African Journal of Biotechnology Vol. 10(23), pp. 4759-4766, 1 June, 2011
Available online at http://www.academicjournals.org/AJB
ISSN 1684–5315 ©2011 Academic Journals

Full Length Research Paper

Combining ability of maize (*Zea mays* L.) inbred lines resistant to stem borers

Yoseph Beyene[1]*, Stephen Mugo[1], John Gakunga[1], Haron Karaya[1], Charles Mutinda[2], Tadele Tefera[1], Stephen Njoka[2], Dorcas Chepkesis[2], Jackson M. Shuma[2] and Regina Tende[2]

[1]International Maize and Wheat Improvement Center (CIMMYT), P.O. Box 1041 - 00621 Nairobi, Kenya.
[2]Kenya Agricultural Research Institute (KARI), P.O. Box 57811 - Nairobi 00200, Kenya.

Accepted 13 January, 2011

Ten inbred parents with varying resistance levels to *Chilo partellus* and *Busseola fusca* were crossed in a half diallel mating scheme to generate 45 F1 hybrids. The hybrids and five commercial checks were evaluated across four locations in Kenya under artificial and natural infestation in 2009. Genotype (G) by environment (E) interaction (G x E) was non-significant for stem borer leaf damage, number of exit holes and tunnel length, suggesting that screening for stem borer resistance at one location would be adequate. On the other hand, G x E and general combining ability (GCA) x environment interactions were highly significant for gray leaf spot and turcicum leaf blight, indicating an inbred line resistance to a disease in one location may have a different reaction to the same disease in another location. The results of combining ability analysis showed that GCA effects were significant for stem borer resistance traits (leaf damage scores, number of exit holes, and tunnel length) while the opposite was true for specific combining ability (SCA) effects. Parents 5, 2, 6, 9 and 3, were good sources of genes for higher grain yield while parents 1 and 4 were good sources of resistance genes for stem borers. Hybrid 5 x 9 was the best performing hybrid in grain yield (6.53 t/ha) across the locations, while hybrid 1 x 4 was the least performing in grain yield (3.08 t/ha). The source of stem borer resistance identified in the study may be useful for improving levels of stem borer resistance in maize breeding programs in eastern and southern Africa.

Key words: Combining ability, maize, inbred lines, stem borers.

INTRODUCTION

Maize is the most important cereal crop in eastern and southern Africa accounting for over 29% of the total harvested area of annual food crops and 25% of total caloric consumption (FAOSTAT, 2010). The African stem borer (*Busseola fusca*) and the spotted stem borer (*Chilo partellus*) are the most damaging maize pests in sub Saharan Africa (SSA), causing 20–40% yield losses. For instance, yield losses of 12.9% have been reported (De Groote, 2002), equivalent to 400,000 metric tons of maize annually, in Kenya.

The magnitude of the problem will increase as maize farming intensifies to meet the food demands of the region's growing population. Recognizing the problem, and the possibility of alleviating it, the International maize and Wheat Improvement Center (CIMMYT), the Kenya Agricultural Research Institute (KARI) and the Syngenta Foundation for Sustainable Agriculture jointly initiated in 1999 the Insect Resistance Maize for Africa (IRMA) project with the aim of developing and deploying maize varieties resistance to stem borers and other biotic and abiotic stresses and with good adaptation to different agro-ecologies in Kenya. Through the project, a large number of new stem borer resistance (SBR) and storage

---

*Corresponding author. E-mail: y.beyene@cgiar.org. Tel: +254 (0) 20 722 4654. Fax: +254 (0) 20 722 4601.

Abbreviations: GxE, Genotype by environment interaction; **SCA,** specific combining ability; **GCA,** general combining ability; **SSA,** sub Saharan Africa; **CIMMYT**, International Maize And Wheat Improvement Center; **KARI,** Kenya Agricultural Research Institute; **SBR,** stem borer resistance; **SPR,** storage pests resistance; **MBR,** multiple borer resistance; **SWCB,** Southern corn borer; **SCB,** sugarcane borer; **FAW,** fall armyworm; **ECB,** European corn borer; **EXHL,** exit holes; **TL,** tunnel length; **TLPH,** tunnel length plant height ration; **GLS,** gray leaf spot; **ET,** *Exerohilum turcicum*; **CMLs,** CIMMYT maize lines; **IRMA,** Insect Resistance Maize for Africa.

Table 1. List of lines, pedigree and characteristics used in the diallel crosses.

