Full Length Research Paper

Combining ability of maize inbred lines resistant to *Chilo partellus* (Swinhoe) in the mid-altitude environment of Kenya

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Gene action conditioning important traits in maize is useful to breeders in order to design appropriate breeding methods. A study was conducted to determine the combining ability of 10 maize inbred lines adapted to Kenya's mid-altitude environment and being resistant to spotted stem borer, *Chilo partellus*. The inbred lines were crossed in a diallel scheme and the resulting 45 single crosses were evaluated under conditions of artificial infestation at four locations in Kenya in 2008 and 2009. Data were recorded on grain yield, foliar damage, exit holes and tunnel length to plant height ratio. Significant differences (P<0.001) for foliar damage, exit holes, tunnel length to plant height ratio, and grain yield were found. General combining ability (GCA) and specific combining ability (SCA) gave significant differences for grain yield and exit holes. There was discord in GCA between grain yield and resistance traits among lines. The most favorable SCA for grain yield occurred in hybrid 5 × 7, while hybrids 7 × 10, 3 × 5 and 4 × 8 were superior in resistance. Our results suggest that the development of *C. partellus* resistant maize varieties should consider both grain yield and stem borer resistance traits. This study identified additive gene action as important in controlling stem borer resistance, stem borer resistant inbred line donors and elite single crosses.

Key words: *Chilo partellus,* gene action, general combining ability, specific combining ability.

INTRODUCTION

Among the insect pests that attack maize, lepidopteran insects (moths), the order to which stem borers belong, have the widest worldwide distribution and cause the greatest yield losses to maize (Seshu-Reddy, 1983; De Groote 2001). The species which cause the most damage to the economy in Kenya are the African stem borer (*Busseola fusca* Fuller), the pink stem borer (*Sesamia calamistis* Hamptons), the African sugarcane borer (*Eldana saccharina* Walker), the spotted stem borer (*Chilo partellus* Swinhoe), and the coastal stem borer (*C. orichalcociliellus* Strand), (Seshu-Reddy, 1998; Gethi et al., 2001; Songa et al., 2001). About 13.5% or more of maize production nationally is lost due to stem borers; a loss valued at over 72 million USD annually (De Groote, 2001). *Chilo partellus* is an economically important damaging stem borer species in the mid-altitude environment of Kenya (De Groote et al., 2002), and the most prevalent stem borer species in this environment (Overholt et al., 1994b; Songa et al., 1998), causing losses of up to 60% (Gethi, 1994). Losses of about 56% of potential yield in the mid-altitude environment have recently been reported (Karaya et al., 2009). These losses are severe to the smallholder subsistence farmers to whom maize is the number one staple crop. Six distinct maize-growing agro-ecological zones have been identified in Kenya based on three environmental determinants, namely elevation, temperature and rainfall.

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Table 1. Pedigree of inbred parents used in the diallel crosses.

No.	Pedigree	Comment
1	Pool B –36-B-4-3-B-B-B	
2	CML 395	CML
3	MBR C5 Bc F114-1-1-3-B-8-2-B-B-B-B-B-B	MBR
4	MBR C5 Bc F13-3-2-1-B-3-2-B	Sub-Tropic
5	CML 204	CML
6	MBR C5 Bc F108-2-3-1-B-5-2-B	Ex-KARI
7	Pob.SEW-HG"B"c0F39-1-1-1-1xMBR C5 Bc F22-2-1-4-B-B-B-B-2-2-B-B-B	MBR
8	MBR E.T(W)C3 S5/SINTxMBR F15-2-1-2-B-B-B	MBR
9	CML 384xMBR/MDR C3 Bc F58-2-1-3-B-B-B-B-3-1-B-B-B-B-B	CML
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-2-B-B	LGB resistant line

The mid-altitude environment receives a bimodal rainfall pattern and it is here that about 49% of Kenya's maize is grown (Hassan et al., 2001). Host Plant Resistance (HPR) to stem borers has been identified in several varieties of maize germplasm. There is a need to understand the type of gene action involved in this resistance. The General and Specific combining abilities (GCA and SCA) of breeding lines as originally concept-tualized (Sprague and Tatum, 1942) are useful in the characterization of inbred lines in order to identify the gene action which controls traits of interest in crop plants (Hallauer and Miranda, 1988). The diallel analysis approach is widely used to study both the genetic control of quantitatively inherited traits (Hayman, 1954; Jinks and Hayman, 1953) and the computation of GCA and SCA (Griffing, 1956).

