performance across environment are among limiting factors for commercialization of new maize hybrids. The objectives of this study were, therefore, to evaluate yield, agronomic performance and reaction to foliar diseases among experimental maize hybrids with varying level of resistant to postharvest insect pests, the larger grain borer and maize weevil tested in nine environments in Kenya and Ethiopia.

MATERIALS AND METHODS

Germplasm: In 2009, the well adapted CIMMYT elite inbred lines CML202 and CML204, susceptible to LGB and MW, were crossed to 27 resistant to MW and LGB advanced lines to obtain the respective 27 Single Crosses (SC). The 27 SC served as parents in crosses with either CML202 or CML204 to obtain 27 three-way crosses hybrids (Table 1). The resistant lines were developed

Table 1: List and description of the maize hybrids tested for yield and agronomic traits across nine locations in Ethiopia and Kenya

Genotype (Entry)	Name		Genotype (Entry)	Name	
1	CKPH09001	Exp. hybrid[1]	16	CKPH08002	Exp. hybrid
2	CKPH10001	Exp. hybrid	17	CKPH08003	Exp. hybrid
3	CKPH09002	Exp. hybrid	18	CKPH08004	Exp. hybrid
4	CKPH10002	Exp. hybrid	19	CKPH09004	Exp. hybrid
5	CKPH09003	Exp. hybrid	20	CKPH08009	Exp. hybrid
6	CKPH08035	Exp. hybrid	21	CKPH08012	Exp. hybrid
7	CKPH08036	Exp. hybrid	22	CKPH08013	Exp. hybrid
8	CKPH08037	Exp. hybrid	23	CKPH08018	Exp. hybrid
9	CKPH08038	Exp. hybrid	24	CKPH08020	Exp. hybrid
10	CKPH08039	Exp. hybrid	25	CKPH08024	Exp. hybrid
11	CKPH08040	Exp. hybrid	26	CKPH08025	Exp. hybrid
12	CKPH08041	Exp. hybrid	27	CKPH08028	Exp. hybrid
13	CKPH08043	Exp. hybrid	28	WH505	Com. check[2]
14	CKPH08044	Exp. hybrid	29	CKPH08020	Res. Check[3]
15	CKPH08001	Exp. hybrid	30	Duma-41	Sus. check[4]

[1]Exp. hybrid: Experimental hybrid, [2]Com. check: Commercial check, [3]Res. check: Resistant check, [4]Sus. check: Susceptible check

Table 2: Geographical and climatic data for 9 trial sites used in evaluation of maize hybrids in Kenya and Ethiopia

Site	Longitude	Latitude	Elevation (masl)	Rainfall (mm)	Temp max. (°C)	Temp min.	Soil texture
Alupe	34°7'E	0°30'N	1150.0	1688.0	28.6	15.8	Sandy loamy
Bako	36°46'E	5°16'N	1088.0	1210.1	30.7	15.6	Clay loam
Bumula	34°32'E	0°33'N	1451.0	1300.0	20.0	25.0	Clay loam
Katumani	37°25'E	1.6S	1580.0	528.0	24.7	13.9	Loamy sand
Kiboko	37°75'E	2.15S	975.0	530.0	35.1	14.3	Sandy clay
Mpeketoni	40°41'E	2°23'S	11.9	980.0	32.0	23.0	Sandy loam
Msabaha	40°02'E	3°16'S	91.0	1157.0	39.5	13.3	Sandy loam
Mtwapa	39°219'E	4.347S	30.0	965.0	29.0	21.6	Sandy soils
Sangalo	34°37'E	0°30'N	1459.0	1553.0	25.4	13.3	Sandy clay loam

from a cross between “CubaGuard” and “Kilima”. Kilima is a Tanzanian Open Pollinated Variety (OPV) which has resistance to LGB (Derera *et al.*, 2001). The “CubaGuard” originated from Cuba and Caribbean landraces obtained from CIMMYT gene bank (accessions 89, 90 and 106) and formed at CIMMYT in 1993 from seed regeneration nursery that had undergone more than four cycles of selection and inbreeding under infestation with LGB and MW.

