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# Combining Ability of Inbred Lines of Maize (*Zea mays*) in Kiambu and Embu Counties, Kenya

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***Authors' contributions***

*This work was carried out in collaboration between all authors. Author JMK designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors FMN and PKL were the research supervisors. Authors JMK and DWM read the first manuscript. Authors FMN and PKL managed the literature searches. Authors JMK and DWM managed the analyses of the study performed. All authors read and approved the final manuscript.*

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## ABSTRACT

Despite the fact that virtually all households in Kenya grow maize, over 60% of them are net maize buyers because they do not produce enough for their consumption. This is due to both biotic and abiotic factors such as poor planting materials, diseases and unreliable weather among others. This study was conducted to select lines with good combining ability. The trials were conducted in 2012 at experimental stations of Kenya Agricultural and Livestock Research Organization (KALRO) Muguga South and Embu in Kiambu and Embu counties of Kenya respectively. The study was conducted with 18 inbred lines. The experiment was laid out in a 6 x 6 lattice incomplete randomized block design with two replications. In Embu inbred line POPA produced the best grain yields when crossed with MUL 541 and MUL 521. Its high grain yield was also witnessed in Muguga where on average its performance was superior to other inbred lines. Inbred line MUL 513 can further be evaluated for grain yield improvement with all the other inbred lines which had high

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grain yields. The best general combiners for grain yield were MUL 508, MUL 688, POP A, MUL 541, MUL 513 and MUL 114. POP A x MUL 541 produced the highest yield of 0.49 t/ha. Based on SCA estimates, the best cross combinations for plant height were MUL 508 x MUL 688, POP A x MUL541 and MUL513 x MUL114. For ear height best cross combinations were: MUL 508 x MUL 688, POP A x MUL 141, POP A x MUL 541 and MUL 513 x MUL 114. The best combinations for grain yield were MUL 508 x MUL 688, POP A x MUL 541 and MUL 513 x MUL 114. Crosses MUL508 x MUL 521, MUL 541 x MUL 508, and MUL 688 x MUL508 were good combinations for MSV disease resistance since in both research sites they had an MSV score of 1. For grain yield improvement on specific combining ability crosses MUL 508 x MUL 688, POP A x MUL 141, MUL 513 x MUL 114 and MUL 513 x CN244 can further be evaluated and eventually released to farmers as they indicated promising relationship with yield potential compared to other crosses. Crosses MUL 508 x MUL 516, POP A x MUL 141 and POP A x MUL 688 can further be evaluated for disease resistance. The results will be useful to breeders and farmers in selecting the potential parental materials for improvement in maize breeding programs.

*Keywords: Combining ability; inbred line; positive; negative; estimates; combiner.*

## 1. INTRODUCTION

Maize (*Zea mays*) also known as corn is an economically important crop worldwide and particularly in Africa where the annual production exceeds that of wheat and other important staple crops. Combining ability is of special importance in cross pollinated crops like maize because it helps in identifying potential inbred parents with hybrid vigor. Utilization of heterosis for genetic improvement of different traits and combining ability are fundamental tools for enhancing productivity in the form of filial one hybrid [1]. Farmers require high yielding maize hybrids with stable grain yield across environments that differ in terms of biotic and abiotic stress factors.

Heterosis increases yield potential and improves adaptation to stress in maize, however the underlying mechanism of heterosis and combining ability remains elusive [2]. A wide range of natural genetic diversity has been captured in the current maize germplasm [3,4].

The concept of general combining ability and specific combining ability (GCA & SCA) was introduced by Sprague and Tatum [5] and its mathematical modeling was set about by Griffing [6] in his classical paper in conjunction with the diallel crosses. The value of any population depends on its potential and it's combining ability in crosses [7]. The average performance of a particular inbred in a series of hybrid combinations is known as its general combining ability while specific combining ability refers to the performance of a combination of two specific inbred lines in a particular cross [8]. Maize displays an orderly sequence of development of yield component namely; number of cobs per plant, number of rows per cob, number of kernels per row and kernel weight [9,10,11,12,13] reported that GCA and SCA effects were highly significant but GCA effects on 100 grain weight under high temperature condition was non-significant. The use of diallel crosses to study genetic control of trait and to select parents to obtain synthetics or hybrids is frequent in maize breeding [14,15,16]. This study was conducted to evaluate the effects of GCA and SCA of the inbred lines using complete diallel scheme. The results in this study will be useful to maize breeders and farmers in selecting the potential parental materials for improvement in maize breeding programs in Kenya.