Entry	Pedigree	Characteristic
1	MBR C5 Bc F13-3-2-1-B-4-2-B	Developed from multiple borer resistant population (MBR)
2	CML444	Good combiner and tolerant to drought and low nitrogen
3	CML334	Good combiner and tolerant to drought and low nitrogen
4	MBR C5 Bc F4-1-2-1-B-1-2-B-B-B-B-#-#	Developed from multiple borer resistant population
5	CML311/MBR C3 Bc F65-1-2-2-B-B-B-B-B	Developed from a line resistant to E *turcicum* and MBR population
6	CML311/MBR C3 Bc F35-2-2-1-B-B-B-B	Developed from a line and resistant to *E turcicum* and MBR population
7	P590 C7 Blancos F11-1-1-1-B-B-B-B-B	Developed from multiple insect resistant population 590
8	P590 C7 Blancos F57-1-3-1-B-B-B-B-B	Developed from multiple insect resistant population 590
9	CML 380xMBR/MDR C3 Bc F21-1-1-2-B-B-B-B-3-1-B-B-B-B-B	Developed from a line with good combining ability and multiple borer resistant population
10	(CUBA/GUAD C1 F27-4-3-3-B-1-Bx[KILIMA ST94A]-30/MSV-03-2-10-B-2-B-B)-277-1-B-3-B-B	Developed from post harvest resistant population

Table 2. Agro-climatic description of trial sites.

Site	Longitude	Latitude	Elevation (masl)	Rain fall (mm)	Temperature (0°C)		Soil texture
					Min	Max	
Kiboko	37° 75′E	2° 15S′	975	530	14.3	35.1	Sandy clay
Embu	37° 42′E	0° 449′S	1510	1200	14.1	25	Clay loam
Kakamega	34° 45′E	0° 16′N	1585	1916	12.8	28.6	Sandy loam
Mtwapa	39° 44′E	3° 50′ S	15	1200	22	30	Sandy

pests resistance (SPR) inbred lines, hybrids and open-pollinated varieties have been developed, and germplasm tested in regional trials, and varieties released in Kenya (Mugo et al., 2001).

Host plant resistance is an approach to stem borer management, by which a plant is able to resist infestation and damage by pests. This control strategy is availed to farmers in the seed, which ensures that the technology is inexpensive, and safe to use in the control of stem borers. Use of stem borer resistance maize increases efficiency of farming by reducing or eliminating the expense of insecticides thus reducing the environmental pollution that goes with chemical use. Therefore, for resource poor small-scale farmers in developing countries, host plant resistance packaged in improved maize varieties will offer a practical and economic means of minimizing stem borer losses.

The use of diallel crosses to study the genetic control of traits, and to select parents useful in constitution of synthetics and hybrids, is frequent in maize breeding (Pixley and Bjarnason, 1993; Vivek et al., 2010; Zhang et al., 1996). One of the commonly used procedures in the diallel analysis is Griffing's method, that estimates the general (GCA) and specific (SCA) combining ability of the parents and crosses (Griffing, 1956). Karaya et al. (2009) used combining ability analysis and identified inbred lines superior in grain yield and resistance to *C. partellus* and *B. fusca*. Given the diversity of environments in which maize is grown in SSA, the genotype by environment interaction is normally expressive (Pixley and Bjarnason, 1993; Vivek et al., 2010). It is therefore necessary to identify hybrids that present not only wide adaptation, assessed by the mean yield, but also have high stability. The objectives of the present study were: (1) To estimate the effects of the general and specific combining abilities of stem borer resistant maize inbred lines and (2) To identify inbred lines with suitable agronomic traits and resistance to stem borer for use in hybrid maize breeding.

MATERIALS AND METHODS

Germplasm used and experimental design

Ten elite maize lines (Table 1) were developed by CIMMYT through the Insect Resistance Maize for Africa (IRMA) project from CIMMYT multiple borer resistance (MBR) populations. CIMMYT developed a multiple borer resistance population by recombination and recurrent selection under infestation with Southern corn borer (SWCB), sugarcane borer (SCB), (*Diatrae sacharalis*), European corn borer (ECB), *Ostrinia nubilalis* and fall armyworm (FAW), (*Spodoptora*). These MBR were developed after noticing that germplasm with resistance to a single species of insect pest was not as useful as one resistance to the complex problems in a given area (Mugo et al., 2001). The ten elite lines were crossed in half diallel combinations to produce 45 F1. Seeds of 45 F1s along with five commercial checks were planted in four locations (Table 2) in 10 x

Table 3. Analysis of variance of yield and agronomic traits for 45 F1 insect resistant hybrids and five checks evaluated across four locations in Kenya in 2009.

Source	DF	GY	AD	ASI	PH	EH	DF	GLS	ET	SB	DF	EXHL	TL	TLPH
Env	3	538.6***	12019.28***	93.1***	399022.8***	2289.4***	2	25.44***	117.34***	73.35***	1	65.12***	49.41**	0.001
Rep(env)	8	8.2***	32.3***	2.06	5649.9***	31.02***	6	0.15***	0.04	1.29***	4	0.78	18*	0.001*
Entry	44	9.56***	49.5***	10.81***	1933.01***	9.57***	44	0.03*	0.4***	0.23*	44	1.13*	9.83*	0.001
GCA	9	39.4	191.01***	39.34***	8449.24***	3123.62***	9	0.1***	1.61***	0.36*	9	4.16***	34.05***	0.001*
SCA	35	2.02***	13.16***	3.47***	257.4**	136.84**	35	0.01	0.09*	0.2	35	0.35	3.6	0.0004
Entry x Env	132	3.23***	6.5**	3.05***	194.05*	1.5**	88	0.03*	0.4***	0.13	44	0.66	2.21	0.0001
GCA x Env	27	10.1	11.68***	7.56***	375.74***	207.67***	27	0.07***	1.08***	0.12	27	0.36	5.56	0.0002
SCA x Env	105	1.42***	5.17	1.9*	147.3	93.5	105	0.01	0.06	0.08	105	0.18	1.76	0.0001
Error	351	0.84	4.56	1.48	143.2	78.13	264	0.02	0.05	0.16	176	0.82	6.09	0.001

