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Combining Ability among Twenty Insect Resistant Maize inbred lines Resistant to *Chilo partellus* and *Busseola fusca* Stem borers

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Abstract

A partial diallel design was used among 20 maize inbred lines to form 110 F_1 hybrids to generate information on the values of these lines for developing insect resistant maize varieties during the short rains season of 2006. The hybrids were evaluated for resistance to the *C. partellus* and *B. fusca*, and for agronomic performance over two seasons during long and short rains of 2007 at a mid-altitude dry early maturity site at KARI Kiboko, and the moist mid-altitude medium maturity site at KARI Embu. leaf damage score (using a scale of 1-9 where: 1= No damage and 9= extremely damaged), number of exit holes, cumulative tunnel length, and grain yield were measured as resistance traits. The genotype sum of square was partitioned into general combining ability (GCA) and specific combining ability (SCA) effects. Maize inbred lines with good general combining ability for insect resistance including maize inbred lines with significant and negative GCA`s for leaf damage were identified as lines 12,16,18,19 and 20 at Kiboko and lines 8, 17, 18, and 20 in Embu. Results showed that the problem of stem borers intensified by over 40% within four years in the experimental region of Eastern Kenya; currently mean yield loss due to stem borers was assessed to be about 56%. Several hybrids had significant negative SCA for leaf damage and significant positive SCA for grain yield. The maize inbred lines studied revealed their potential for use in breeding programs for insect resistance that could result in a correlated response for increased grain yield. Recurrent selection would be the best option to develop high yielding insect resistant germplasm for this region of Kenya considering that additive gene action were predominant. Evidently, it would be more difficult to develop host plant resistance to *B. fusca* than to *C. partellus*.

Keywords: Kenya; Maize; Stem borers; Combining ability; Partial diallel; Insect resistance.

Introduction

Maize (*Zea mays* L.) is the third most important cereal after wheat and rice globally and the most widely distributed (Purseglove, 1981). Maize is popular for being more resistant to pests and diseases and easier to store and process than traditional food cereals including sorghum and millets in Kenya. Productivity in grain yield in maize is a factor of its genetic make up and its interaction with the environmental factors such as soils, water, temperature, pests' pressure, diseases, and cultural practices (Chumo, 1986). A major breeding objective is resistance to pests, foliar diseases, lodging, improved grain quality, and nutritive value (Bajaj, 1994) and other agronomic traits such as plant height which is a major factor affecting growth status and yield potential (Zhang et al., 2007). Stem borers play a considerable role in reducing the yield of an otherwise high yielding variety, through damaging the leaves, stem, ears, and kernels in some cases. Lepidopteran stem borers are the most damaging pest to maize crop in semi-arid areas of eastern Kenya (Songa et al., 1999) and all maize growing areas in Kenya (De Groote et al., 2002). Stem borers cause significant annual loss of maize (*Zea mays* L.) estimated at 13.5%, and worth US $91 millions in Kenya. The spotted stem borer (*Chilo partellus* Swinhoe) and the African stem borer (*Busseola fusca* Fuller) are the most important stem borer species. Host plant resistance in insect resistant maize varieties is a practical and easy to adopt and use method of stem borer control.

Stem borer is mainly managed using pesticides which results in risks to farmers' health and environment (Kumar, 1984). Chemical control may involve the use of chemicals that affect the biological processes of the stem borers and thus acting as poison (Kumar, 1984), and may be in form of sprays or dust and either systemic or contact pesticides (Hill, 1983). Cultural method including crop and land husbandry practices such as destruction of crop residues and inclusion of non host crops are other methods of pest control, aiming at making the environment unfavorable for the pest and thereby avert damage all together or limit the severity of their damage. Biological control through use of their natural enemies, including parasites, predators, or pathogens are used to reduce pest populations. Examples are *Trichogramma* spp. (Chalcidoidea) which are egg parasites and *Apanteles* spp. (Bracomidae) which are larval parasites of stem borers.