The objectives of this study were: 1) to understand the combining ability and the type of gene action involved in the control of the insect resistance of 10 newly developed inbred lines resistant to *C. partellus* and to assess their grain yield potential, and 2) to determine the agronomic performance of the 45 single-cross hybrids across locations in the mid-altitude environment of Kenya.

MATERIALS AND METHODS

Ten (10) newly developed insect-resistant medium-maturity maize inbred lines from CIMMYT were crossed in a diallel-mating scheme using Griffing's method 4 (Table 1). Two of the lines, CML204 and CML395, were CIMMYT Maize Lines (CMLs), which belongs to heterotic group B. CML204 is a white grained, dent-textured late maturing line with resistance to maize streak virus, leaf blight and leaf rust. CML395 is a white grained semi flint line with good agronomic adaptation across a range of environments. Inbred lines 3, 4, 6, 7, 8 and 9, whose heterotic groups were unknown, were derived from multiple borer resistant (MBR) populations hence, they were putative sources of resistance to resistant *C. partellus*. Inbred line 10 was included in the study as an elite source of resistance to postharvest pests (maize weevil and larger grain borer). Forty-five (45) single-cross hybrids were formed ($C= p (p-1)/2$), where C designates the total number of crosses (progeny) and p refers to the number of inbred parents. The checks included in trial evaluations were CKIR 06009, Duma 41, DH01, H513 and WH502.

The 45 single crosses together with the five local checks were evaluated for resistance to *C. partellus* stem borer and for agronomic adaptation at four trial locations in Kenya (Table 2). Evaluation was done for two rainfall seasons (April to August 2009 and October 2009 to March 2010). A 10 × 5 alpha-lattice design with three replications was used with two-row plots of five-meter length planted 75 cm between rows and 25 cm within rows, resulting with a plant density of 53,333 plants/ha. The plots were divided into two parts such that the first two and the next five hills of every row was separated from the rest to make a swathe of five plants in every row. The five plants per row were infested with the five first instar neonate larvae at the fourth leaf stage of growth. Neonates of *C. partellus* stem borer were obtained from a rearing laboratory at the Kenya Agricultural Research Institute (KARI) Katumani Center. The remaining 32 plants per plot were protected by applying *beta cyfluthrin* (BULLDOCK[1], Bayer East Africa, Nairobi), a systemic synthetic pyrethroid pesticide, at a rate of (0.5 g a. i./kg) 8 kg/ha into the whorl of each plant. Data were recorded on both the infested and protected plot areas separately. The leaf damage score was visually assessed 14 days after infestation on a 1 to 9 scale (1 = undamaged leaves, 9 = extreme foliar damage) on each of the ten infested plants per plot in order to determine the extent of the damage caused by the feeding of the *C. partellus* larvae. This was repeated 14 days later. Other data recorded on the infested plots included number of plants showing dead hearts. Both the infested and protected plots, anthesis and silking dates, and the anthesis silking interval (ASI), which was computed as the difference between the number of days to 50% silking and the number of days to 50% anthesis were recorded. Plant and ear heights, root and shoot lodgings (assessed as the number of lodged plants per plot leaning at more than 45° from the vertical position below and above the ear respectively) were recorded on both plot treatments as well. Foliar disease scores for four common diseases, namely, gray leaf spot, (*Cercospora zeae-maydis*), common rust (*Puccinia sorghi*), leaf blight (*Exserohilum turcicum*) and maize streak virus were also recorded on both infested and protected plot areas. At harvest, stems in the infested plots were stripped of their leaves, the numbers of exit holes (EXHL) counted, stems split and the cumulative stem borer larvae tunnel length (TL) was measured in centimeters. The tunnel length to plant height ratio (TLPH) was computed and recorded. Infested and protected plot grain yield (GY) (t ha^{-1}) per plot was computed after shelling the ears in each plot, taking grain weight and adjusted to 12.5% moisture content.