*, ** and ***, Level of significance at 95%, 99% and 99.9% respectively; †GY, grain yield (t ha^{-1}); AD, number of days to anthesis; ASI, anthesis silking interval; PH, plant height (cm); EH, ear height (cm); GLS, gray leaf spot; ET, *Exserohilum turcicum*; SB, stem borer leaf damage scores; EXHL, number of exit holes; TL, cumulative tunnel length; TLPH, tunnel length-plant height ratio.

5 alpha lattice design with three replications per location during long rain season of 2009. Each entry was planted into two rows of 5 m long. The rows were spaced 0.75 m apart and the hills spaced 0.25 m apart. Two seeds per hill were planted and later thinned to one plant per hill to obtain a final plant density of 53,333 plants/ha.

Infestation with stem borers

Four weeks after seedling emergence, each row was divided into two unequal halves where 5 plants in the front half were infested with *C. partellus* at Kiboko and *B. fusca* in Embu. The back half consisting of 14 maize plants were protected using Bulldock® 0.05 GR granule, which is a systemic insecticide, a synthetic pyrethroid with Beta-cyfluthrin 0.5 g/kg as the active ingredient. Infestation was done using 20 first instar larvaes per plant for each of the 5 plants per row. The larvae were placed in the whorl at the 4th leaf stage. The insects were obtained from KARI-Katumani stem borers' mass rearing laboratory. Insect damage was assessed two weeks after infestation and repeated two more weeks after, by scoring on per plant basis on a 1–9 scale, where 1= no damage and 9 = completely damaged (CIMMYT, 1989). Plants with a leaf damage score of 0–3 were rated highly resistant, 3.1–5.0 moderately resistant, 5.1–6.0 susceptible and 6.1–9.0 highly susceptible (CIMMYT, 1989). At harvest, 10 plants (five plants per row) from each plot were dissected and the number of borer exit holes (EXHL), tunnel length (TL), and tunnel length plant height ration (TLPH) were recorded. Natural infestation of *Cercospora zeae-maydis* gray leaf spot (GLS) and *Exerohilum turcicum* (ET) leaf blight were visually scored on a scale of 1–5 (1 = resistance; 5 = susceptible) by assessing the severity of the symptoms on plants in the entire plot. Diseases were scored twice during the period of crop growth, with the first scores taken when there were perceivable differences between plots for the severity of disease symptoms. This was followed by a second score 10–14 days from the date of first evaluation. Grain yield (tons/ha) was calculated using shelled grain weight adjusted to 12.5% moisture.

Statistical analysis

Least square means for grain yield, disease scores and insect damage parameters were calculated using plot data for each loca-tion separately (data not shown). Analysis of variance was carried out for individual as well as for combined environments, considering environments as random effects and genotypes as fixed effects. Griffing's Method 4 (Griffing, 1956) Model I (fixed parental effects) was used to obtain estimates of GCA and SCA effects using Proc GLM model of SAS (SAS, 2003).

RESULTS

Analysis of variance

Analysis of variance showed highly significant different mean squares ($P<0.001$) for grain yield due to environment, genotype and genotype x environment interaction (Table 3). Genotype mean squares were significant ($P<0.05$) for leaf damage scores, number of exit holes and tunnel length. G x E interaction mean squares was significant for grain yield ($P<0.001$), GLS ($P<0.05$) and *E. turcicum* ($P<0.001$) but not significant for stem borer resistance traits (leaf damage scores, number of EXHL and TL, Table 3).

Partitioning genotype mean squares into GCA and SCA effects revealed presence of highly significant mean squares due to GCA ($P<0.001$) for all traits except grain yield. Mean squares due to SCA were significant ($P<0.001$) for grain yield and *E. turcicum* (Table 3), indicating the differences among parental lines for GCA and among crosses for SCA effects for those traits. The GCA effects showed significant interaction with location for gray leaf spot and *E. turcicum* while SCA effect showed significant interaction for grain yield and *E. turcicum* (Table 3). This suggested the differential response of lines and crosses for GCA and SCA effects, respectively. Number of exit holes and tunnel length showed highly significant differences ($P<0.001$) due to GCA but not due to SCA. The SCA effects for *E. turcicum*, gray leaf spot, leaf damage scores, number of exit holes and tunnel length were relatively stable over locations as indicated by non-significant SCA x location interactions, whereas the reverse was the case for grain yield suggesting that different hybrids are required for different locations.