Development of the host plant resistance (HPR) to stem borers may improve farming by reducing the application of insecticides and yield loss to stem borers. HPR is being employed by the International Maize and Wheat Improvement Centre (CIMMYT) and the Kenya Agricultural Research Institute (KARI) to conduct the project 'Insect resistant Maize for Africa (IRMA) through both conventional breeding and biotechnology to enable the consumers to choose the technology they prefer (Mugo et al., 2005). HPR is often expressed in two forms: as tolerance (the ability to yield despite the infestation) and resistance (the ability to inhibit the damage from infestation resulting in high yields). Several inbred lines and germplasms have been developed from this work but their combining abilities have remained unknown. Combining ability of maize inbred lines is the ultimate factor determining future usefulness of the lines to develop hybrids (Hallauer and Miranda, 1988). The value of any population depends on its potential *per se* and its' combining ability in crosses (Vacaro et al., 2002). The diallel cross has been defined as the group of all possible crosses among several genotypes and has been widely used by researchers to determine combining ability (Brenner et al., 1991). Combining ability has been used in maize to detect good combiners for many agronomic traits including yield, plant height and resistance to diseases; however it is rarely used in breeding for insect resistance especially for *C. partellus* and *B.fusca* stem borers in Africa. This study aimed to investigate both general and specific combining abilities for insect resistance in maize.

The objective of this work was to determine the combining ability of 20 insect resistant maize inbred lines, developed by IRMA project, and their potential to produce hybrids or open pollinated varieties (OPVs) which are resistant to *C. partellus* and *B. fusca* stem borers.

Material and methods

The CIMMYT multiple borer resistant (MBR) maize population was developed by compositing global maize germplasm reputed to be "resistant" to a number of stem borer species (Mihm 1997, Smith et al., 1989). 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*). This MBR was developed after noticing that a germplasm with resistance to a single species of insect pest was not as useful as one resistant to the complex problems in a given area (Mugo et al., 2001).

Twenty (20) insect resistant maize inbred lines developed from CIMMYT's multiple borer resistant population through artificial infestation with *C. partellus* and *B. fusca* stem borer species at Kiboko and Embu sites were used (Table 1). The multiple borer resistant populations was developed from maize germplasm with resistance to tropical and temperate global stem borer species including *C. partellus* and *B. fusca.* Some of the maize inbred lines also had multiple disease resistance (MDR).

Table 1. Maize inbred lines used in making F1 hybrids.

Entry	Pedigree	Entry	Pedigree
1	MBR/MDR C3 Bc F8-1-2-1-B-2-2-B	11	MBR C5 Bc F14-3-2-8-B-4-2-B
2	MBR C5 Bc F43-3-1-1-B-3-2-B	12	MBR/MDR C3 Bc F1-1-1-1-B-3-2-B
3	MBR C5 Bc F14-3-2-8-7-2-B	13	MBR C5 Bc F114-1-2-3-B-2-2-B
4	MBR C5 Bc F8 –1-1-1-B-2-2-B	14	MBR C5 Bc F13-1-2-2-B-1-2-B
5	MBR C5 Bc F13-2-1-3-B-4-2-B	15	MBR C5 Bc F14-3-2-9-B-2-2-B
6	MBR C5 Bc F13-1-2-2-B-2-2-B	16	MBR C5 Bc F113-1-2-2-B-3-2-B
7	MBR C5 Bc F113-3-2-1-B-3-2-B	17	MBR C5 Bc F114-3-2-5-B-1-2-B
8	MBR C5 Bc F14-3-2-5-B-2-2-B	18	MBR C5 Bc F14 –3-2-8-B-8-2-B
9	MBR C5 Bc F14-3-2-9-B-1-2-B	19	MBR C5 Bc F114-1-1-3-B-5-2-B
10	MBR C5 Bc F114-1-2-3-B-6-2-B	20	MBR/MDR C3 Bc F44-2-1-2-B-1-2-

These inbred lines will be referred to by their entry numbers in this paper.