Experimental design and field management: Trials composed of 30 hybrids were planted at nine environments (locations): Kiboko, Mtwapa, Bumula, Katumani, Sangalo, Msabaha, Alupe, Mpeketon in Kenya and Bako in Ethiopia, in 2010 (Table 2). The locations were different in soil type, temperature and mean seasonal rainfall. Each trial involved 27 experimental hybrids in which the parental lines carrying genes for resistance against the MW and LGB, along with a commercial check (genotype 28), a resistant check (genotype 29) and a susceptible check (genotype 30) (Table 1). The trials were laid out in 6×5 alpha lattice designs with three replications. Two maize seeds were planted per hill in a row of 5 m length and thinned to one seedling per hill 2 weeks after emergence. There were two rows per plot spaced 75 cm apart with plant-to-plant distance of 25 cm to attain a population density of 53,000 plants ha^{-1}. Fertilizers were applied at the rate of 60 kg N and 60 kg P_2O_5/ha as recommended for the area. Nitrogen was applied in two splits: at planting and knee stage. The fields were kept free of weeds by hand weeding.

Testing maize hybrids against LGB and MW: In preparation of insects for infestation, adults of MW and LGB were obtained from the Kenya Agricultural Research Institute (KARI), Kiboko Postharvest Insect Pest Laboratory. Four hundred gram of maize kernels (H513) was placed in 1 L 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 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 kernel in glass jars with lids and kept at the experimental conditions until sufficient number of such insects were obtained.

At harvest, a random bulk of about 500 g kernels were taken from each plot of trial planted at Kiboko and fumigated with phostoxin for seven days to disinfest from any possible sources of infestations. The F_2 kernel was used to evaluate resistance because this represents the generation that is stored by farmers and will be vulnerable to the attack by the MW and LGB. The kernels were sieved to remove any dirt, dust or broken kernels. The moisture content of kernels varied from 11-12%. About 100 g kernels of each variety were kept in a glass jar at room temperature for 24 h before infestation with insects.

Thirty, 7-10 days old, unsexed adults (sex ratio 1:1) of LGB and MW were introduced separately into a glass jar containing 100 g kernels of each hybrid. The glass jars were covered with a lid made of wire mesh to allow adequate ventilation and prevent escape of the insects. The treatments were arranged in a completely randomized design with three replications, kept on wooden shelves in a laboratory at 28±2 and 65±5% RH.

Data collection

Yield, agronomic performance and reaction to foliar diseases: At physiological maturity, ears from each plot were separately harvested and shelled. Kernel yield in tons per hectare adjusted to 12.5% moisture was calculated using unshelled kernel weight from entire plot. Agronomic traits including days to anthesis (when more than 50% plants in a row shed pollen), plant height (from the base to the flag leaf), ear height (from the ground to the base of the first ear) and number of ears per plant were recorded from all plants per plot. Foliar diseases, rust *Puccinia sorghi*, Gray leaf spot *Cercospora zeae maydis* and leaf blight *Exerohilium turcicum* were recorded for disease severity on all plants per plot using a 1-5 scale where, 1 = no symptom on leaves, 2 = light disease symptom on leaves, 3 = moderate symptoms on leaves, 4 = severe symptom on 60% of leaf area, 5 = severe symptom on 75% or more of the leaf area. The Maize Streak Virus (MSV) severity was rated on all plants per plot using a 1-5 scale with half points where 1 = no symptom on leaves, 1.5 = very few streaks on leaves, 2 = light streak on old leaves, gradually decreasing on young leaves, 2.5 = light streaking on an old and young leaves, 3 = moderate streaks on old and young leaves, 3.5 = moderate streaks on old and young leaves and slight stunting, 4 = severe streaking on 60% of leaf area, plants stunted, 4.5 = severe streaking on 75% of leaf area, plants severely stunted, 5 = severe streaking on 75% or more of the leaf area, plants severely stunted, dying or dead. No artificial inoculations were carried out for the diseases as natural infestation was assumed to occur every year. For all diseases using the visual scale, a plant showing = 1 considered highly resistant; 1.1-2 resistant; 2.1-3 moderately resistant; 3.1-4 susceptible; 4.1-5 highly susceptible.