Mean performance

Mean value for grain yield and important agronomic traits of genotypes averaged across locations are presented in Table 4. Hybrids P_5 x P_9 and P_5 x P_7 (6.5 t/ha) and P_2 x P_5 (6.4 t/ha) were the best performing hybrids for grain yield across the locations, while hybrid P_1 x P_4 (3.1 t/ha), P_7 x P_{10} (3.3 t/ha) and P_7 x P_8 (3.6 t/ha) were the least (Table 4). Tunnel length of most of the hybrids varied from 1.33 to 6.53 cm compared to that of H513 which was 8.77cm (Table 4). Eight hybrids had equal or greater grain yield than H513 mean (best commercial check, Table 4). In addition, the top eight hybrids performed at least reasonably well for the other agronomic traits measured (Table 4). None of the top eight entries flowered later or had tall plant and ear heights than H513.

General and specific combining abilities

The GCA effects (Table 5) revealed that P_4 was an ideal general combiner for stem borer resistance traits (leaf damage scores, number of exit holes and tunnel length and tunnel length-plant height ratio) followed by P_1, as they had negative and significant GCA effects. However, both lines had significant and negative GCA effect for grain yield (Table 5). P_5 was a good general combiner for grain yield (positive and significant GCA effect) and favorable genes for gray leaf spot, *E. turcicum*, number of exit hole and tunnel length (Table 5). Parent 6 was a good combiner for grain yield but poor combiner for gray leaf spot; stem borer leaf damage, number of exit holes and tunnel length as it had positive GCA effects (Table 5). Inbred lines P_5, P_2 and P_6 were the best general combiners for grain yield with GCA values of 0.86, 0.70, and 0.56, respectively. The smallest GCA estimates for grain yield were observed on P_{10}, P_1 and P_4, with values of -0.93, -0.75 and -0.46, respectively (Table 5). P_5 x P_7 was the most desirable cross combination for grain yield SCA effects followed by P_1 x P_{10} and P_2 x P_4 (Table 6). An important inference that can be drawn from these results is that cross combinations involving P_5 as a common parent recorded desirable SCA effects for all or most of the traits studied (Table 6). Parent 5 had desirable attributes and can be used as a donor line in a maize improvement program to develop insect and disease resistance germplasm.

DISCUSSION

Two factors considered important for the evaluation of an inbred line in the production of hybrid maize are the characteristics of the inbred line *per se* and its combination with another inbred line to form a hybrid. Combining ability results showed existence of significance of genotype mean squares for grain yield showing variability among the 45 single crosses. The importance of genotype by location interaction was non- significant for stem borer leaf damage, number of exit holes and tunnel length (Table 3), suggesting that screening maize germplasm at one location would be adequate. Similar results were reported for sugarcane borer, *Eldana saccharina* (Milligan et al., 2003). On the other hand, G x E interaction and GCA x environment were highly significant ($P<0.01$) for gray leaf spot and *E. turcicum* suggesting that an inbred line resistance to a disease in one location may have a different reaction to the same disease in another location. Similar results were reported for 12 African maize inbred lines evaluated for seven diseases in eastern and Southern Africa (Vivek et al., 2010).

Eight hybrids had equal or greater than the H513 mean (best commercial check, Table 4). Indeed, H513, the susceptible check used in the current study, expressed the highest number of exit holes, the longest tunnel length and the highest proportion of tunnel length to plant height ratio. Tunnel length of most of the hybrids varied from 1.33 to 6.53 cm compared to that of H513 which was 8.77 cm (Table 4). Therefore, the performance of these hybrids relative to that of H513 indicated that the superior lines identified in this study are useful sources of insect resistance for improving yield in maize growing areas of Kenya.

The grain yield GCA sum of squares component was five times greater than SCA sum of squares (Table 3), suggesting that variation among crosses was mainly due to additive rather than non-additive gene effects, and selection would be effective in improving grain yield. The highest GCA estimates for grain yield were obtained for P_5, P_2 and P_6, respectively (Table 5), indicating that these lines had a higher favorable allele frequency for grain yield. This fact can be verified from the mean yields obtained for these hybrids across environments (the top eight high yielding hybrids had one of these lines as a parent (Table 4). The smallest GCA estimates for grain yield were recorded by P_{10}, P_1 and P_4 with values of -0.93, -0.75 and -0.46, respectively (Table 5) suggesting that these lines had unfavorable allele frequency for grain yield. These results are confirmed by mean yield obtain-

Table 4. Means of grain yield and agronomic traits of 45 single cross hybrids and five checks evaluated in four locations in Kenya in 2009.