The F1 hybrids were made from the 20 maize inbred lines using partial diallel mating design at KARI Kiboko during the April - August 2006 period (Table 2). Crosses were made this way to ensure that each of the twenty maize inbred lines was involved in the crosses but not necessarily the same number of crosses or with the same maize inbred lines using the formula below to arrive at formation of 110 F1 hybrids**.**

No. of crosse$s=PS/2=20(11)/2=110$, Where, P=Total number of parents and, S=Number of parents that each parent is crossed to.

Table 2. The 110 crosses made through use of partial diallel mating design.

Males			Females										
1st	2nd	3rd											
1	1	1	6	7	8	9	10	11	12	13	14	15	16
2	2	2	7	8	9	10	11	12	13	14	15	16	17
3	3	3	8	9	10	11	12	13	14	15	16	17	18
4	4	4	9	10	11	12	13	14	15	16	17	18	19
5	5	5	10	11	12	13	14	15	16	17	18	19	20
6	6	6	11	12	13	14	15	16	17	18	19	20	
7	7	7	12	13	14	15	16	17	18	19	20		
8	8	8	13	14	15	16	17	18	19	20			
9	9	9	14	15	16	17	18	19	20				
10	10	10	15	16	17	18	19	20					
11	11	11	16	17	18	19	20						
12	12	12	17	18	19	20							
13	13	13	18	19	20								
14	14	14	19	20									
15	15	15	20										

To obtain the parent to cross with, the formula, $K= (P+1-S)/2=5$, Where, K is a constant and S is the sample size. S was 11, while P was 20. The experimental material consisted of F_1's generation only without reciprocals i.e. $½P\ (P-1)$ combinations, where P=number of parents which were used according to Griffings (1956) model method 4. *PS/2* gave 110 Combinations, where *P* (total number of parents)=20 and *S* (selected sample)=11.

Males were staggered by planting on three dates to ensure nicking with the female parents. Males were sown five days before the female parents, on the same day with the females, and five days after sowing the females. The F_1 hybrids were grown at KARI Kiboko and KARI Embu. Kiboko is located at 20^0 15' S and 37^0 75' E at an elevation of 975 masl, with sandy clay soils and 530 mm annual rainfall. KARI Embu is located at 0^0 30' S and 37^0 27' E at an elevation of 1633 masl, with nitisol soils and 1265 mm annual rainfall. An 11x10 alpha lattice design (11x10) with single 5-m row plots was followed. The row-to-row distance was 75cm while plant-to-plant distance was 25 cm, giving a plant density of 53,000 plants ha^{-1}. Fertilizers were applied to give 60kgN and 60kgP2O5 ha^{-1} as recommended for the area. Nitrogen was applied in two splits. Supplemental irrigation was applied when needed. The fields were kept free of weeds by hand weeding.

Each row was divided into two halves. The front half was infested with *C. partellus* at Kiboko and *B, fusca* in Embu. The back halves at both sites were protected using Bulldock® 0.05 GR granule, which is a systemic insecticide, a synthetic pyrethroid with Beta-cyfluthrin 0.5g/kg as the active ingredient. Infestation was done using 20 blackhead stage eggs per plant for each of the 11 plants per row. The eggs were placed in each of the 11 plants whorl at the 4^{th} leaf stage. Insect damage was assessed by scoring each plant on a 1-9 scale, where 1= immune (no damage) and 9= completely damaged. Scores for the foliar damage was according to CIMMYT (1989) as follows. The first scoring scores were taken two weeks after infestation and repeated after two more weeks. The number of stem borer exit holes per plant was counted at harvest. The cumulative tunnel length was measured after splitting the stems of each of the 11 infested plants. Grain yield loss was calculated by subtracting grain yield per unit area of the infested area from the grain yield per unit area of the protected area as follows:

Yp -Yi Where; *Yp* = yield of the protected area in a plot.
Yi = yield of the infested area in a plot.

Table 3. Scale for scoring stem borer damage to whorl-stage maize plants.