Testing maize hybrids against LGB and MW: Ninety days after incubation, the glass jars were opened and the content were separated into kernels, insects and dust using 4.7 and 1.0 mm sieves (Endecotts Limited, UK). The weight of the kernel and dust produced were recorded. The dust or flour produced due to insect feeding and the kernels were weighed on a precision electronic scale. Kernel weight loss was determined according to Alonso-Amelot and Avila-Nunez (2011):

$$\text{Kernel weight loss (\%)}\ \frac{W_1\text{-}W_2\text{-Wdust}}{W_1}\times 100$$

where, W_1 and W_2 represent the initial and final kernel weight; W_{dust} the dust weight produced by the insect feeding. The hybrids were classified as resistant or susceptible based on kernel weight loss following Derera *et al.* (2001). Genotype with kernel weight loss = 2% considered resistant, 2.1-6% moderately resistant, 6.1-8% susceptible and >8% highly susceptible to the MW; while, for the LGB, kernel weight loss = 4% resistant, 4.1-8% moderately resistant, 8.1-12% susceptible and >12% highly susceptible. Percent reduction in grain weight loss was expressed relative to the susceptible check:

$$\frac{\text{Mean \% weight of susceptible check-mean \% weight loss of genotype}}{\text{Mean \% weight of susceptible check}}\times 100$$

Statistical analysis: Analysis of variance (ANOVA) was done for grain yield (t ha^{-1}), number of ears per plant, days to 50% anthesis, anthesis-silking interval, plant height (cm) and ear height (cm) for each location separately and combined across locations. For the combined analysis, variances were partitioned into relevant sources of variation to test for differences among genotypes and the presence of G×E interaction. The foliar diseases score data were categorical variables, hence were not subjected to ANOVA; however, they were used to categorize the hybrids into susceptible or resistance group.

RESULTS

Analysis of variance and hybrid performance: There were significant differences ($p<0.001$) among the Genotype (G), Environments (E) and genotype by environment interaction (G×E) for yield and agronomic traits (Table 3). The contribution of the environment main effect was high accounted for 46.1% for grain yield, 84.9% for days to 50% anthesis, 26.9% for ears per plant, 63.3% for anthesis-silking interval, 76.5% for plant height and 74.7% for ear height (Table 4). However, the contribution of the genotype main effect to the total sum of squares was low ranging from 2.6-4.3%. The proportion of G×E was relatively higher than that of the genotype main effects.

Table 3: Mean square and degrees of freedom from analysis of variance of grain yield and agronomic traits of maize hybrids evaluated across 9 environments in Kenya and Ethiopia

Source	df	Grain yield (t/ha)	Ears per plant	Days to 50% anthesis (days)	Anthesis silking interval	Plant height (cm)	Ear height (cm)
REP	2	7.7***	0.20*	91.0***	7.1*	2137.4***	698.2*
Genotype	29	2.0***	0.04	54.3***	2.1	1370.5***	852.7***
Environment	8	79.1***	1.40***	5795.1***	289.8***	113835.2***	66822.3***
GxE	232	1.1***	0.04	16.4***	1.3	364.2**	278.3***
Error	538	0.8	0.04	2.8	1.6	265.9	168.3

*,**,***Indicate significant level at 95, 99 and 99.9%, respectively

Table 4: Percent sum of squares (SS) contributed to the environments, genotype and genotype x environment interactions

Source	Grain yield (t ha^{-1})	Ears per plant	Days to anthesis (days)	Anthesis silking interval	Plant height (cm)	Ear height (cm)
REP	1.1	0.8	0.5	0.6	0.4	0.2
Genotype	4.3	3.1	4.6	2.6	3.8	3.5
Environment	46.1	26.9	84.9	63.5	76.5	74.7
GxE	18.3	21.1	7.0	8.2	7.1	9.0
Error	30.3	48.1	2.9	25.1	12.2	12.7

Table 5: Mean grain yields (ton ha^{-1}) of 30 maize hybrids with different level of resistance to postharvest insect pests tested in 9 environments in Kenya and Ethiopia