No.	Cross	Entry	GY	AD	ASI	PH	EH	GLS	ET	SB	EXHL	TL	TLPH
1	5 x 9	34	6.5	66.8	1.6	192.0	93.0	1.2	1.3	1.0	1.1	3.0	0.02
2	5 x 7	32	6.5	66.3	0.8	187.0	100.0	1.3	1.3	1.4	1.2	3.8	0.03
3	2 x 5	12	6.4	69.1	1.0	193.0	102.0	1.2	1.4	1.4	1.3	3.6	0.01
4	2 x 6	13	6.3	69.1	1.6	195.0	107.0	1.3	1.3	1.3	1.9	2.7	0.01
5	3 x 6	20	6.2	69.9	2.3	208.0	109.0	1.3	1.7	1.2	1.4	3.5	0.02
6	3 x 5	19	6.1	68.8	0.2	196.0	101.0	1.2	1.3	1.3	1.3	3.1	0.01
7	6 x 9	38	6.1	67.0	1.6	205.0	106.0	1.3	1.5	1.3	2.2	6.5	0.03
8	2 x 9	16	5.9	69.3	1.2	205.0	108.0	1.2	1.5	1.5	1.4	3.5	0.01
9	3 x 9	23	5.8	71.8	1.7	212.0	109.0	1.2	1.4	1.6	1.2	3.8	0.01
10	2 x 4	11	5.8	67.4	2.7	180.0	93.0	1.3	1.4	1.2	0.8	2.4	0.01
11	6 x 7	36	5.8	68.9	2.0	198.0	106.0	1.3	1.3	1.3	1.7	3.1	0.01
12	2x 3	10	5.7	71.1	2.6	206.0	110.0	1.3	1.6	1.3	1.4	2.5	0.01
13	5 x 8	33	5.6	64.4	0.9	189.0	95.0	1.2	1.4	1.2	1.1	3.1	0.01
14	5 x 6	31	5.5	66.8	0.8	178.0	94.0	1.2	1.3	1.4	1.0	2.1	0.01
15	4 x 5	25	5.5	66.3	1.3	173.0	88.0	1.2	1.2	1.4	0.6	1.3	0.00
16	2 x 8	15	5.4	67.5	1.3	196.0	106.0	1.3	1.5	1.1	1.3	3.6	0.01
17	6 x 8	37	5.4	66.0	0.9	201.0	107.0	1.3	1.4	1.6	1.6	4.2	0.02
18	2 x 7	14	5.3	69.3	1.3	195.0	110.0	1.3	1.6	1.3	1.3	2.3	0.01
19	4 x 6	26	5.1	68.6	2.6	183.0	97.0	1.3	1.4	1.1	0.8	1.6	0.00
20	3 x 8	22	5.0	69.8	0.9	212.0	114.0	1.3	1.6	1.6	1.2	3.1	0.01
21	1 x 2	1	5.0	67.2	2.5	176.0	91.0	1.2	1.5	1.1	0.9	2.5	0.01
22	8 x 9	43	5.0	68.2	1.8	208.0	106.0	1.3	1.6	1.3	2.0	6.4	0.04
23	1 x 9	8	4.9	67.2	2.3	185.0	96.0	1.2	1.6	1.2	1.1	3.2	0.02
24	3 x 7	21	4.9	73.0	1.9	203.0	115.0	1.3	1.6	1.1	0.9	2.6	0.00
25	1 x 5	4	4.9	67.1	2.2	168.0	88.0	1.2	1.3	1.2	0.7	2.4	0.02
26	4 x 9	29	4.8	68.3	2.7	184.0	91.0	1.2	1.5	1.0	0.8	1.8	0.01
27	5 x 10	35	4.7	63.8	0.5	188.0	91.0	1.2	1.5	1.3	1.0	3.4	0.02
28	1 x 3	2	4.7	68.7	2.4	185.0	102.0	1.2	1.5	1.1	0.7	1.6	0.00
29	6 x 10	39	4.7	65.3	2.0	192.0	96.0	1.2	1.8	1.2	1.2	5.0	0.04
30	3 x 4	18	4.7	70.2	3.9	182.0	94.0	1.2	1.4	0.9	0.6	1.4	0.00
31	7 x 9	41	4.5	70.5	2.7	197.0	99.0	1.3	1.6	1.2	1.6	4.6	0.03
32	3 x 10	24	4.4	66.5	0.8	206.0	104.0	1.2	1.8	1.2	1.6	3.9	0.01
33	2 x 10	17	4.4	65.6	0.8	192.0	96.0	1.2	1.8	1.3	1.6	5.1	0.03
34	4 x 7	27	4.4	68.4	2.8	180.0	100.0	1.3	1.4	1.2	0.7	0.8	0.00
35	9 x 10	45	4.4	66.6	1.3	200.0	97.0	1.2	2.2	1.5	2.0	5.0	0.03
36	1 x 7	6	4.3	67.5	3.0	179.0	100.0	1.3	1.6	1.3	0.8	2.1	0.02
37	1 x 6	5	4.2	67.3	2.4	179.0	94.0	1.3	1.6	1.1	0.3	1.6	0.01
38	4 x 8	28	4.2	68.2	2.8	178.0	90.0	1.3	1.4	1.1	1.0	2.9	0.01
39	1 x 10	9	4.1	65.1	1.5	187.0	95.0	1.2	1.7	1.3	0.9	2.4	0.01
40	8 x 10	44	3.7	64.3	1.2	199.0	99.0	1.3	2.0	1.2	1.6	4.4	0.01
41	1 x 8	7	3.6	66.4	2.8	181.0	98.0	1.3	1.5	1.2	0.8	1.8	0.01
42	4 x 10	30	3.6	66.8	2.2	173.0	86.0	1.2	1.7	1.0	0.8	2.1	0.01
43	7 x 8	40	3.6	71.8	2.3	181.0	101.0	1.3	1.7	1.3	1.3	2.7	0.01
44	7 x 10	42	3.3	66.3	1.4	194.0	104.0	1.3	2.1	1.3	1.7	4.0	0.03
45	1 x 4	3	3.1	67.1	5.3	152.0	78.0	1.3	1.4	0.9	0.5	1.6	0.02
46	CKIR06009	46	5.2	67.9	1.7	182.0	101.0	1.2	1.6	1.0	1.1	2.6	0.01
47	Duma 41	47	4.1	67.2	3.6	184.0	85.0	1.2	1.2	1.2	1.4	2.6	0.01
48	DH01	48	2.7	58.3	3.3	161.0	75.0	1.2	1.8	1.3	1.6	3.5	0.01
49	H513	49	5.9	68.9	1.8	207.0	113.0	1.3	1.5	1.5	3.7	8.8	0.06
50	WH502	50	5.5	72.0	2.8	200.0	108.0	1.3	1.6	1.3	1.5	5.4	0.03
	Mean		5	67.8	1.9	190	99.2	1.3	1.5	1.2	1.2	80.6	0.01
	CV		18	3.1	64.9	6.3	8.9	11.9	15.0	32.5	78.2	3.1	177.60
	Lsd		0.8	1.7	1	9.8	7.3	0.1	0.2	0.4	1.0	2.8	0.03