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[1]Mention of a trade name of a product does not amount to its endorsement by the authors or their respective institutions.

Table 2. Geographical information of four trial sites used in the evaluations of the trials in the long and short rain seasons of 2009.

Site	Longitude	Latitude	Elevation (masl)	Mean daily temp (°C)	Mean annual precipitation (mm)	Dominant borer	Soil type
KARI Embu	37°42' E	0°449' S	1510	>= 18 < 24	1200	*B. fusca*	Clay loam
KTI Kirinyaga	37°19' E	0°34' S	1282	>= 18 < 24	1500	*B. fusca*	Clay loam
Mitunguu	37°46' E	06°1' S	985	>= 22 < 25	700***	*C. partellus*	Black cotton
Kiboko	37° 75' E	02°15' S	975	>=14.3<35.1	530	*C. partellus*	Sandy clay

1, Google earth by the American National Aeronautics and Space Administration (NASA); 2, Meteorological department, Embu station (Personal communication).

Data were subjected to Analysis of Variance (ANOVA) using the General Linear Model (GLM) procedure of the Statistical Analysis Systems (SAS) program, considering genotypes as fixed effects, and locations and seasons as random effects (SAS, 2003). Mean squares for each of the above traits were computed for each site and across the sites for both infested and protected plots. Mean separation was performed using the Least Significant Difference (LSD) method. GCA and SCA effects for each trait were also computed and tested for significance of difference. Subsequently, variances due to diallel progenies were computed and partitioned into three components: those due to GCA, those due to SCA, and those due to genotype × environment interaction. These three components were used to perform combining ability analyses (Sharma, 1998; Singh and Chaudhary, 1985).

RESULTS

Variety H513, a commercial cultivar widely grown by farmers in the target environment was out-yielded by at least 15 experimental hybrids, meaning that the newly developed hybrids were better in grain yield performance than this check (Table 3). Similarly, the top 14 hybrids performed as well as, the insect-resistant check, which was developed for resistance to stem borer pests and released as KH 414-3 SBR for cultivation in Kenya's dry mid-altitude environment. Parental lines 1 and 2 and non-insect resistant inbred lines were the top hybrids in grain yield performance, whereas hybrids formed from lines 3 and 4 showed superiority as regards leaf damage, number of exit holes and tunnel length to plant height ratio. Line 2, however, formed the cross combination hybrid 2 × 5, which was the most susceptible to foliar damage, number of exit holes and tunnel length traits. This was a pointer to the fact that even though the line was a good combiner for yield, this was not the case as regards insect resistance.

Hybrids formed by insect-resistant lines 6, 8 and 9, either as male or female parents, displayed only a few exit holes and a low tunnel length to plant height ratio, confirming their resistance to the spotted stem borer. Analysis of variance revealed significant (P<0.001) differences among genotypes for foliar damage, number of exit holes, tunnel length to plant height ratio and grain yield (Table 4). Both General (GCA) and Specific (SCA) combining abilities were significant sources of variation for grain yield and number of exit holes. The GCA sums of squares were larger than the SCA sums of squares. SCA was not an important source of variation for foliar damage, tunnel length, and tunnel length to plant height ratio. Additive gene action was predominant over non-additive gene action for grain yield as well as foliar damage, number of exit holes and tunnel length to plant height ratio and the three traits used to measure resistance of stem borer in maize. The mean squares due to environment were significant for all traits, and all the locations were distinct, thus, suggesting that different hybrids should be developed for different environments. Genotype × location interactions showed significant differences (P<0.001) for grain yield, days to anthesis and anthesis silking interval; significant differences (P<0.01) for number of exit holes and tunnel length; and significant differences (P<0.05) for foliar damage and tunnel length to plant height ratio (Table 4). Genotype × season interactions showed significant differences (P<0.05) for leaf damage and tunnel length, indicating that genotypes responded differently for these traits during the two seasons. GCA × environment interactions were significant (P<0.05) for foliar damage and number of exit holes, while SCA × environment interactions were not significant for the same traits.