	Environments									
Genotype	1	2	3	4	5	6	7	8	9	Mean (LSD = 0.31)
1	6.12	5.10	4.57	3.49	6.34	5.01	4.14	4.88	5.68	5.0
2	5.05	5.04	3.57	4.00	6.30	3.45	3.95	3.16	5.75	4.5
3	5.07	4.56	3.56	3.88	6.00	4.76	4.81	4.96	5.70	4.8
4	5.45	4.32	3.51	3.83	6.30	5.02	4.96	3.92	4.93	4.7
5	6.29	4.91	4.21	3.5	6.81	4.58	4.73	4.59	4.92	4.9
6	5.09	4.36	3.95	4.00	6.16	5.25	3.77	4.24	5.45	4.7
7	5.77	4.85	4.59	4.72	6.35	5.11	3.83	5.19	5.72	5.1
8	5.48	4.78	3.60	3.95	6.57	4.19	3.37	4.94	4.68	4.6
9	5.64	5.05	3.38	3.98	6.98	3.74	3.60	4.31	4.91	4.6
10	6.94	5.63	4.13	3.58	7.06	5.82	3.81	3.40	5.37	5.1
11	4.74	4.44	3.18	3.15	5.77	4.02	3.26	4.29	5.02	4.2
12	6.56	5.08	4.49	3.70	6.54	4.84	4.17	4.68	5.81	5.1
13	5.26	4.57	3.96	2.74	7.46	5.52	4.25	3.75	6.19	4.9
14	4.98	5.11	3.72	3.64	6.89	4.83	4.51	3.65	5.01	4.7
15	5.51	4.54	3.17	3.39	5.53	4.03	2.27	4.47	6.33	4.4
16	6.20	4.16	4.44	4.10	5.98	6.04	2.92	5.47	4.50	4.9
17	5.73	4.82	3.49	4.24	6.41	5.23	3.78	4.44	5.53	4.9
18	5.15	5.89	3.56	4.82	6.64	3.79	4.60	4.62	4.65	4.9
19	4.67	4.23	3.67	3.22	6.42	4.53	2.61	3.34	5.65	4.3
20	5.80	4.52	4.25	3.49	6.64	4.62	3.94	4.88	6.18	4.9
21	5.56	4.55	3.29	3.65	6.01	5.27	4.45	4.57	4.96	4.7
22	6.50	4.79	4.13	3.85	6.01	5.09	5.28	4.54	5.27	5.1
23	6.46	4.74	4.14	4.02	7.02	5.53	2.30	4.79	5.57	5.0
24	6.19	5.28	3.74	3.53	6.05	4.09	3.71	4.28	6.23	4.8
25	5.94	5.00	4.13	3.48	6.32	5.41	3.56	4.90	5.32	4.9
26	5.45	4.33	3.71	3.86	7.07	6.17	3.87	4.71	5.92	5.0
27	6.85	3.86	3.92	4.33	6.04	5.08	3.60	4.37	5.49	4.8
28	5.51	5.27	3.29	4.21	5.50	7.39	4.26	4.57	6.08	5.1
29	5.99	5.27	2.44	3.79	2.46	5.10	6.19	4.32	5.69	4.6
30	3.90	3.6	3.66	3.42	2.29	4.8	2.93	4.08	5.66	3.8
LSD	1.91	1.20	1.24	1.27	1.31	1.80	2.04	1.76	1.20	
Mean (LSD = 0.57)	5.66	4.76	3.78	3.78	6.13	4.94	3.91	4.41	5.47	4.8

Environment 1: Mpeketoni, 2: Mtwapa, 3: Msabaha, 4: Katumani, 5: Kiboko, 6: Sangalo, 7: Bumula, 8: Alupa, 9: Bako

The mean yield performance of the hybrids across locations was 4.8 t ha^{-1} (Table 5); though, performance varied across locations. The hybrids yielded the highest at Kiboko (6.13 t ha^{-1}) followed by Mpeketoni (5.66 t ha^{-1}) and Bako (5.47 t ha^{-1}). However, the yield performance of the hybrids was low (3.7 t ha^{-1}) at Msabaha and Katumani. On average, six hybrids (entries 7, 10, 12, 20, 22, 26) produced high yield of 4.9 to 5.1 t ha^{-1} which was either equivalent or comparable to the commercial check, entry 28 (5.1 t ha^{-1}) across locations. Entry 30 was the earliest, 59.1 days to anthesis; whilst, the rest of the hybrids had similar days to anthesis (65-68 days) as the commercial check (Table 6). Most of the hybrids were relatively taller (183-227 cm) and had higher ear height (88-116 cm) compared to the commercial check (plant height 204 cm and ear height

Table 6: Mean agronomic performance of 30 maize hybrids with different level of resistance to postharvest insect pests tested in 9 environments in Kenya and Ethiopia