*, ** and ***, Level of significance at 95%, 99% and 99.9% respectively; †GY, grain yield (t ha^{-1}); AD, number of days to anthesis; ASI, anthesis silking interval; PH, plant height (cm); EH, ear height (cm); GLS, gray leaf spot; ET, *Exserohilum turcicum*; SB, stem borer leaf damage scores; EXHL, number of exit holes; TL, cumulative tunnel length; TLPH, tunnel length-plant height ratio.

Table 5. General combining ability effects for yield and agronomic traits of ten insect resistant maize inbred lines evaluated in four locations in Kenya in 2009.

Entry	Yield (t/ha)	50% days to anthesis	Anthesis siliking interval (days)	Plant height (cm)	Ear height (cm)	Glay leaf spot (1-5)	*Turcicum* blight (1-5)	Leaf damage score (1-9)	Exit holes (no.)	Tunnel length (cm)	Tunnel length/ plant height (ratio)
1	-0.75***	-0.86	0.92***	-14.78**	-6.31*	-0.020	-0.036	-0.094	-0.47***	-1.05**	-0.002
2	0.70**	0.64	-0.24	3.60	3.78	0.003	-0.029	0.053	0.17	0.07	-0.003
3	0.34	2.42**	-0.03	12.33*	8.07*	0.000	0.006	0.014	-0.04	-0.26	-0.007
4	-0.46*	0.12	1.16***	-15.73**	-9.57**	0.000	-0.119	-0.161*	-0.51***	-1.47***	-0.009
5	0.86***	-1.36	-0.95***	-5.81	-5.11	-0.050	-0.231	0.042	-0.16	-0.23	0.001
6	0.56**	-0.18	-0.09	3.56	2.83	0.038	-0.057	0.024	0.18	0.34	0.003
7	-0.29	1.48*	0.15	0.52	5.30	0.058	0.040	0.021	0.08	-0.20	0.001
8	-0.43*	-0.46	-0.25*	4.33	2.79	0.051	0.040	0.054	0.18	0.57*	-0.001
9	0.40*	0.67	-0.03	9.48*	1.43	-0.030	0.033	0.039	0.36*	1.26***	0.009
10	- 0.93***	-2.48**	-0.65***	2.50	-3.19	-0.050	0.353	0.007	0.22	0.97**	0.007

*, ** and ***, Level of significance at 95%, 99% and 99.9%, respectively.

Table 6. Specific combining ability effects for grain yield and agronomic traits of 45 single cross hybrids evaluated in four locations in Kenya in 2009.