Parental inbred lines 2, 1, 5 and 9, in order of importance, displayed favorable and significant GCA for grain yield (Table 5), while the worst general combiners for grain yield were parents 3 and 4. Using foliar damage as a measure of resistance, parent 9 presented the best GCA value, followed by parents 4 and 6, and these three had, therefore, the highest number of favorable alleles for this trait. When the number of exit holes was considered, inbred line 6 showed the highest level of resistance as it had the best GCA value; however, when tunnel length to plant height ratio was considered as a measure of resistance, parents 3 and 6 were the best performers for this trait. Parents 3, 4 and 6 showed favorable GCA for traits used to measure resistance, but had unfavorable GCA values for grain yield. Parent 9 presented the best compromise in GCA for both grain yield and traits used to measure resistance.

The most favorable SCA occurred in the hybrid 5 × 7, which could be used in the development of three-way

Table 3. Means of top ten and bottom ten single cross hybrids and 5 check varieties for selected traits of trials evaluated in Kiboko, KTI and Embu over two seasons in 2008 and 2009 under artificial *C. partellus* infestation.

Rank	Cross	Entry	Grain yield Infested (t ha^{-1})	Days to silking	Foliar damage scores	Number of exit holes	Tunnel length (cm)	Tunnel length-plant height ratio
1	1 x 2	1	8.02	70.0	2.7	2.3	6.4	0.028
2	5 x 7	32	8.00	73.1	2.3	1.6	5.5	0.025
3	1 x 5	4	7.86	70.9	2.6	1.6	4.3	0.018
4	2 x 5	12	7.84	77.1	2.9	3.2	8.3	0.037
5	2 x 9	16	7.83	73.7	2.2	1.3	4.1	0.017
6	5 x 9	34	7.83	74.0	2.0	1.0	4.1	0.016
7	2 x 6	13	7.70	75.4	2.3	1.5	3.5	0.016
8	2 x 10	17	7.66	70.1	2.6	1.9	5.5	0.023
9	1 x 6	5	7.64	68.5	2.1	0.9	3.2	0.014
10	5 x 6	31	7.52	72.7	2.1	0.9	3.4	0.015
36	3 x 10	24	5.93	68.8	2.0	0.8	3.7	0.016
37	3 x 8	22	5.89	70.8	1.8	0.9	3.0	0.013
38	4 x 5	25	5.62	72.1	2.0	1.1	3.6	0.015
39	3 x 5	19	5.47	72.8	2.1	0.7	2.5	0.011
40	6 x 7	36	5.40	69.6	2.1	0.5	2.0	0.011
41	3 x 7	21	5.18	71.0	2.1	0.8	2.6	0.013
42	3 x 6	20	4.82	72.8	1.9	0.9	2.9	0.015
43	4 x 7	27	4.79	68.5	2.0	0.8	2.5	0.015
44	4 x 6	26	3.55	71.4	1.8	0.7	2.7	0.016
45	3 x 4	18	3.37	73.1	1.8	0.9	2.8	0.015
46	CKIR6009	46	7.91	67.8	2.8	2.3	7.2	0.03
47	Duma 41	47	7.04	65.5	2.6	2.1	6.2	0.03
48	DH01	48	6.47	59.0	2.1	0.9	3.6	0.02
49	H513	49	6.30	71.0	2.7	2.0	5.5	0.03
50	WH502	50	5.29	73.1	2.9	1.9	6.3	0.03
Hybrid mean			6.60	70.6	2.1	1.2	3.9	0.02
Checks mean			6.60	67.8	2.6	1.8	5.8	0.03
CV			20.09	68.8	20.4	95.9	102.8	105.8
LSD (0.05)			0.78	6.4	0.3	0.7	2.2	0.01
Mean			6.60	11.6	2.1	1.2	3.9	0.01