Visual rating of damage	Numerical score	Resistance reaction
No damage	0	(Likely escape)
Few pin holes	1	Highly resistant
Few shot holes on a few leaves	2	Resistant
Several shot holes or small holes on A few (<50%) leaves	3	Resistant
Several (>50%) leaves with shot holes or small lesions (<2cm long)	4	Moderately resistant
Elongated lesions (>2cm long) on a few leaves	5	Moderately resistant
Elongated lesions on several leave	6	Susceptible
Several leaves with long lesions or tattering	7	Susceptible
Most of the leaves with long lesions or Severe tattering	8	Highly susceptible
Plant dying as a result of foliar damage	9	Extremely sensitive to Damage

Adapted from CIMMYT, (1989)

Standard ANOVA were performed for the various agronomic traits measured per environment.
For combining ability, analysis of variance followed method 4 of the fixed model I (Griffing, 1956) for a circulant partial diallel allowing for a balanced incomplete block design (Hallauer and Miranda, 1988) and excluding both the parents and the reciprocal crosses. The statistical model was:
$x_{ij} = \mu + r_k + g_i + g_j + s_{ij} + e_{ijk}$
Where:
x_{ij} = the effect of the ijth genotype ($i,j = 1,2$ ----------p, $i < j$)
μ = grand mean
r_k = kth replication effect
g_i and g_j = GCA effects of parents *i* and *j*
s_{ij} = SCA effects between parent *i* and *j*
e_{ijk} = experimental error for the observation x_{ijk} ($k = 1,2,$ ---------r, $i = j = 1,2,$---------n).

The analysis allowed for an estimate of the variances from EMS and the effect of GCA (representing additive effects) and SCA (denoting non–additive effects) and for the sums of squares of GCA and SCA.

Significant genotype mean square was partitioned into GCA and SCA effects. The GCA and SCA were tested using the appropriate error terms.

Results and discussion

The GCA mean square in all the maize inbred lines were highly significant at 99.9% probability level in yield both in Kiboko (Table 4) and Embu (Table 5), while exit holes and tunnel length were found to be significant at 99% and 95% probability levels in Kiboko and Embu, respectively.

Pooled analysis of variance for combining ability revealed the presence of highly significance mean of squares due to GCA for yield, exit holes, stem borer damage and tunnel length both in Kiboko and Embu. This was a good indicator of additive and additivex additive type of gene action. Both GCA and SCA effects revealed significant interaction with seasons for yield, exit holes and tunnel length at Kiboko while in Embu the interaction with season was observed in all traits. The lines therefore exhibited different reactions to both *B. fusca* and *C. partellus* stem borers calling for different varieties targeted for the two ecologies. The SCA mean squares were not significant both under *B. fusca* and *C. partellus* infestation, and the inference was that dominance effect were less important compared to additive effects. Thus the result reflected preponderance towards additive gene action in insect resistance, grain yield and associated characters measured in this study.

Table 4. Mean squares for general and specific combining ability for various traits of 20 inbred lines at Kiboko.

Sour Source	Degrees of freedom(Df)	Yield (tons/ha)	Yield loss (tons/ha)	Exit Holes(no.)	Stem borer Damage (1-9)	Tunnel Length (cm.)
Season	1	47237202.80***	35090212.67	29.46***	414.42	10.66***
Treatment	1	80138175.24***	.	.	.	.
Crosses	109	5951068.99***	1305194.97*	0.65**	5.49*	0.12**
Crosses vs.checks	1	122132292.08***	6239022.23**	10.30***	128.77***	2.51***
GCA	19	3233157.93***	1510971.11	0.53*	4.63*	0.09*
SCA	90	6524850.22	1261753.34	0.67	5.68	0.13
Pooled error	109	1050219.9	1180546.20	0.45	4.89	0.07
GCA:SCA ratio		0.50	1.20	0.79	0.82	0.69

*, **, and *** significant at 95%, 99% and 99.9% probability levels, respectively.

Table 5. Mean squares for general and specific combining ability for various traits of 20 inbred lines at Embu.