## 2. MATERIALS AND METHODS

### 2.1 Study Site

Field trials were grown at the KALRO experimental stations in Kiambu and Embu counties, during the long rain growing season from March to September 2012.

### 2.2 Study Materials

The germplasm used in the study were 18 inbred lines and their respective single crosses derived from KALRO, Muguga. The inbred lines were white, tropical lines and were rain fed throughout the growing season. The sets were without reciprocals (Table 1).

### 2.3 Experimental Layout

The experiment was laid out in a 6 x 6 lattice design consisting of 6 blocks with two replication in each site. Each block had 6 plots making a total of 36 plots in each replication. The distance from each block to the other was 1 meter and from one replication to the other was 2 meters. The plots consisted of 3 rows of 11 hills each at a spacing of 75 cm inter row and 25 cm between hills. Planting at Muguga was done on 10/4/2012 and in Embu on 14/4/2012 at the onset of the long rains. Two seeds were planted per hill but later thinned to leave one plant per hill. The plot area measured 5.55 $m^2$ (0.75 m x 3 rows) x (0.3 x 11 plants) and had a population of 33 plants, giving a total population of 53333 plants per $ha^{-1}$ (Fig. 1).

## 2.4 Data Collection

Data was collected during growth period and after attainment of physiological maturity. The data was recorded on 12 randomly picked plants from each plot. The pre-harvest data included plant height, ear height, grey leaf spot and maize streak virus disease scores while post -harvest data was grain yield per hectare.

## 2.5 Data Analyses

The data was subjected to analysis of variance (ANOVA) using Genstat 12 program for individual test crosses as well as for combined environments considering environments as random effects and crosses as fixed effects.

**Table 1. Inbred lines and their respective crosses used in the study**

| Sets | Entry | Crosses | Grain texture |
|---|---|---|---|
| 1 | 1 | MUL 508X MUL 516 | INT |
| | 2 | MUL 508 X MUL 521 | FL |
| | 3 | MUL 508 X MUL141 | FL |
| | 4 | MUL 508 X MUL 541 | FL |
| | 5 | MUL 508 X MUL 688 | INT |
| | 6 | MUL 508 X CN 244 | FL |
| 2 | 7 | POP A X MUL 511 | INT |
| | 8 | POP A X MUL 521 | INT |
| | 9 | POP A X MUL 114 | INT |
| | 10 | POP A X MUL 141 | INT |
| | 11 | POP A X MUL 536 | INT |
| | 12 | POP A X MUL 541 | FL |
| | 13 | POP A X MUL 688 | INT |
| 3 | 14 | MUL 513 X MUL 531 | FL |
| | 15 | MUL 513 X MUL 533 | FL |
| | 16 | MUL 513 X MUL 114 | INT |
| | 17 | MUL 513 X CN 244 | INT |
| | 18 | MUL 513X MUL 516 | FL |