cross hybrids for release to farmers (Table 6). None of the hybrids showed any appreciable SCA for foliar damage, and therefore, this trait is not a useful selection criterion when developing the spotted borer-resistant hybrids. However, the hybrids expressed favorable SCA for other traits used to measure resistance: stem tunnel length, number of exit holes and ratio of tunnel length to plant height, with the most favorable values occurring in hybrids 7 × 10, 3 × 5 and 4 × 8. There was discordance among hybrids between grain yield SCA and traits used to measure resistance, for example, hybrid 8 × 9 had unfavorable SCA effects for resistance but good SCA effects for grain yield.

All these results showed that in the development of insect-resistant hybrids, both grain yield and the traits used to measure resistance should always be given due attention.

DISCUSSION

The experimental hybrids performed better than the checks in the number of exit holes, the tunnel length to plant height ratio and the other agronomic traits measured. It was clear from the results that parent 1 contributed more early-maturing hybrids compared to the other inbred lines, and could thus, be an important source of early maturity in a breeding program for stem borer resistance. Significant differences for resistance traits among the hybrids showed existence of potential to select for these traits in the hybrids. Genotype × season interactions showed significant (P<0.05) differences for leaf damage and tunnel length, indicating that genotypes responded differently for these traits during the two seasons. It would, therefore, be prudent to test the materials in both rainfall seasons because weather

Table 4. Analysis of variance for grain yield and traits used to measure resistance among 45 hybrids and 5 checks evaluated across two seasons in Kiboko, KTI and Embu under artificial infested conditions in 2009 and 2010.

Source of variation	DF	Grain yield (t ha⁻¹)	Ears/ plant	Days to anthesis	Anthesis silking interval	Foliar damage score	Number of exit holes	Tunnel length (cm)	Tunnel length- plant height ratio
Env	2	1712.03***	0.78***	17202.27***	14.44***	87.12***	47.97***	94.41***	0.001**
Season	1	2.45	0.35***	471.71***	82.14***	0.11	0.47	67.46*	0.0001
Season*Env	2	96.66***	0.41***	94.41***	0.24	0.42*	97.64***	1427.12***	0.035***
REP(Season*Env)	12	5.44***	0.04*	5.33**	5.33***	1.59***	12.75***	59.64***	0.001***
Entry	49	20.07***	0.09***	90.25***	13.55***	2.16***	6.32***	46.54***	0.001***
Env*Entry	98	2.72***	0.04***	6.43***	2.91***	0.24*	1.58**	16.7**	0.0004*
Season*Entry	49	3.19***	0.02	5.48**	2.12*	0.24*	1.03	16.62*	0.0004**
Season*Env*Entry	98	1.51***	0.03	4.27***	2.61***	0.21	1.5*	16.42**	0.0004*
GCA	9	75.3***	0.03***	266.7***	62.9***	7.95***	20.9***	132.4***	0.002***
SCA	35	6.91***	0.05**	13.2***	3.36**	0.23	1.98*	18.2	0.0004
GCA × Env	18	6.96***	0.03	9.1	3.5**	0.34*	2.54*	14.07	0.0003
SCA × Env	70	1.8	0.03	2.7	1.9	0.17	1.17	13.6	0.0003

NB: *, ** and *** denotes level of significance at 95, 99 and 99.9% respectively.

Table 5. Estimates of general combining ability effects for grain yield and other traits for 10 inbred parents used to form 45 diallel crosses evaluated across Kiboko, KTI, Embu and Mitunguu locations in the short rains of 2009 and 2010.