Source	Df	Yield (tons/ha)	Yield loss (tons/ha)	ExitHoles (no.)	Stem borer Damage (1-9)	Tunnel Length(cm.)
Season	1	222138656.41***	76351256.32***	27.47***	30.84***	20.40**
Treatment	1	442287052.43***	.	.	.	.
Crosses	109	2986567.81***	992168.90*	0.61*	0.16*	3.54*
Crosses vs.checks	1	30422425.54***	15622564.07***	7.83**	5.17***	32.20**
GCA	19	1166359.63***	603628.86*	0.47*	0.09*	2.44*
SCA	90	3370833.98	1074194.02	0.64	0.17	3.77
Pooled error	109	382737.50	872429.18	0.64	0.13	3.50
GCA:SCA ratio		0.35	0.56	0.73	0.53	0.65

*, **, and *** significant at 95%, 99% and 99.9% probability levels, respectively.

Stem borer damage was significant at 99.9% probability level in both Kiboko (Table 6) and Embu (Table 7). Some of the F1 hybrids were found to be resistant to stem borers and also yielded high compared to the commercial checks and other F1 hybrids. As expected most of the F1 hybrids in Kiboko and Embu were above the experimental mean in terms of yield while both checks were well below the mean yield, indicating that some F1 hybrids were resistant to the respective stem borers. In this study it was found out that yield can not be used as the only trait in selecting for the stem borer resistance similar to the results by CIMMYT (1989). A good example was observed in entry 108 and 45 which were the 2nd best under *C. partellus* and *B. fusca* infestation respectively though they exhibited a highly significant tunnel length. These two entries can be regarded as being tolerant and they can be used in breeding programs to incorporate resistance into more adapted but susceptible materials. The percentage yield loss for the checks were high compared to the resistant F1 hybrids and the range was between 37-76% and averaged about 56%, compared to the results of De Groote et al., (2002). This probably indicated the increase of stem borers threatening the production of maize from 2002 to 2007. Entry 68 yielded the most grain under *C. partellus* infestation while entry 103 was the best under *B. fusca* infestation.

Table 6. Mean performance of the top 18 F1 hybrids and two local checks (PH3253 and H513) infested with *Chilo partellus* at Kiboko.

Rank	ENTRY	Yield (t/ha)	Yield loss (t/ha)	Stem borer damage Scale (1-9)	Exit holes (no.)	Tunnel Length(cm)
1	68	7.0	1.1	2.1	0.6	2.2
2	108	6.8	0.8	2.7	1.4	5.6
3	78	6.5	1.5	2.3	1.1	3.6
4	32	6.5	1.3	2.4	1.8	4.8
5	18	6.4	1.3	2.8	0.8	1.8
6	95	6.3	1.5	2.7	1.0	2.3
7	45	6.2	1.6	3.0	1.0	2.2
8	54	6.1	2.0	2.6	0.9	2.2
9	4	6.1	1.2	3.0	1.0	2.8
10	110	6.0	1.2	2.7	1.0	2.7
11	3	6.0	2.0	2.9	0.8	1.4
12	43	6.0	1.4	2.7	2.3	6.6
13	16	5.9	1.6	2.5	1.2	3.3
14	100	5.9	0.8	2.5	1.4	4.0
15	87	5.9	1.3	2.4	1.4	4.6
16	105	5.8	1.0	2.7	1.0	2.8
17	99	5.8	0.7	2.4	1.4	5.0
18	15	5.8	1.3	2.5	0.6	1.9
19	14	4.1	4.1	5.3	3.5	11.1
20	90	3.7	2.5	4.7	2.0	7.2
	MEAN	5.9	1.5	2.8	1.3	3.9
	CV	21.29	67.75	22.86	89.52	98.93
	LSD	1.10	1.20	0.90	1.20	2.80
	SIG	***	***	***	***	**

*, **, and *** significant at 95% 99% and 99.9% probability levels respectively.
Local checks: Entry 14-PH3253, entry 90-H513 both in Kiboko and Embu