Rank	Cross	Entry	GY	AD	ASI	PH	EH	GLS	ET	SB	EXHL	TL	TLPH
1	5 x 9	34	6.5	66.8	1.6	192.0	93.0	1.2	1.3	1.0	1.1	3.0	0.024
2	5 x 7	32	6.5	66.3	0.8	187.0	100.0	1.3	1.3	1.4	1.2	3.8	0.029
3	2 x 5	12	6.4	69.1	1.0	193.0	102.0	1.2	1.4	1.4	1.3	3.6	0.013
4	2 x 6	13	6.3	69.1	1.6	195.0	107.0	1.3	1.3	1.3	1.9	2.7	0.008
5	3 x 6	20	6.2	69.9	2.3	208.0	109.0	1.3	1.7	1.2	1.4	3.5	0.023
6	3 x 5	19	6.1	68.8	0.2	196.0	101.0	1.2	1.3	1.3	1.3	3.1	0.008
7	6 x 9	38	6.1	67.0	1.6	205.0	106.0	1.3	1.5	1.3	2.2	6.5	0.033
8	2 x 9	16	5.9	69.3	1.2	205.0	108.0	1.2	1.5	1.5	1.4	3.5	0.012
9	3 x 9	23	5.8	71.8	1.7	212.0	109.0	1.2	1.4	1.6	1.2	3.8	0.007
10	2 x 4	11	5.8	67.4	2.7	180.0	93.0	1.3	1.4	1.2	0.8	2.4	0.008
11	6 x 7	36	5.8	68.9	2.0	198.0	106.0	1.3	1.3	1.3	1.7	3.1	0.010
12	2x 3	10	5.7	71.1	2.6	206.0	110.0	1.3	1.6	1.3	1.4	2.5	0.010
13	5 x 8	33	5.6	64.4	0.9	189.0	95.0	1.2	1.4	1.2	1.1	3.1	0.006
14	5 x 6	31	5.5	66.8	0.8	178.0	94.0	1.2	1.3	1.4	1.0	2.1	0.006
15	4 x 5	25	5.5	66.3	1.3	173.0	88.0	1.2	1.2	1.4	0.6	1.3	0.003
16	2 x 8	15	5.4	67.5	1.3	196.0	106.0	1.3	1.5	1.1	1.3	3.6	0.010
17	6 x 8	37	5.4	66.0	0.9	201.0	107.0	1.3	1.4	1.6	1.6	4.2	0.024
18	2 x 7	14	5.3	69.3	1.3	195.0	110.0	1.3	1.6	1.3	1.3	2.3	0.005
19	4 x 6	26	5.1	68.6	2.6	183.0	97.0	1.3	1.4	1.1	0.8	1.6	0.003
20	3 x 8	22	5.0	69.8	0.9	212.0	114.0	1.3	1.6	1.6	1.2	3.1	0.009
21	1 x 2	1	5.0	67.2	2.5	176.0	91.0	1.2	1.5	1.1	0.9	2.5	0.009
22	8 x 9	43	5.0	68.2	1.8	208.0	106.0	1.3	1.6	1.3	2.0	6.4	0.035
23	1 x 9	8	4.9	67.2	2.3	185.0	96.0	1.2	1.6	1.2	1.1	3.2	0.022
24	3 x 7	21	4.9	73.0	1.9	203.0	115.0	1.3	1.6	1.1	0.9	2.6	0.003
25	1 x 5	4	4.9	67.1	2.2	168.0	88.0	1.2	1.3	1.2	0.7	2.4	0.023
26	4 x 9	29	4.8	68.3	2.7	184.0	91.0	1.2	1.5	1.0	0.8	1.8	0.005
27	5 x 10	35	4.7	63.8	0.5	188.0	91.0	1.2	1.5	1.3	1.0	3.4	0.022
28	1 x 3	2	4.7	68.7	2.4	185.0	102.0	1.2	1.5	1.1	0.7	1.6	0.003
29	6 x 10	39	4.7	65.3	2.0	192.0	96.0	1.2	1.8	1.2	1.2	5.0	0.040
30	3 x 4	18	4.7	70.2	3.9	182.0	94.0	1.2	1.4	0.9	0.6	1.4	0.002
31	7 x 9	41	4.5	70.5	2.7	197.0	99.0	1.3	1.6	1.2	1.6	4.6	0.026

Table 6. Contd.

32	3 x 10	24	4.4	66.5	0.8	206.0	104.0	1.2	1.8	1.2	1.6	3.9	0.009
33	2 x 10	17	4.4	65.6	0.8	192.0	96.0	1.2	1.8	1.3	1.6	5.1	0.027
34	4 x 7	27	4.4	68.4	2.8	180.0	100.0	1.3	1.4	1.2	0.7	0.8	0.002
35	9 x 10	45	4.4	66.6	1.3	200.0	97.0	1.2	2.2	1.5	2.0	5.0	0.031
36	1 x 7	6	4.3	67.5	3.0	179.0	100.0	1.3	1.6	1.3	0.8	2.1	0.021
37	1 x 6	5	4.2	67.3	2.4	179.0	94.0	1.3	1.6	1.1	0.3	1.6	0.005
38	4 x 8	28	4.2	68.2	2.8	178.0	90.0	1.3	1.4	1.1	1.0	2.9	0.009
39	1 x 10	9	4.1	65.1	1.5	187.0	95.0	1.2	1.7	1.3	0.9	2.4	0.007
40	8 x 10	44	3.7	64.3	1.2	199.0	99.0	1.3	2.0	1.2	1.6	4.4	0.014
41	1 x 8	7	3.6	66.4	2.8	181.0	98.0	1.3	1.5	1.2	0.8	1.8	0.006
42	4 x 10	30	3.6	66.8	2.2	173.0	86.0	1.2	1.7	1.0	0.8	2.1	0.005
43	7 x 8	40	3.6	71.8	2.3	181.0	101.0	1.3	1.7	1.3	1.3	2.7	0.010
44	7 x 10	42	3.3	66.3	1.4	194.0	104.0	1.3	2.1	1.3	1.7	4.0	0.029
45	1 x 4	3	3.1	67.1	5.3	152.0	78.0	1.3	1.4	0.9	0.5	1.6	0.020
46	CKIR06009	46	5.2	67.9	1.7	182.0	101.0	1.2	1.6	1.0	1.1	2.6	0.010
47	Duma 41	47	4.1	67.2	3.6	184.0	85.0	1.2	1.2	1.2	1.4	2.6	0.010
48	DH01	48	2.7	58.3	3.3	161.0	75.0	1.2	1.8	1.3	1.6	3.5	0.010
49	H513	49	5.9	68.9	1.8	207.0	113.0	1.3	1.5	1.5	3.7	8.8	0.060
50	WH502	50	5.5	72.0	2.8	200.0	108.0	1.3	1.6	1.3	1.5	5.4	0.030
	Mean		5.0	67.8	1.9	190.0	99.2	1.3	1.5	1.2	1.2	80.6	0.000
	CV		18.4	3.1	64.9	6.3	8.9	11.9	15.0	32.5	78.2	3.1	177.600
	Lsd		0.8	1.7	1.0	9.8	7.3	0.1	0.2	0.4	1.0	2.8	0.030