Entry	Ears/plant	Days to anthesis	Anthesis silking interval	Plant height (cm)	Ear height (cm)
1	1.0	67.6	2.9	215.3	108.4
2	1.0	67.4	2.8	201.8	99.9
3	1.0	67.4	2.7	212.0	110.4
4	1.0	67.9	2.7	206.4	105.5
5	1.0	67.8	2.7	211.7	105.1
6	1.1	67.4	2.6	210.4	106.7
7	1.0	68.4	2.3	209.1	107.6
8	1.0	67.8	2.6	211.1	110.2
9	1.0	67.2	3.2	217.0	108.8
10	1.0	68.3	3.1	220.4	113.8
11	1.0	67.3	2.6	206.5	106.2
12	1.0	68.4	3.0	213.9	109.5
13	0.9	68.3	2.9	204.5	104.4
14	1.0	67.6	3.1	204.4	102.2
15	1.0	68.9	2.3	214.4	108.8
16	1.0	68.0	2.4	214.4	107.8
17	1.1	66.5	2.7	206.9	103.0
18	1.1	66.6	2.5	206.9	101.2
19	1.0	68.5	2.3	217.5	113.2
20	1.0	67.6	2.8	215.1	110.7
21	1.0	67.2	2.6	210.3	105.2
22	1.1	66.8	2.6	211.1	106.9
23	1.1	68.4	2.2	217.2	113.8
24	1.2	68.7	2.3	227.9	116.9
25	1.0	67.5	2.2	211.7	108.8
26	1.1	67.4	2.2	209.9	110.8
27	1.0	67.6	2.3	213.9	113.5
28	1.0	68.3	1.7	204.6	98.3
29	1.0	65.2	3.2	206.3	112.2
30	1.0	59.1	2.8	183.1	88.7
Mean	1.04	67.4	2.6	210.5	107.3
LSD	0.1	1.10	0.8	9.2	6.9

98 cm). The hybrids were all resistant to common rust and gray leaf spot diseases and moderately resistant to *Turcicum* leaf blight. They were, however, susceptible or highly susceptible to the MSV (Table 7).

Testing of maize hybrids against the MW and LGB: The hybrids exhibited varying levels of resistance to the MW and the LGB (Table 8). Six hybrids were resistant (CKPH08037, CKPH08041, CKPH08010, CKPH08012, CKPH08024 and CKPH08026) and two were moderately resistant (CKPH08038, CKPH09004) to the LGB. All hybrids, except the susceptible check were either resistant or moderately resistant to the MW. Reduction in kernel weight loss for the hybrids over the susceptible check ranged from 26.4-94.5% for MW and from 6.6-85.7% for the LGB. For LGB, six genotypes (CKPH08037, CKPH08041, CKPH08009,

Table 7: Mean diseases reaction for common rust, GLS, MSV and Turcicum blight of maize hybrids evaluated across 9 environments in Kenya and Ethiopia

Genotype	Rust	MSV	GLS	TLB
1	1.4 (R)	5.3 (HS)	1.3 (R)	2.0 (R)
2	1.4 (R)	5.6 (HS)	1.3 (R)	2.1(MR)
3	1.4 (R)	5.0 (HS)	1.4 (R)	2.3 (MR)
4	1.5 (R)	4.7 (HS)	1.4 (R)	2.2 (MR)
5	1.4 (R)	4.9 (HS)	1.3 (R)	2.2 (MR)
6	1.4 (R)	5.1 (HS)	1.4 (R)	2.0 (R)
7	1.4 (R)	5.6 (HS)	1.3 (R)	2.0 (R)
8	1.5 (R)	5.5 (HS)	1.3 (R)	2.3 (MR)
9	1.3 (R)	5.6 (HS)	1.3 (R)	2.5 (MR)
10	1.4 (R)	5.9 (HS)	1.3 (R)	2.2 (MR)
11	1.4 (R)	5.3 (HS)	1.4 (R)	2.4 (MR)
12	1.4 (R)	5.7 (HS)	1.3 (R)	2.1 (MR)
13	1.4 (R)	5.4 (HS)	1.4 (R)	2.1 (MR)
14	1.4 (R)	5.4 (HS)	1.4 (R)	2.4 (MR)
15	1.4 (R)	3.3 (HS)	1.3 (R)	2.0 (R)
16	1.4 (R)	5.0 (HS)	1.3 (R)	2.1 (MR)
17	1.4 (R)	5.1 (HS)	1.3 (R)	2.3 (MR)
18	1.4 (R)	5.3 (HS)	1.4 (R)	2.0 (R)
19	1.4 (R)	3.7 (S)	1.4 (R)	1.9 (R)
20	1.4 (R)	5.3 (HS)	1.3 (R)	2.2 (MR)
21	1.3 (R)	5.5 (HS)	1.3 (R)	2.1 (MR)
22	1.4 (R)	4.8 (HS)	1.3 (R)	1.9 (R)
23	1.5 (R)	4.9 (HS)	1.3 (R)	2.0 (R)
24	1.5 (R)	3.3 (S)	1.4 (R)	2.2 (MR)
25	1.4 (R)	5.1 (HS)	1.4 (R)	2.1 (MR)
26	1.5 (R)	4.8 (HS)	1.3 (R)	2.1 (MR)
27	1.4 (R)	5.1 (HS)	1.6 (R)	2.2 (MR)
28	1.4 (R)	5.3 (HS)	1.2 (R)	1.8 (R)
29	1.4 (R)	4.4 (HS)	1.3 (R)	2.0 (R)
30	1.6 (R)	7.1 (HS)	1.6 (R)	2.4 (MR)
Mean	1.4	5.1	1.3	2.1