Entries 3, 16, 43, 45, 54, 68, 78 and 95 appeared in both Kiboko and Embu among the 20 best F1 hybrids thus confirming predominance of additive effects. These entries revealed resistance for *C.partellus* and *B. fusca* under different environments (Tables 5&6) even though the resistance varied from one stem borer to the other. Both materials showed high resistance to the borers tested, and it was clear that *B. fusca* was the most difficult insect to control. Several researchers also have indicated additive effects in the inheritance of different agronomic traits in maize (Mungoma & Polak, 1988; Vasal et al., 1992; Ngaboyisonga et al., 2008). Significant negative GCA effects were observed in Kiboko and Embu in entries; 8, 17, 18 and 20 (Tables 8 & 9) for stem borer damage scores and they can therefore be classified as good general combiners for yield and insect damage, an indication of a probable negative correlation between resistance and yield (Ceballos et al., 1991).

Table 7. Mean performance of the top 18 F1 hybrids and two local checks (PH3253 and H513) infested with *Busseola fusca* at Embu.

Rank	ENTRY	Yield (t/ha)	Yield loss (t/ha)	Stem borer damage Scale(1-9)	Exit holes (no.)	TunnelLength (cm)
1	103	5.4	1.1	2.3	0.4	1.1
2	45	5.3	2.0	2.6	1.4	4.7
3	78	5.1	2.2	2.5	1.1	2.5
4	85	5.0	1.3	2.7	2.1	4.6
5	110	4.9	1.5	2.5	0.9	1.9
6	27	4.7	2.3	2.8	1.6	4.6
7	16	4.7	2.6	2.5	1.0	2.8
8	3	4.7	2.2	2.9	2.2	3.7
9	68	4.6	1.7	2.6	2.0	4.2
10	95	4.5	1.2	2.9	2.3	4.3
11	43	4.5	1.8	2.4	1.3	2.5
12	44	4.5	3.1	2.6	1.4	4.1
13	46	4.4	2.3	2.7	0.5	1.5
14	17	4.4	1.9	2.5	1.2	2.6
15	57	4.4	2.4	3.0	1.8	4.6
16	54	4.3	2.6	2.6	1.0	4.2
17	91	4.3	1.4	2.5	1.3	2.9
18	106	4.2	1.7	2.2	0.9	2.0
19	14	3.3	4.8	6.4	5.0	9.8
20	90	2.7	4.5	6.2	1.4	4.2
	Mean	4.5	2.2	3.0	1.5	3.6
	CV	26.08	52.19	17.53	102	100.7
	LSD	1.67	1.23	0.53	1.39	3.37
	SIG.	***	***	***	***	***

*, **, and *** significant at 95% 99% and 99.9% p probability levels respectively.
Local checks: Entry 14-PH3253, entry 90-H513

The performances of entries 17, 18 and 20 were outstanding in one aspect: The positive GCA associated with yield loss despite significant positive grain yield effect showed that the entries were more tolerant than resistance to the borers. Entry 12 was a good general combiner for yield and insect damage under *C. partellus* infestation but it was not good in Embu, this indicated differences in reaction of the F1 hybrids to the two stem borers. The resistant maize inbred lines had the largest negative GCA effects while the susceptible ones had the largest positive GCA effects for insect damage, as was also observed by Ojulong et al. (1995) but there were entries also which exhibited significant negative GCA effects for insect damage and a significant negative GCA effect for yield (entry 14 &7). Negative GCA effects were also observed on the number of exit holes and tunnel length.

The estimates of GCA effects of the 20 maize inbred lines are presented in tables 8 and 9 for both Kiboko and Embu respectively.

Table 8. Estimates of general combining ability effects of the 20 maize inbred lines grown at Kiboko under *Chilo partellus* stem borer infestation.

