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# Combining ability and heterosis for grain yield and its components in maize inbreds over environments (*Zea mays* L.)

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**Twelve inbred lines were crossed with each of five testers in a line × tester design to evaluate combining ability and heterosis to identify promising hybrids of maize for various characters like, 50% tasseling, 50% silking, 75% dry husk, ear length, ear diameter, kernels per ear, kernel rows per ear, 1000 kernel weight and grain yield. The resulting $F_1$s along with three checks and the parents were evaluated in two environments during *kharif* 2010 and *rabi* 2010 to 2011. Pooled analysis of variance revealed highly significant differences among the genotypes. Crosses excelled their perspective parents in performance for most of the traits studied. $L_9$ among the parental lines and $T_2$ among the testers were identified as the best general combiner for grain yield. Whereas among the hybrids, ($L_6 \times T_5$) was identified as a potential cross combination for grain yield while the cross ($L_9 \times T_2$) recorded highest magnitude of economic heterosis of 84.60% over the best standard check (Vivek hybrid-9). So the crosses ($L_6 \times T_5$) and ($L_9 \times T_2$) can be utilized for developing high yielding hybrid varieties as well as for exploiting hybrid vigor.**

**Key words:** Combining ability analysis, heterosis, line × tester, maize (*Zea mays* L.).

## INTRODUCTION

Maize (*Zea mays* L.) is the world's most widely grown cereal and is the primary staple food in many developing countries (Morris et al., 1999). It is a versatile crop with wider genetic variability and able to grow successfully throughout the world covering tropical, subtropical and temperate agro-climatic conditions. Maize acreage and production have an increasing tendency with the introduction of hybrids due to its high yield potential.

Efforts are, therefore, required to be made to develop hybrids with high yield potential in order to increase production of maize. Most efficient use of such materials would be possible only when adequate information on the amount and type of genetic variation and combining ability effects in the materials is available. Heterosis and combining ability is prerequisite for developing a good economically viable hybrid maize variety. Combining ability analysis is useful to assess the potential inbred lines and also helps in identifying the nature of gene action involved in various quantitative characters. This information is helpful to plant breeders for formulating hybrid breeding programmes. Information on the heterotic patterns and combining ability among maize germplasm is essential in maximizing the effectiveness of hybrid development by Beck et al. (1990). In maize, appreciable percentage of heterosis for yield and combining ability were studied by several workers like, Roy et al. (1998), Paul and Debnath (1999) and Rokadia and Kaushik (2005). A wide array of biometrical tools is available to breeders for characterizing genetic control of economically important traits as a guide to decide upon an appropriate breeding methodology to involve in hybrid breeding. Line × tester mating design developed by

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**Table 1.** Pooled analysis of variance (MS) of combining ability for different traits in a line × tester cross of maize.