*FL Flint, INT Intermediate between Flint and Dent*

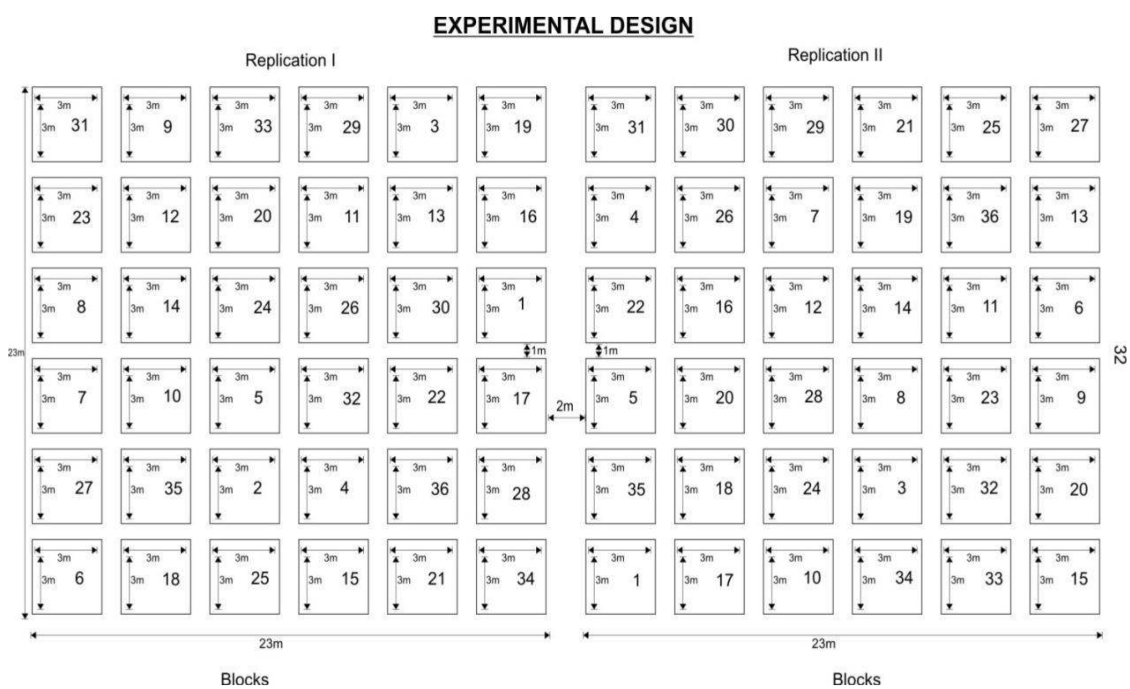


**Fig. 1. Experimental design (randomized incomplete block design)**

Mean separation was done using Tukey's comparison method at 0.05% significance level. Combining ability was estimated using Griffing (1956) analysis method, model 1 expressed as:

$$Xij = u + gi + gj + sij + e$$

where:

*u* was the overall mean of all entries in the diallel design
*gi* is the general combining ability of the *ith* parent
*gj* was the general combining ability of the *jth* parent
*sij* was the specific combining ability between the *ith* and *jth* parent
*e* was the error.

## 3. RESULTS

### 3.1 Mean Performance on Different Morphological Traits in KALRO Embu

The analysis of variance (ANOVA), showing the mean squares of plant height (PH),ear height (EH), disease scores of maize streak virus (MSV) disease, grey leaf spot (GLS), and grain yield (GY) for Embu are shown in Table 2. The crosses showed a highly significant difference ($p < 0.001$) for plant height and ear height. They also showed a significant difference ($p<0.05$) on grain yield.

### 3.2 Mean Performance in KALRO Muguga

The analysis of variance (ANOVA) for plant height, ear height, disease scores for MSV and GLS and grain yield for Muguga shown in Table 3 showed significant ($p<0.05$) difference for plant height, ear height and GLS, while there was no significant difference on MSV and grain yield on the crosses in Muguga (Table 3).

General combining ability analysis revealed significant difference on plant height, ear height and grain yield. Data on GCA (Table 4) revealed that set one where MUL 508 was used the GCA range on grain yield was -0.8 to 0.5 t/ha, when POP A was used the GCA range on grain yield was -0.09 to 0.21 t/ha, while when inbred line MUL 513 was used the GCA range on grain yield was -0.18 to 0.62 t/ha. Data (Table 4) showed that inbred line MUL 508 had positive significant ($p<0.05$) GCA for ear height when crossed with inbred line MUL 541, it also showed a positive significant GCA for grain yield when crossed with inbred line MUL 688. Inbred line MUL508 further showed a positive significant GCA for GLS disease resistance when crossed with inbred line CN 244 (Table 4). Data for set two showed inbred line POP A had a negative GCA -1.71 and -1.57 for plant height and ear height respectively when crossed with MUL 511, however there was positive GCA with grain yield 0.21, MSV disease resistance 0.31 and GLS disease resistance 0.71 (Table 4). The data further showed that when POP A was

**Table 2. Performance of for different morphological traits in KALRO Embu**

| | | Mean sum of squares | | | | |
|---|---|---|---|---|---|---|
| **Source of variation** | **Df** | **PH (cm)** | **EH(cm)** | **MSV** | **GLS** | **GY( t/ha)** |
| Replication | 1 | 6290.7 | 660.1 | 10.889 | 27.5035 | 3.19 |
| Genotype | 35 | 2047.7** | 1221.8** | 2.2 | 0.5527 | 4.02* |
| Error | 35 | 175.8 | 169 | 1.203 | 0.5035 | 1.74 |
| Overall mean | | 185 | 99.5 | 1.00 | 1.44 | 2.68 |
| CV% | | 7.1 | 4.3 | 5.5 | 49.4 | 7.2 |

**,** Significant at (p<0.05), and (p<0.001) respectively, PH-plant height, EH-ear height, MSV-maize streak virus, GLS-grey leaf spot, GY-grain yield, CV%-Coefficient of variation*