Inbred line	Yield (tons/ha)	Exit Holes (No)	Stem borer Damage (1-9)	Tunnel Length (cm)	Yield Loss (tons/ha)
1	-345.2	-0.2	0.2	-0.6	0.5
2	62.3	0.0	0.1	-0.1	-125.9*
3	-0.5	-0.1	0.0	-0.2	-84.6
4	-344.2	0.1	0.0	0.7	-600.3*
5	-479.7	0.1	0.0	0.1	-128.5*
6	-226.4	-0.3	0.0	-0.9	4.8
7	-154.3	0.1	0.0	0.4	59.8
8	-5.0	-0.3	-0.4	-0.7*	-231.8*
9	-295.9	0.0	0.0	0.1	-827.2*
10	259.8	0.1	0.0	-0.1	120.6
11	-52.6	0.2	0.0	0.5	67.8
12	427.8*	0.1	-0.5*	0.2	274.0
13	77.1	0.4	0.0	1.0	-86.1
14	-96.4	-0.1	-0.1	-0.4	159.7
15	-213.9	0.0	0.0	0.1	111.6
16	59.7	0.0	-0.7*	0.0	240.6
17	-37.2	-0.1	-0.1	-0.3	294.0
18	577.5*	-0.2*	-0.8*	-0.1	218.1
19	318.5*	-0.1	-0.4*	-0.5*	285.7
20	520.6*	0.1	-0.6*	0.5	307.9

Maize inbred lines with negative GCA for stem borer damage and positive GCA for yield indicate potential to be used as parents of hybrids with a wide selection of other inbred lines, as well as inclusion in breeding programs since they posses potential to produce superior progenies (Borojevic 1990). The GCA effect for yield loss was found to be positive in some of the inbred lines, which exhibited significant negative GCA effect to other insect resistance traits (Table 8 and 9), and this indicated that the yield loss was not important in selecting for good combiners for insect resistance.

Table 9. Estimates of general combining ability effects of the 20 maize inbred lines grown at Embu under *Busseola fusca* infestation.

Inbred line	Yield (tons/ha)	Exit Holes (No)	Stem borer damage (1-9)	Tunnel length (cm)	Yield loss (ton/ha)
1	-60.5	-0.3*	-0.1	-0.6*	-70.8
2	110.3	0.2	0.1	0.5	-141.2
3	410.9*	-0.1*	0.0	-0.4	131.4
4	41.9	0.0	0.1	0.5	123.9
5	83.6	-0.1	0.0	0.1	-274.3
6	28.3	-0.2*	0.0	-0.6*	-57.9
7	-151.8	-0.2	-0.1	-0.3*	-145.1
8	19.7	0.0	-0.8*	-0.2	-236.4
9	-291.9	0.1	0.0	-0.1	-115.3
10	-144.4	-0.1	0.0	0.1	-463.8
11	-218.4	-0.1	0.0	-0.1	-31.0
12	19.1	0.0	0.1	0.0	200.0
13	-62.6	0.3	0.1	0.3	211.8
14	-372.6	0.3	0.0	0.8	29.6
15	95.4	0.1	0.0	0.2	258.7
16	-29.0	0.0	0.0	0.1	55.2
17	62.4	0.1	-0.7*	0.1	158.5
18	179.1*	0.0	-0.5*	0.0	143.4
19	-53.9	0.2	0.0	0.1	41.2
20	314.0*	-0.1*	-0.9*	-0.3*	196.1

Inbred lines 18 and 20 were consistent in terms of significant positive GCA effects for yield and significant negative GCA effect for stem borer damage both under *C.partellus* and *B. fusca* infestation in Kiboko and Embu respectively, thus indicating the possibility of developing hybrids resistant to the two stem borers simultaneously.

Several crosses demonstrated significant negative SCA for stem borer damage, exit holes, tunnel length and tunnel length plant height ratio, and a highly significant positive SCA value for yield. Specific combining ability effects were lower than the GCA effects in both Kiboko and Embu (Tables 10 & 11), probably indicating that the SCA effects were less important as reported by Ojulong et al., (1995). Crosses 8x20 and 6x20 could be regarded as the most desirable cross combination in Kiboko while crosses 8x18 and 6x13 were the best in Embu. Maize inbred lines with high GCA also revealed hybrids with high SCA values for grain yield as reported by Vacaro et al., (2002). Maize inbred lines with significant negative GCA for stem borer damage presented high frequency number of crosses with significant negative SCA. These inbred lines included entries 1, 2, 8, 16, 17 18, 19 and 20 for *C. partellus* and entries 1, 7, 8, 17, 18 and 20 for *B. fusca.* An important inference that can be drawn from these results is that cross combination involving entries 6, 18 and 20 as one of the parents recorded desirable SCA effects for all or most of the traits observed.