GY, Grain yield (t/ha); AD, number of days to anthesis; ASI, anthesis silking interval; PH, plant height (cm); EH, ear height (cm); GLS, gray leaf spot; ET, *Exserohilum turcicum*; SB, stem borer leaf damage scores; EXHL, number of exit holes; TL, cumulative tunnel length; TLPH, tunnel length-plant height ratio.

ed for these hybrids across environments (Table 4) where the lowest ten yielding hybrids had one of these lines as a parent. Parent 1 and 4 had negative GCA effects for stem borer resistance traits (leaf damage scores, number of exit holes, and tunnel length, Table 4). These parents could be released as CIMMYT maize lines (CMLs) for wider use by national maize breeding program in sub-Saharan Africa, as sources of useful genes for stem borer resistance. Karaya et al. (2009) reported similar negative GCA effects for the same stem borer resistance traits in the study of combining abilities among 20 selected insect resistance line.

Our results suggested that selection for stem borer resistance was not at the expense of yield (Table 4). In contrast to the present study, other authors have reported penalties in yielding ability after selection for resistance to insect pest resistance (Butron et al., 2002; Nyhus et al., 1989; Russell et al., 1979).

Conclusion

The source of stem borer resistance identified in the study may be useful for improving levels of stem borer resistance in maize breeding programs in eastern and southern Africa. Parent 1 and 4 could be released as CMLs for wider use by national maize breeding program in sub-Saharan Africa, as sources of useful genes for stem borer resistance.

ACKNOWLEDGEMENTS

The authors wish to thank Andrew Chavangi for his assistance in data analyses. This paper was supported by the Syngenta Foundation for Sustainable Agriculture through the Insect Resistance Maize for Africa Project.

REFERENCES

Butron A, Widstrom N, Snook M, Wiseman B (2002). Recurrent selection for corn earworm (Lepidoptera: Noctuidae) resistance in three closely related corn southern synthetics. J. Econ. Entomol. 95: 458-462.

CIMMYT (1989). Toward insect resistance maize for the Third World: Proceedings of the International Symposium on methodologies for Developing Host Plant Resistance to Maize Insects, pp. 175.

De Groote H (2002). Maize yield losses from stemborers in Kenya. Insect Sci. Appl. 22: 89-96.

FAOSTAT (2010) Food and Agriculture Organization Statistical Database: http// faostat.fao.org.

Griffing B (1956). Concept of general and specific combining ability in relation to diallel crossing systems. Austr. J. Biol. Sci. 9: 463-493.

Karaya H, Njoroge K, Mugo S, Nderitu H (2009). Combining ability among 20 insect resistant maize inbred lines resistant to *Chilo partellus* and *Busseola fusca* stem borers. Int. J. Plant Prod. 3: 1735-8043.

Milligan S, Balzarini M, White W (2003). Broad-sense heritabilities, genetic correlations, and selection indices for sugarcane borer resistance and their relation to yield loss. Crop Sci. 43: 1729-1735.

Mugo S, Bergvinson D, Hoisington D (2001). Options in developing stem borer-resistant maize: CIMMYT approaches and experiences. Insect Sci. Appl. 21: 409-415.

Nyhus K, Russell W, Guthrie W (1989). Changes in agronomic traits associated with recurrent selection in two corn synthetics. Crop Sci. 29: 269-275.

Pixley K, Bjarnason M (1993). Combining ability for yield and protein quality among modified-endosperm opaque-2 tropical maize inbreds. Crop Sci. 33: 1229-1234.

Russell W, Lawrance G, Guthrie W (1979). Effects of recurrent selection for European corn borer resistance on other agronomic characters in synthetic cultivars of corn. Maydica 24: 33-47.

SAS (2003) SAS ® 9.1 for Windows. Cary, NC,: SAS Institute Inc.

Vivek S, Odongo O, Njuguna J, Imanywoha J, Bigirwa G, Diallo A, Pixley K (2010). Diallel analysis of grain yield and resistance to seven diseases of 12 African maize (*Zea mays* L.) inbred lines. Euphytica 172: 329-340.

Zhang Y, Kang M, Magari R (1996). A diallel analysis of ear moisture loss rate in maize. Crop Sci. 36: 1140-1144.