| Source of variation | Degree of freedom | Days to 50% flowering | Days to 50% silking | Days to 75% dry husk | Ear length (cm) | Ear diameter (cm) | Kernels/ear | Kernel rows/ear | 1000 Kernel weight (g) | Grain yield (q/ha) |
|---|---|---|---|---|---|---|---|---|---|---|
| Replicates | 2.00 | 3.05* | 1.68 | 11.02* | 0.15 | 0.01 | 498.63* | 0.14* | 148.81 | 73.37** |
| Environments | 1.00 | 397936-0.00** | 399400.22** | 319634.81** | 125.79** | 8.27** | 332685.44** | 36.42** | 82053.41** | 200052.73** |
| Rep * Env. | 2.00 | 7.09** | 9.43** | 6.67 | 0.18 | 0.01 | 131.59 | 0.03 | 74.72 | 25.21 |
| Crosses | 59.00 | 45.00** | 49.47** | 20.90** | 2.98** | 0.14** | 7763.12** | 2.00** | 4184.06** | 402.15** |
| Line effect | 11.00 | 111.76** | 105.37** | 31.85** | 9.97** | 0.43** | 10161.25 | 2.21 | 11263.73** | 914.16** |
| Tester effect | 4.00 | 171.17** | 199.50** | 90.81** | 2.73 | 0.12 | 12578.00 | 2.25 | 538.90 | 118.88 |
| Line * Tester effect | 44.00 | 16.84** | 21.85** | 11.80** | 1.25** | 0.07** | 6725.87** | 1.92** | 2745.52** | 299.90** |
| Env * Crosses | 59.00 | 20.25** | 21.29** | 16.31** | 4.31** | 0.22** | 6020.71** | 1.04** | 32.25 | 156.32** |
| Env * Line effect | 11.00 | 49.73** | 48.39** | 39.03** | 16.03** | 0.74** | 10786.79* | 1.61 | 69.94** | 457.42** |
| Env * Tester effect | 4.00 | 38.96* | 40.79* | 47.05** | 3.76* | 0.09 | 5899.26 | 0.88 | 12.49 | 100.07 |
| Env * L * T effect | 44.00 | 11.17** | 12.75** | 7.83** | 1.43** | 0.10** | 4840.23** | 0.91** | 24.62 | 86.16** |
| Error | 236.00 | 0.83 | 0.92 | 2.42 | 0.08 | 0.01 | 135.22 | 0.04 | 107.88 | 13.38 |
| $\sigma^2$ gca | - | 3.41 | 3.22 | 0.97 | 0.30 | 0.01 | 310.48 | 0.07 | 344.17 | 27.93 |
| $\sigma^2$ sca | - | 10.29 | 13.35 | 7.21 | 0.76 | 0.04 | 4,110.25 | 1.18 | 1,677.82 | 183.27 |

** = $P < 0.01$; * = $P < 0.05$.

Kempthorne (1957), which provides reliable information on the general and specific combining ability effects of parents and their hybrid combinations was used to generate the information. The design has been widely used in maize by several workers like, Joshi et al. (2002) and Sharma et al. (2004) and continues to be applied in quantitative genetic studies. The present investigation was carried out to determine the nature and magnitude of gene action and heterosis for yield and other important traits in maize (*Zea mays* L.) over two environments.

## MATERIALS AND METHODS

The basic material for the present study comprised 17 parents that is, twelve diverse , vigorous and productive maize (*Zea mays* L.) inbred lines viz., $L_1$, $L_2$, $L_3$, $L_4$, $L_5$, $L_6$, $L_7$, $L_8$, $L_9$, $L_{10}$, $L_{11}$ and $L_{12}$ and five well adapted testers of varying genetic base viz., $T_1$, $T_2$, $T_3$, $T_4$ and $T_5$. These were crossed in line × tester mating design during *kharif* 2010 and *rabi* 2010 to 2011 at B. A. U research farm, ranchi to generate 60 hybrids. These 60 hybrids and seventeen parental lines with three standard checks viz., HQPM-1, Vivek Hybrid-9 and Suwan were grown in a randomized block design in three replications. Each entry was sown in two rows having 70 × 25 cm crop geometry in two environments. All the characters including maturity parameters, ear attributes and yield components were recorded as per standard procedure. Combining ability analysis was carried as per procedure given by Kempthorne (1957) and modified by Elitriby (1981) for multiple environments.

## RESULTS AND DISCUSSION

Pooled analysis of variance to test the significance of difference among the genotypes (Table 1) revealed highly significant differences for most of the traits reflecting thereby presence of adequate diversity in the genetic material chosen for the study. The magnitude of mean sum of squares due to line × environment interaction was significant for all the characters studied in two environments except kernel rows per ear. Tester × environment interactions were found to be significant for days to 50% tasseling, days to 50% silking, days to 75% dry husk and ear length. Crosses × environment interactions were significant for all the characters except thousand kernel weight. Pooled analysis over environments showed significant gca and sca variances for most of the traits. Based on estimates, higher magnitude of $\sigma^2$ *sca* in relation to $\sigma^2$ *gca* implied the greater importance of non-additive gene effects in inheritance of maturity related traits, grain yield and it's component traits. These results were also supported by the earlier findings of