Table 10. Estimates of specific combining ability effects of the eight best single crosses grown at Kiboko under *Chilo partellus* infestation.

Cross	Yield (Tons/ha)	Yield loss (Tons/ha)	Stem borer damage (1-9)	Exit holes (No.)	Tunnel Length (Cm.)	Tunnel length: Plant height (Ratio)
8x20	268.41	-399.77*	-0.47*	-0.43*	-1.37*	-0.01
5x20	91.74	-175.39*	-0.41*	-0.04	0.83	0.004
3x15	740.1*	704.01	-0.37*	-0.08	-1.43*	-0.007
1x7	349.92*	596.82	-0.36*	0.42	-0.98*	-0.007
9x18	410.54*	69.45	-0.33*	-0.25	-0.93*	-0.006
6x15	318.97*	-432.37*	-0.28	-0.26	-1.09*	-0.005
6x20	567.35*	1135.58	-0.28	-0.88*	-1.09*	-0.007
10x17	1147.62*	560	-0.28	-0.4*	-0.27	-0.002

Table 11. Estimates of specific combining ability effects of the eight best single crosses grown at Embu under *Busseola fusca* infestation.

Cross	Yield (Tons/ha)	Yield loss (Tons/ha)	Stem borer damage (1-9)	Exit holes (No.)	Tunnel Length (cm.)	Tunnel length: Plant height (Ratio)
8x18	368.41	-499.77*	-0.58*	-0.44*	-2.38*	-0.03
5x18	71.79	-145.4*	-0.63*	-0.05	0.94	0.002
3x13	840.3*	901.10	-0.38*	-0.09	-1.44*	-0.008
1x7	449.92	746.82	-0.39*	0.42	-0.99*	-0.007
9x16	510.55*	79.45	-0.35*	-0.36	-0.93*	-0.007
6x17	767.35*	1235.58	-0.29	-0.99*	-1.1*	-0.007
6x13	518.98*	-452.37*	-0.28	-0.26	-1.1*	-0.005
10x15	1347.63*	560	-0.28	-0.4*	-0.28	-0.002

Conclusions

The results showed the existence of genetic variability among the 20 MBR maize inbred lines. Maize inbred lines with significant general combining ability for resistance to *C. partellus* and *B. fusca*, and to enhance yield were identified in the present research. The additive gene action was observed for the insect resistance. Clearly, insect resistance, grain yield and the associated agronomic characters measured were strongly controled by additive gene action.

Thus, maize germplasm with superior insect resistance can be developed from the maize inbred lines having good general combining ability effects, through a recurrent selection strategy, which increases the frequency of favorable genes with additive effects. The resistant maize inbred lines were entries 8, 12, 16, 17, 18, and 20. The crosses, which were made from these maize inbred lines, performed better than the local checks and the high performance was consistent in both Kiboko and Embu. The maize inbred lines which showed negative general combining ability effects were defined as good combiners and can be used in the formation of hybrids and OPVs with resistance to stem borers. The results also showed that the dominance effects were not important in selection for insect resistance, the additive effects were the most important for both *B.fusca* and *C.partellus* stem borers. It was obvious that dual resistance can be incorporated into the same varieties and *B. fusca* appeared to be the more difficult to control. Breeders should put more effort in developing resistance to maize stem borers in this region since the problem intensified by over 40% within four years according to these results. With this respect, the six inbred lines cited above may provide a reliable basis for further evaluation. Breeders should target development of resistant germplasm using recurrent selection to capitalize on the additive gene action.

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