Inbred parent	Grain yield (t ha⁻¹)	Foliar damage score	Number of exit holes	Tunnel length (cm)	Tunnel length-Plant height ratio	Plant height (cm)	Ear height (cm)
P1	0.61**	0.20***	0.36***	0.77*	0.003*	13.3***	9.73***
P2	1.13***	0.44***	0.72***	1.61***	0.007***	14.16***	6.37***
P3	-1.02***	-0.17***	-0.36***	-1.06***	-0.005**	-4.53*	1.33
P4	-1.20***	-0.21***	-0.38***	-0.66*	-0.002	-17.1***	-10.13***
P5	0.56**	0.19***	0.30**	0.91**	0.003*	14.42***	9.55***
P6	-0.26	-0.21***	-0.43***	-1.28***	-0.005***	-10.64***	-7.88***
P7	-0.27	0.05	-0.03	-0.21	0.001	-16.59***	-9.54***
P8	0.01	-0.15**	0.02	-0.23	-0.0003	-8.65***	-2.02
P9	0.43*	-0.27***	-0.30**	-0.63*	-0.004**	8.77***	7.09***
P10	0.01	0.12*	0.11	0.76*	0.003*	6.87***	-4.50**

NB: *, ** and *** denotes tests of significance at 95, 99 and 99.9% respectively.

Table 6. Specific combining ability estimates for grain yield and other traits for top 10 and bottom 10 diallel crosses ranked in terms of grain yield SCA values for trials evaluated across Kiboko, KTI, Embu and Mitunguu locations in 2009 and 2010.

Cross	Entry	Grain yield infested (t ha⁻¹)	Grain yield protected (t ha⁻¹)	Days to silking	Foliar damage scores	Number of exit holes	Tunnel length (cm)	Tunnel length-plant height ratio
5 × 7	32	1.11*	0.93*	1.14	-0.12	0.07	0.96	-0.003
4 × 8	28	0.81	0.64*	-0.42	-0.11	-0.29	-1.16	0.003
4 × 10	30	0.8	0.19	-0.06	-0.04	0.13	0.27	-0.0004
2 × 3	10	0.76	0.03	-0.17	-0.16	-0.25	-0.91	0.0001
1 × 6	5	0.69	0.47	0.33	-0.09	-0.29	-0.16	-0.001
1 × 4	3	0.64	0.37	-0.21	-0.12	-0.29	-0.92	-0.005
5 × 6	31	0.62	0.39	-1.23	-0.04	-0.15	-0.12	-0.003
1 × 3	2	0.61	0.51	-0.62	0.07	0.01	0.42	0.002
6 × 8	37	0.61	-0.001	-0.48	-0.14	-0.33	-0.62	-0.004
4 × 9	29	0.58	0.58	-0.01	0.07	0.25	1.49*	-0.005
6 × 9	38	0.44	0.5	-0.21	0.06	0.08	0.04	0.0002
2 × 4	11	0.41	0.32	-1.43	0.13	-0.39	-0.03	0.009*
3 × 10	24	0.33	0.22	-0.06	-0.13	-0.21	0.18	-0.002
3 × 8	22	0.31	0.57	-0.43	0.01	0.05	0.45	-0.003
3 × 9	23	0.27	-0.25	-1.29	-0.04	0.1	-0.88	0.005
7 × 8	40	0.24	-0.1	-0.78	-0.04	0.28	0.84	0.007*
2 × 6	13	0.23	0.64*	0.91	-0.09	-0.03	-0.65	-0.002
5 × 9	34	0.23	0.09	0.3	-0.12	-0.21	-0.07	0.005
7 × 10	42	0.2	0.22	1.45	-0.2	-0.33	-1.44*	-0.006
2 × 5	12	-0.45	-0.46	1.15	0.17	0.92***	1.89*	-0.004
1 × 10	9	-0.49	-0.11	-0.91	-0.05	-0.13	0.48	-0.005
1 × 8	7	-0.5	-0.3	0.52	0.16	0.32	0.47	0.002
3 × 6	20	-0.5	-0.34	0.38	0.12	0.45*	1.33	0.001
1 × 7	6	-0.56	-0.41	-0.64	0.07	0.15	-0.28	0.0003
3 × 5	19	-0.67	-0.23	-1.18	-0.05	-0.47*	-1.22	-0.001
6 × 7	36	-0.68	-0.63*	-0.84	0.1	-0.29	-0.35	0.001
8 × 9	43	-0.81	-0.41	0.65	0.02	-0.45*	-1.27	-0.005
3 × 4	18	-0.96*	-0.64*	2.44	0.08	0.36	0.63	0.007*
4 × 6	26	-1.58**	-1.44***	0.45	0.06	0.27	0.77	0.006*