**Table 2.** Pooled estimates of gca effects for different traits in lines and testers of maize.

| | Days to 50% tasseling | Days to 50% silking | Days to 75% dry husk | Ear length | Ear diameter | Kernel/ear | Kernel rows/ear | 1000 kernel weight | Grain yield (q/ha) |
|---|---|---|---|---|---|---|---|---|---|
| $L_1$ | 2.77** | 2.85** | 1.17** | -0.14** | -0.01 | 6.98** | 0.01 | 10.16** | -2.48** |
| $L_2$ | -1.10** | -0.92** | 0.54 | -0.13* | -0.02 | 9.19** | -0.16** | -25.81** | -8.45** |
| $L_3$ | -3.93** | -3.69 | -1.26** | 0.43** | -0.02 | -13.95** | -0.19** | -3.21 | -3.04 ** |
| $L_4$ | -0.76** | -0.69** | -0.36 | 0.30** | 0.08 ** | -1.15 | 0.02 | 20.83** | -1.20 |
| $L_5$ | -0.73** | -0.82** | -0.36 | 0.31** | 0.08 ** | -1.15 | 0.02 | 19.66** | -1.20 |
| $L_6$ | 1.44 ** | 1.31** | 1.31** | -0.09 | -0.09** | -19.26** | -0.12 | -32.01** | -9.84** |
| $L_7$ | 0.37** | 0.35* | 1.51** | 0.16** | -0.06 ** | 9.24** | 0.01 | -29.91** | 5.38** |
| $L_8$ | 0.47** | 0.61** | 0.38 | -0.19 ** | -0.26 ** | -14.30** | -0.37** | 11.23** | 6.08** |
| $L_9$ | -0.93** | -1.32** | -1.42** | -0.93** | -0.02 | 9.13** | 0.18** | -2.74 | 7.99** |
| $L_{10}$ | -0.80** | -0.52** | -0.99** | 1.33** | 0.25 ** | 46.52** | 0.74** | 0.93 | 3.80** |
| $L_{11}$ | 3.40** | 3.25** | 0.41 | -0.56** | 0.04* | -15.61** | -0.06 | 15.29** | 1.49* |
| $L_{12}$ | -0.20 | -0.42* | -0.93** | -0.49** | 0.04* | -15.61 | -0.06 | 15.59** | 1.49* |
| $T_1$ | -2.27** | -2.34** | -0.54 | 0.06 | 0.07 ** | -1.96 | 0.02 | -2.63* | 0.26 |
| $T_2$ | -0.06 | 0.07 | -0.63 | 0.19** | 0.01 | -9.17** | -0.03 | 3.80** | 2.10** |
| $T_3$ | 0.05 | -0.21 | -1.19 | -0.16** | -0.02* | -13.22** | -0.27** | 1.37 | -1.14** |
| $T_4$ | 0.19 | 0.12 | 0.89 | -0.25** | -0.04** | 3.82** | 0.06* | 0.04 | -0.40 |
| $T_5$ | 2.08** | 2.36** | 1.46 | 0.16** | -0.02 | 20.53** | 0.22** | -2.59* | -0.82 |

** = $P < 0.01$; * = $P < 0.05$.

Vasal et al. (1992) and Joshi et al. (1998). Prevalence of greater magnitude non-additive genetic component of variance relative to additive in present study favors production of hybrid cultivars and detection of genotype × environment interaction for various traits which emphasize multi-environment testing of genetic materials. Debnath et al. (1988), Sanghi et al. (1983) Roy et al. (1998) and Das and Islam (1994) also reported predominance of non-additive gene action for grain yield and its components in the same crop.