**Table 3. Performance for different morphological traits in Muguga**

| | | Mean sum of squares | | | | |
|---|---|---|---|---|---|---|
| **SV** | **Df** | **PH(cm)** | **EH(cm)** | **MSV** | **GLS** | **GY(t/ha)** |
| Replication | 1 | 19 | 32 | 0.0868 | 0 | 1.488 |
| Genotype | 35 | 2175.9** | 796.8** | 0.1725 | 0.2865** | 11.536 |
| Error | 35 | 362.4 | 115.7 | 0.2225 | 0 | 8.215 |
| Overall mean | | 214 | 79.9 | 1.16 | 1.94 | 4.84 |
| CV% | | 0.3 | 1.2 | 4.2 | 0 | 4.2 |

****** *Significant at (p<0.05), PH- Plant height, EH- Ear height, MSV-Maize streak virus, GLS- Grey leaf spot, GY-Grain yield, CV%-Coefficient of variation*

**Table 4. Estimates of G.C.A effects for inbred lines for yield and yield components for Embu and Muguga sites combined**

| Sets | Inbred lines | PH(CM) | EH(CM) | GY(T/HA) | Msvscores | GLS scores |
|---|---|---|---|---|---|---|
| MUL 508 | MUL 516 | 34.17 | 19 | -0.8 | 0.42 | 1.24 |
| | MUL 521 | 32.17 | 16 | 0.5 | 0.28 | 1.52 |
| | MUL 141 | -17.83 | -14 | 0.1 | -0.12 | -0.36 |
| | MUL 541 | 6.17 | 0.0** | 0.5 | -0.12 | 0.61 |
| | MUL 688 | 57.93 | -26 | 0.0** | 0.08 | -2.99 |
| | CN 244 | 3.17 | 0.5 | -0.3 | 0.28 | 0.01* |
| POP A | MUL 511 | -1.71 | -1.57 | 0.21 | 0.31 | 0.71 |
| | MUL 521 | -13.71 | 2.43 | -0.09 | -0.29 | -0.34 |
| | MUL 114 | 38.29 | 29.43 | -0.29 | -0.19 | 1.22 |
| | MUL 141 | -4.71 | -14.57 | -0.09 | 0.11 | -0.31 |
| | MUL 536 | -12.71 | -6.57 | -0.19 | -0.09 | -0.29 |
| | MUL 541 | -24.71 | -14.57 | 0.21 | 0.31 | -2.62 |
| | MUL 688 | 19.29 | 5.43 | 0.21 | -0.19 | 1.66 |
| MUL 513 | MUL 531 | 13 | 7.8 | 0.18 | -0.28 | 1.16 |
| | MUL 533 | 19 | 17.8 | 0.38 | 0.28 | 0.91 |
| | MUL 114 | -29 | -23.2 | -0.12 | 0.28 | -1.3 |
| | CN 244 | -25 | -12.2 | 0.62 | -0.02* | -0.67 |
| | MUL 516 | 22 | 9.8 | -0.18 | -0.32 | -0.06 |

**,** Significant at p< 0.05 and p<0.001 levels respectively,*
*PH=Plant height, EH= Ear height, GY=Grain yield, MSV=Maize streak virus disease, GLS=Grey leaf spot*

crossed with inbred line MUL 521 there was negative GCA in all the traits except ear height which had positive GCA of 2.43 cm. Further negative GCA was seen when the inbred line POP A was crossed with inbred line MUL 536 in all the traits studied, however with inbred line MUL 688 there was positive GCA for all traits except for MSV disease resistance (-0.19). When inbred line MUL 513 in set three was crossed with inbred line MUL 531 there was a negative GCA for MSV resistance (-0.28) but a positive GCA for all the other traits. The data also showed positive GCA for all the traits when POP A was crossed with MUL 533 (Table 4).