NB: * and ** denotes level of significance at 95%, 99% and 99.9% respectively.

conditions affect insect behavior. GCA and SCA were important sources of variation for insect resistant traits. Other researchers reported GCA as the only significant source of variation for the traits used to measure resistance to *C. partellus* (Butron et al., 1999; Karaya et al., 2009).

Lines with unfavorable GCA for yield but favorable GCA for resistance parameters may not be useful in direct hybrid making but could be useful as sources of *C. partellus* resistance alleles. In similar previous findings (Ajala et al., 1994), there was evidence of genotype × trait interactions since genotypes expressing good GCA for grain yield did not necessarily present favorable effects for traits used to measure resistance. There was an observed discord between GCA for grain yield and GCA for resistance traits. Good general combiners for

grain yield were not always good combiners for traits used to measure resistance (Karaya et al., 2009; Soengas et al., 2004).

Additive gene action was predominant over non-additive gene action for grain yield as well as, for foliar damage, number of exit holes and tunnel length to plant height ratio; the three traits were used to measure stem borer resistance in maize. These results agreed with those of earlier workers (Ajala, 1992; Karaya et al., 2009; Kumar and Saxena, 1992). Since non-additive gene action were not detected in all the four damage traits measured, then, hybrid vigor should not be expected probably in the inheritance of these traits (Ajala, 1992). In contrast, additive gene action, which conditions the traits used to measure resistance, is advantageous because alleles for resistance cannot be combined from different

sources. Breeding methods that take advantage of additive gene actions, as in recurrent selection strategies, would be efficient in the development of new varieties from the germplasm evaluated, whereas grain yield shown to be conditioned by additive gene action (Table 5), can be selected unless found otherwise by other workers. Non-additive gene action has been found to condition grain yield among hybrids developed from insect-resistant hybrids (Beyene et al., 2011) and hence the nature of gene action conditioning grain yield cannot be generalized. Breeders will more often than not evaluate different hybrids across different environments with varying ecological conditions and insect intensities. The mean squares due to environment were significant for all traits, and all the locations were distinct, thus suggesting that different hybrids should be developed for different environments. The differential responses of lines but not of hybrids, was consistent with the recent work of Beyene et al. (2011).

Lack of significant GCA × environment interaction for tunnel length and tunnel length to plant height ratio meant that breeders could use these traits reliably to select useful inbred lines in any one of the evaluation environments. Neither GCA nor SCA interacted significantly with the environment for tunnel length trait, and this trait, therefore, was seen as the most important in the evaluation of the level of defense in maize to the spotted stem borer.

Conclusions

The parents used in this study showed good general combining abilities for grain yield and other characteristics used to measure resistance. The materials therefore, have good potential for use as breeding stock in the development of maize hybrids resistant to the spotted stem borer in the target environment. Although, hybrid vigor may not be expected for some of the traits used to measure resistance in the spotted stem borer because they were under additive gene control; the observed additivity was overwhelmingly under selectable genetic control. Tunnel length was the best trait to select resistance to stem borers in maize, partly because it interacted minimally with the environments of the crops grown. Inbred lines 6, 8 and 9, (Table 4) were good combiners for both yield and resistance to the borer. Inbred lines 3 and 6 were good for resistance but not for grain yield. Inbred line 1 was also good for both traits and a good source for early maturity as well. Single cross 7 × 10 was the most resistant when tunnel length was considered; cross 3 × 5 was the most resistant when the number of exit holes was considered; and cross 4 × 5 was the most resistant when tunnel length to plant height ratio was considered. Cross 5 × 7 had the highest SCA for grain yield. These could be used to make superior 3-way cross hybrid varieties for grain yield and for resistance to *C. partellus.*

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