The analysis of combining ability effects revealed that none of the parents possessed desirable *gca* effects for all the traits studied (Table 2). However, $L_9$ was found to have the highest positive and highly significant *gca* effect for grain yield followed by $L_8$, $L_7$, $L_{10}$, $L_{11}$ and $L_{12}$. These parents also showed significant positive gca effect and simultaneously possessed high mean value indicating that the *per se* performance of the parents could prove as an useful index for combining ability. Roy et al. (1998) and Hussain et al. (2003) also observed similar phenomenon. Regarding maturity related traits, $L_3$ revealed the most desirable negative and significant value for tasseling and silking while $L_9$ revealed the most desirable negative and significant value for dry husk. The inbred $L_{10}$ exhibited highest positive and significant *gca* value for various yield components viz., ear length, ear diameter, kernels per ear and kernel rows per ear besides being a good general combiner for maturity traits. The lines with desirable *gca* should be extensively used in the crossing programme to exploit maximum genetic variability.

A critical evaluation of the results with respect to specific combining ability effects showed that none of the cross combinations exhibited desirable significant *sca* effects for all the characters. The estimates of specific combining ability based on pooled analysis demonstrated various cross combinations having significant positive *sca* effects (Table 3). The highest magnitude of desirable *sca* effects for grain yield in q/ha was detected in ($L_6$ × $T_5$) followed by ($L_4$ × $T_2$) and ($L_5$ × $T_2$). Beck et al. (1990), Singh and Mishra (1996), Chaudhary et al. (2000) and Surya and Ganguli (2004) also reported high positive

**Table 3.** Pooled estimates of sca effects for different traits.

| Crosses | Days to 50% tasseling | Days to 50% silking | Days to 75% dry husk | Ear length | Ear diameter | Kernel/ear | Kernel rows /ear | 1000 kernel weight | Grain yield (q/ha) |
|---|---|---|---|---|---|---|---|---|---|
| $L_1 \times T_4$ | -1.83** | -2.56** | 0.67 | -0.07 | 0.04 | 35.82** | 0.82** | 13.83** | 10.16** |
| $L_2 \times T_5$ | 0.82* | 1.14** | 1.40* | 1.26** | 0.31** | 101.01** | 0.89** | 40.25** | 4.73** |
| $L_3 \times T_1$ | -1.17** | -1.06 | -2.96** | -0.41** | -0.01 | -17.35** | 0.19* | 23.69** | 4.79** |
| $L_4 \times T_2$ | -0.71 | -0.47 | -0.77 | -0.23 | -0.03 | 1.31 | 0.29** | -1.27 | 7.89 |
| $L_5 \times T_2$ | -0.74* | -0.50 | -0.77 | -0.28 | -0.03 | 1.31 | 0.29** | -1.10 | 7.89** |
| $L_6 \times T_5$ | 1.62** | 1.41** | -0.03 | -0.20 | -0.13** | 28.12** | 0.84** | 18.29** | 13.26** |
| $L_9 \times T_3$ | -2.82** | -5.22** | -0.31 | -0.33** | -0.06 | -22.57 | -0.16 | 10.56* | 2.20 |
| $L_9 \times T_5$ | 3.32** | 4.54** | 2.37** | 0.64** | 0.23** | 21.29** | 0.58** | 4.35 | 7.15 |
| $L_{10} \times T_1$ | 0.20 | 0.27 | -0.23 | 0.59** | -0.03 | 48.59** | 0.55** | 23.06** | 7.80** |
| $L_{12} \times T_4$ | 2.47 | 2.71** | -0.89 | 0.74** | 0.10* | 21.69** | 0.62** | 6.89 | -1.90 |

** = $P < 0.01$; * = $P < 0.05$.

**Table 4.** Identified hybrid combinations showing consistent performance across seasons based on superiority over check Vivek hybrid-9.