**Table 5. Estimates of S.C.A effects for inbred lines for yield and yield components for Embu and Muguga sites combined**

| Sets | Crosses | PH(CM) | EH(CM) | GY(T/ha) | MSV(Scores) |
|---|---|---|---|---|---|
| 1 | MUL508XMUL516 | -8.33 | -4.75 | -0.31 | 0.16 |
| | MUL508XMUL521 | -8.08 | -4.00 | -0.38 | -0.16 |
| | MUL508XMUL141 | 4.42 | 3.50 | 0.09 | 0.06 |
| | MUL508XMUL541 | -1.58 | 0.0** | -0.15 | -0.14 |
| | MUL508XMUL688 | 14.42 | 6.5 | 0.75 | 0.04* |
| | MUL508XCN244 | -0.83 | -1.25 | 0.0** | 0.04* |
| 2 | POPAXMUL511 | -0.31 | 0.17 | -0.18 | -0.06 |
| | POPAXMUL521 | 2.09 | -0.63 | 0.03* | -0.06 |
| | POPAXMUL114 | -8.31 | -6.03 | -0.28 | 0.12 |
| | POPAXMUL141 | 0.29 | 2.77 | 0.03* | 0.14 |
| | POPAXMUL536 | 1.89 | 1.17 | 0.02* | 0.00** |
| | POPAXMUL541 | 4.29 | 2.77 | 0.49 | -0.06 |
| | POPAXMUL688 | 0.09 | -0.23 | -0.12 | -0.06 |
| 3 | MUL513XMUL531 | -3.6 | -1.93 | -0.32 | -0.08 |
| | MUL513XMUL533 | -5.6 | -5.26 | -0.23 | -0.15 |
| | MUL513XMUL114 | 10.4 | 8.40 | 0.51 | 0.02* |
| | MUL513XMUL516 | 9.1 | 4.74 | 0.28 | 0.19 |
| | MUL513XCN244 | -10.3 | -5.93 | -0.22 | 0.02* |

***,* Significant at p< 0.001 and p< 0.05 respectively*
*PH=Plant height (cm), EH=Ear height (cm), GY=Grain yield (t/ha), MSV=Maize Streak Virus, GLS=Grey Leaf Spot*

Data on specific combining ability (SCA) (Table 5) showed that there was a significant (p<0.05) difference between the inbred lines in the three sets on grain yield. The SCA range on grain yield in set one where MUL 508 was used was -0.15 to 0.75 t/ha, when POPA was used the SCA range on grain yield was -0.28 to 0.49 t/ha while for inbred line MUL 513 the SCA range was -0.32 to 0.51 (Table 5). Data on grain yield in set one showed a positive SCA on cross MUL 508 x MUL 141 (0.09) and MUL 508 x MUL 688 (0.75) (Table 5). Data further showed a positive SCA in set two on cross POP A x MUL 521(0.03), POP A x MUL 141 (0.03), POP A x MUL 536 (0.02) and POP A x MUL 541 (0.49) on grain yield (Table 5). Further the data showed a positive SCA on yield on crosses MUL 513 x MUL 114 (0.05) and MUL 513 x MUL 516 (0.28).

### 3.3 Performance of Crosses on Both Research Environments Embu and Muguga

Data comparing the mean plant height for the two environments Embu and Muguga revealed that there was a significant (P<0.001) difference on site and also on the crosses performance (Table 6).

Data on mean ear height in the two environments showed that there was a significant P< 0.001 difference between the site and crosses performance (Table 7).

Data on MSV disease score showed a significant P<0.001 difference on the crosses (Table 8), however there was no significant P>0.05 difference on the sites for MSV disease score.

Data on mean grey leaf spot scores showed there was significant (P≤ 0.05) difference among genotypes in the two research sites Embu and Muguga (Table 9).

Data on grain yield for the sampled crosses in both environments Embu and Muguga showed there was significant (P < 0.05) difference in grain yield (t/ha) between the research sites (Table 10).

## 4. DISCUSSION

Data on combining ability where set 1, 2 and 3 (MUL 508, POP A and MUL 513) were crossed in diallel system showed the significant GCA and SCA variances for majority of the traits. This indicated the importance of both additive and non-additive gene actions in the expression of these traits. Diallel mating systems have provided genetic understanding for a chosen set of parents [17] and have been used to study various traits in many crops. Positive GCA deviation for yield indicated high yield potential as seen in cross MUL 508 x MUL 521 (0.5) and POP A x MUL 688 (0.21) (Table 5), while positive GCA values for disease scores indicated vulnerability to disease (Table 5). These observations were in line with those of [18], who observed that GCA and SCA variances were highly significant for yield and yield attributing traits which indicated the importance of both additive and non-additive gene action.

There was a significant difference among GCA and SCA effects on ear height but this trait was highly influenced by the additive effect since GCA contributed highest percentage to the crosses sum squares. MUL 508 showed significant (p<0.05) difference when crossed with MUL 541 for ear height and grain yield. Most of the SCA estimates were non –significant, further indicating that performance of crosses for ear height was dependent on GCA effects (Table 5). Predominance of additive genetic effects in influencing ear height has been reported previously [19,20]. Inbred line MUL 508 showed significant (P<0.05) difference when crossed with MUL 141, MUL 541, MUL 688 and CN 244 for GLS disease. MUL 508 also showed a highly significant (p<0.001) difference when crossed with CN 244 for GLS disease scores.