R: Resistant, S: Susceptible, MR: Moderately resistant, HS: Highly susceptible

Table 8: Percent grain weight loss and level of resistance in 30 maize hybrids to the MW and LGB

Genotype	Grain weight loss due to LGB (%)	Loss reduction in LGB (%)	Resistance category	Grain weight loss due to MW (%)	Loss reduction in MW (%)	Resistance category
1	12.9	46.6	HS	3.0	44.4	M
2	16.9	29.9	HS	2.1	60.3	M
3	9.5	60.3	S	1.5	71.5	R
4	13.8	42.7	HS	1.1	78.6	R
5	14.2	41.1	HS	0.7	85.7	R
6	9.6	60.2	S	1.6	70.3	R
7	8.2	65.9	S	2.8	48.5	M
8	1.3	94.5	R	3.9	28.1	M
9	7.6	68.5	M	1.7	68.5	R
10	11.5	52.3	S	1.9	64.2	R
11	8.6	64.1	S	2.0	61.7	R

Table 8: Continue

Genotype	Grain weight loss due to LGB (%)	Loss reduction in LGB (%)	Resistance category	Grain weight loss due to MW (%)	Loss reduction in MW (%)	Resistance category
12	3.2	86.7	R	3.3	38.3	M
13	11.1	53.9	S	2.9	46.4	M
14	17.8	26.4	HS	1.1	78.9	R
15	16.6	31.3	HS	2.1	60.2	M
16	11.0	54.2	S	0.9	83.5	R
17	14.6	39.3	HS	0.8	84.9	R
18	5.5	77.0	M	3.5	35.1	M
19	11.9	50.5	S	1.8	66.9	R
20	4.0	81.0	R	1.4	74.0	R
21	4.0	81.2	R	1.6	70.1	R
22	16.6	31.2	HS	3.9	28.5	M
23	13.4	44.6	HS	5.1	16.5	M
24	2.5	89.2	R	1.1	79.6	R
25	12.8	46.8	HS	1.4	72.9	R
26	3.6	84.9	R	0.9	83.2	R
27	9.5	60.6	S	2.0	61.8	R
28	12.1	49.7	HS	1.1	78.1	R
29	5.3	78.0	M	1.5	71.6	R
30	24.2	-	HS	6.4	-	S

R: Resistant, S: Susceptible, M: Moderate, HS: Highly susceptible

CKPH08012, CKPH08020 and CKPH08025) and for MW four genotypes (CKPH09003, CKPH08002, CKPH08003 and CKPH08025) had over 80% reductions in kernel weight loss.

DISCUSSION

Results of the current study indicated the existence of different level of variation among the hybrids for yield. Previous work reports that the largest proportion of total variation in yield trials is attributable to environments (Pixley and Bjarnason, 2002; Beyene *et al.*, 2011; Butron *et al.*, 2004; Lee *et al.*, 2003; Pixley and Bjarnason, 2002; Badu-Apraku *et al.*, 2003). Significant genotype by environment interaction for grain yield reduces accuracy of yield estimation and the relationship between genotypic and phenotypic values (Epinat-Le Signor *et al.*, 2001). However, the microenvironments and crop management practices may vary widely between locations among and within countries for the same ecological zone (Badu-Apraku *et al.*, 2003). Epinat-Le Signor *et al.* (2001) reported genotype×environment interaction for kernel yield of 132 early maize hybrids in 229 environments over 12 years. They expressed that earliness of hybrids, water balance around flowering and mean temperature from the 12 leaf stage to the end of the kernel filling phase were determinants of genotype×environment interaction for kernel yield in the considered area. Giauffret *et al.* (2000) showed the genotype x environment interactions observed for vegetative or flowering traits were due to temperature and photoperiod in maize hybrids. The differential response of genotypes to variable environmental conditions constitutes a major limitation to the identification of superior genotypes for narrow or wide adaptation.