| Crosses | Days to 50% tasseling | Days to 50% silking | Days to 75% dry husk | Ear length | Ear diameter | Kernel/ear | Kernel rows /ear | 1000 kernel weight | Grain yield (q/ha) |
|---|---|---|---|---|---|---|---|---|---|
| $L_3 \times T_1$ | -13.28** | -12.25** | -3.95 | -2.34** | 1.40** | 0.28 | 4.44** | 24.64** | 50.82** |
| $L_4 \times T_5$ | -4.36** | -3.75** | -0.41** | 0.63 | 0.85** | 8.88** | 6.00** | 34.54** | 35.63** |
| $L_5 \times T_2$ | -1.66* | -1.38* | 1.63* | -3.06** | -1.55** | 2.33 | 2.89** | 15.30** | 36.80** |
| $L_8 \times T_2$ | -0.83 | -0.99 | -0.54** | -2.16* | -3.10* | 6.89** | 5.56** | 24.56** | 81.21** |
| $L_9 \times T_2$ | -7.68** | -6.92** | -2.59 | -4.59** | 1.63** | 12.60** | 4.22** | 25.04** | 84.60** |
| $L_9 \times T_5$ | 1.45 | 2.77** | 1.91* | -3.42** | 5.12 | 18.68** | 10.89** | 15.54** | 79.71** |
| $L_{10} \times T_1$ | -7.68** | -6.92** | -1.50* | 7.93** | 7.45 | 27.89** | 13.11** | 26.33** | 73.95** |
| $L_{10} \times T_2$ | -4.15* | -4.15** | -0.95** | 5.59** | 9.00 | 22.37** | 11.78** | 20.29** | 53.53** |

** = $P < 0.01$; * = $P < 0.05$.

specific combining ability effects along with high *per se* performance for grain yield. However for maturity related traits, ($L_9 \times T_3$) showed the most desirable value for tasseling and silking while ($L_3 \times T_1$) revealed the most desirable value for dry husk. The cross combination ($L_2 \times T_5$) followed by ($L_{12} \times T_4$) was a good specific combiner for ear length and ear diameter. The cross combination ($L_2 \times T_5$) was the best specific combiner followed by ($L_1 \times T_4$) and ($L_{10} \times T_1$) for kernels per ear, kernel rows per ear and 1000 kernel weight. The superiority of crosses as parents could be explained on the basis of interaction between positive alleles from good combiners and negative alleles for the poor combiners as parents. The high yield of such crosses would be non-fixable and thus could be exploited for heterosis breeding.

All the crosses exhibited highly significant positive heterosis over mid parent and better parent for grain yield in pooled analysis (Table 4). The cross combination ($L_9 \times T_2$) followed by ($L_8 \times T_2$) and ($L_9 \times T_5$) revealed highest magnitude of economic heterosis (84.60%) over the best check Vivek hybrid-9 for grain yield in q/ha.

Appreciable percentage of heterosis for grain yield in maize was also reported by Lonnquist and Gardner (1961), Akhtar and Singh (1981) and Gerrish (1981). In another study, Debnath (1987) and Roy et al. (1998), respectively, observed 13.95 to 245.10% and -16.42 to 71.82% heterobeltiosis. The cross combination ($L_3 \times T_1$) showed the most desirable value for heterosis for maturity traits. However the cross ($L_{10} \times T_1$) followed by ($L_{10} \times T_2$) revealed maximum positive and highly significant heterosis for ear length, ear diameter, kernels per ear and kernel rows per ear. For 1000 kernel weight, the cross combination ($L_4 \times T_5$) followed by ($L_5 \times T_5$) showed highest magnitude of economic heterosis. Most crosses showing significant positive *sca* effect and highest magnitude of economic heterosis for grain yield involved $T_2$ and $T_5$ as testers.

Therefore these promising crosses were identified as overall high general combiners and these could be utilized for development of either the synthetic varieties or an elite breeding population by allowing thorough mixing among them to achieve new genetic recombination and then subjecting the resultant population to recurrent selection.

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