**Table 6. Performance of crosses on plant height in KARLO Embu and KALRO Muguga environments**

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Rep | 1 | 2809.0 | 2809.0 | 8.9 | |
| Env | 1 | 30044.4 | 30044.4 | 95.5 | <.001 |
| Genotype | 35 | 131972.6 | 3770.6 | 12.0 | <.001 |
| Env/Genotype | 35 | 15852.6 | 452.9 | 1.4 | 0.097 |
| GCA | 17 | 116.35 | 58.175 | 70.175 | |
| SCA | 35 | 0.05* | 0.00361* | 207.5 | |
| Residual | 123 | 22336.0 | 314.6 | | |

**Table 7. Performance for ear height in Embu and Muguga environments**

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Rep | 1 | 200.7 | 200.7 | 1.4 | |
| Env. | 1 | 13806.3 | 13806.3 | 93.8 | <.001 |
| Crosses | 35 | 63608.8 | 1817.4 | 12.3 | <.001 |
| Env/Crosses | 35 | 7041.2 | 201.2 | 1.4 | 0.133 |
| GCA | 17 | 4.49 | 2.245 | 200.265 | |
| SCA | 35 | 0.01* | 0.000278* | 207.01 | |
| Residual | 123 | 10456.3 | 147.3 | | |

**Table 8. Performance of crosses for MSV disease scores for Embu and Muguga environments**

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Rep | 1 | 0.16 | 0.16 | 0.03 | |
| Env. | 1 | 17.57 | 17.57 | 3.53 | 0.064 |
| Crosses | 35 | 377.41 | 10.78 | 2.17 | 0.003* |
| Env/Crosses | 35 | 167.04 | 4.77 | 0.96 | 0.542 |
| GCA | 17 | 0.75 | 0.365 | 207.75 | |
| SCA | 35 | 0.1 | 0.000556* | 207 | |
| Residual | 123 | 352.96 | 4.97 | | |

**Table 9. Performance on GLS scores at Embu and Muguga research sites**

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Rep | 1 | 4.516 | 4.516 | 5.690 | |
| Env. | 1 | 0.918 | 0.918 | 1.160 | <.001 |
| Crosses | 35 | 37.769 | 1.079 | 1.360 | 0.286 |
| Env/Crosses | 35 | 45.269 | 1.293 | 1.630 | 0.041* |
| GCA | 17 | 0.09 | 0.05* | 207.09 | |
| Residual | 88 | 56.359 | 0.794 | | |

**Table 10. Performance of crosses for grain yield at Embu and Muguga research sites**

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Rep | 1 | 13.14 | 13.14 | 27.86 | |
| Env. | 1 | 15.02 | 15.02 | 31.84 | <.001 |
| Crosses | 35 | 9.55 | 0.27 | 0.58 | 0.961 |
| Env/Crosses | 35 | 11.67 | 0.33 | 0.71 | 0.869 |
| GCA | 17 | 0.85 | 0.425 | 207.85 | |
| SCA | 35 | 0.07 | 0.000278 | 207 | |
| Residual | 123 | 33.48 | 0.47 | | |

## 5. CONCLUSIONS AND RECOMMENDATIONS

GCA effects showed that inbred line MUL 513 was a good general combiner for grain yield, ear height and plant height. Inbred line POPA was a good general combiner for grain yield. Based on SCA estimates, the best cross combinations for plant height were MUL 508 x MUL 688, POP A x MUL 541 and MUL 513 x MUL 114. For ear height best cross combinations were: MUL 508 x MUL 688, POP A x MUL 141, POP A x MUL 541 and MUL 513 x MUL 114. The best combinations for grain yield were MUL 508 x MUL 688, POPA x MUL 541 and MUL 513 x MUL 114. Inbred line MUL 513 showed positive GCA for plant height, ear height, and grain yield and a negative GCA for MSV when crossed with inbred line MUL 531, MUL 533 and CN244, showing additive genes were more predominant. These traits can be chosen as superior characteristics to help improve maize grain yield. Inbred lines MUL 508, POP A and MUL 513 can be used in improving other genotypes on disease resistant trait.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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