The mean yield performance of the hybrids was high in Kiboko followed by Mpeketoni and Bako. The nine locations in the present study differ in rain fall, temperature, soil fertility and management. The mean yield performance of the six top hybrids (CKPH08036, CKPH08039,

CKPH08041, CKPH08013, CKPH08009, CKPH08025) was as high as (5.1 t ha^{-1}) the commercial check (WH505). From the six top hybrids, however, CKPH08036, CKPH08039 and CKPH08013 were susceptible to the LGB; they were either resistant or moderately resistant to the MW while CKPH08041 was resistant to the LGB and moderately resistant to the MW. Two hybrids, CKPH08009 and CKPH08025 were resistant to both LGB and MW. Therefore, the three high yielding and most resistant hybrids (CKPH08041, CKPH08009 and CKPH08025) to the two insects could be recommended for release in Kenya and Ethiopia and other similar environments in eastern and southern Africa for commercialization. These results indicate that selection for insect resistant did not result in yield penalty. Unlike the present study, other authors have reported losses of yielding ability after selection for insect resistance (Butron *et al.*, 2004).

This study demonstrated differences in resistance levels among the maize hybrids with respect grain weight losses. These differences in the susceptibility of the hybrids indicate the inherent ability of a particular hybrid to resist LGB and MW attack. Out of the 27 experimental hybrids tested six were resistant to the LGB and all were resistant to the MW, suggesting that they contained genes that confer resistance to the two pests coexisting in farmers stores. Resistance of stored maize to insect attack has been attributed to physical factors such as kernel hardness, pericarp surface texture and nutritional factors such as amylose, lipid and protein content (Dobie, 1974; Tipping *et al.*, 1988) or non-nutritional factors, especially phenolic compounds (Serratos *et al.*, 1987). The role of phenolics play in resistance formation in these surface tissues may be both related to structural components and antibiosis factors (Garcia-Lara *et al.*, 2004; Arnason *et al.*, 1992). For MW kernel hardiness has been reported as the main resistance parameter (Bamaiyi *et al.*, 2007).

Resistance to the MW and LGB among maize hybrids were recently reported (Tefera *et al.*, 2011a). Besides, resistance to MW was reported for Ethiopian OPVs and hybrids (Abebe *et al.*, 2009), Mexican landraces, notably Si Naloa 35 and Yucatan-7 (Arnason *et al.*, 1992), for the Tanzanian open-pollinated variety 'Kilima' (Derera *et al.*, 2001), for tropical inbred lines Hi41, Hi34, ICA L29, KU1409, Hi39 and ICA L221 (Kim *et al.*, 1988) and for temperate inbred lines B37, B68, R805 and T220 (Tipping *et al.*, 1988). Kernel factors reported to contribute to resistance include increased kernel hardness and sugar content (Sing and McCain, 1963). Whereas our study did not investigate the chemical basis of kernel's non-preference resistance, Garcia-Lara *et al.* (2004) and Derera *et al.* (2001) reported that the non-preference was based on the lack of feeding stimulants in the resistant kernels. Our results suggest that it is possible to develop hybrids with improved resistance to LGB and MW. The percent kernel weight loss was high for LGB than MW indicating that LGB converts kernel into powder within a short period of time. The extensive tunnelling in maize kernel by LGB adults allows it to convert kernel into flour within a very short time. The flour produced during the insects feeding consists of the insect eggs, excreta and exuvia that are unfit for both livestock and human consumption. The LGB belongs to family Bostrichidae with strong mandibles which are known as pest of timber (Hill *et al.*, 2002). LGB has a remarkable ability to tunnel through hard materials including plastic thickness of 35 mm (Li, 1988).

Besides commercialization, the hybrids identified in this study can be used as a source of resistance in maize breeding program. The information generated in this study can be useful for maize breeders, entomologists and seed companies for the pre-selection of experimental hybrids in maize breeding programs and to use their limited resources effectively.

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