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**Research Article**

# Heterotic hybrid frequency in relation to combining ability and parental genetic divergence in maize

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**Abstract**
Being a highly cross pollinated crop, heterotic hybrid development is the immediate cultivar option in maize. The $F_1$'s developed from the heterotic pools not only serve as hybrid cultivar but also helps in isolation of good inbred lines. Genetic diversity and combining ability of parents are the commonly used criteria for heterotic hybrid development. In this context, an investigation was carried out at College of Agriculture, V. C. Farm, Mandya, India, to test the predictability of heterotic hybrid frequency based on parental *gca* effects and genetic diversity in maize. The 108 $F_1$'s developed by crossing 27 inbred lines and four testers were evaluated along with their parents for six morpho-metric traits. The overall *gca* status of parents and *sca* and heterotic status of hybrids for six characters were determined. Based on genetic divergence and *gca* status of parents, the hybrids were grouped into different classes. The hybrids involving intermediate genetic divergence and/or contrasting for overall *gca* status were more frequently heterotic than those involving extreme genetic divergence and comparable *gca* status. Thus, there is a limit to parental genetic divergence for the occurrence of heterosis. It is hence, desirable to involve parents with contrasting gca effects and intermediate genetic divergence to recover higher frequencies of heterotic hybrids for economic traits in maize.

**Key words**
Genetic divergence, overall *gca* status, overall heterotic status, maize

## Introduction

The phenomenon of heterosis as defined by Shull (1952) "the interpretation of increased vigor, size, fruitfulness, speed of development, resistance to disease and insect pests, or to climatic rigors of any kind manifested by crossbred organisms as compared with corresponding inbreds, as the specific results of unlikeness in the constitution of the uniting parental gametes". The application of heterosis is preferred approach to enhance productivity potential of crop species where development of $F_1$ hybrid is technically and economically feasible. However, $F_1$ hybrid has been the major cultivar option for enhancing maize production. Genetic diversity has always been estimated by maize breeders to identify the suitable parents for development of best hybrid combinations. The hypothetical concerns also implied that genetic diversity among prospective parents is important for the success of a hybrid breeding program as it determines the magnitude of heterosis in $F_1$ hybrid to a large extent (Teklewold and Becker, 2006). However, a strong correlation between heterosis and parental genetic distance has been rarely observed [Melchinger, 1999; Singh and Singh, 2004). The heterotic $F_1$'s are helpful in generating a high frequency of productive inbred lines as compared to non-heterotic $F_1$'s as observed in *Brassica campestris* (Arunachalam and Bandopadhyay, 1984). Therefore, identification of heterotic hybrids is relevant not only for commercial purpose but also for deriving superior inbred lines. In this context, choice of parent for developing high frequency of heterotic hybrid is another issue often debate by plant breeders.

Considering theoretical analysis of single gene systems with two or multiple alleles (Falconer and Mackay, 1996) and two gene system (Arunachalam and Qwen, 1971), phenotypic/ genetic diversity has been very commonly used criterion for choosing parents for developing heterotic hybrids (Durga Prasad *et al*., 1985; Arunachalam and Bandopadhyay, 1984). However, when diverse parents are crossed, heterosis is not always found to occur (Cress, 1966). Combining ability (CA) is another criteria which has been being used as one of the criteria for choosing the parents for producing higher frequency of heterotic hybrids. Practical utility of CA lies in the performance prediction of hybrids (Griffing, 1956). Apart from providing an objective criterion for choosing parents, CA also provides useful clues about mode of action of genes controlling economically important traits. Being used on first degree statistics, the greatest advantage of CA approach for genetic analysis is that it is statistically robust and genetically neutral and hence applicable to crops irrespective of their mode of reproduction (Arunachalam and Reddy, 1981). Under these premises, an attempt, was made to arrive at a simple and rational criteria for choosing the parents for developing high frequency of heterotic hybrids using experimental data from maize.

**Material and Methods**

The material for the study consists of 27 phenotypically diverse inbred lines (used as females) and four testers (used as males) developed at College of Agriculture (CoA) V. C. Farm, Mandya. These inbred lines were planted in single row of 4m length and crossed with four testers (CM500, CM 202, MAI105 and NAI 137) using line × tester mating design (Kempthorne, 1957) to synthesize 108 $F_1$'s during *kharif* 2013. The 108 hybrids so produced were evaluated along with their parents at the experimental plots of college of Agriculture (CoA), V. C. Farm, Mandya in randomized block design with two replications for three seasons (*summer* 2014, *kharif* 2014 and *summer* 2015). The experimental plot represent southern dry zone (Zone 6) located at latitude of $12^0 30^I$N, longitude of $76^0 50^I$E and altitude of 694.65 meters Above MSL.

The seeds of each of the $F_1$ progeny and their parents were planted in two rows of 4 m length following 0.6 m between rows and 0.3 m within a row between the plants. The recommended management practices were followed during the crop growth period to raise healthy crop.

The data were recorded on five randomly chosen plants in each replication on six morpho-metric traits, namely, anthesis-silking interval (ASI), ear length (cm), ear circumference (cm), kernel rows ear$^{-1}$, kernels row$^{-1}$ and grain yield plant$^{-1}$. The traits means of the five plants of hybrids and parents were subjected to statistical analysis.

The mean of quantitative traits of two replications were used for statistical analysis. Non-significant mean squares due to hybrids × seasons provided statistical validity to pool the three season data on quantitative traits. The individual season wise as well as pooled data were used for combining ability (CA) analyses (Kempthorne, 1957) using computer software program Windowstat 8.0 (developed by Indostat services 18.0, Ameerpet, Hyderabad, India). General combining ability (*gca*) effects of four testers and 27 lines and specific combining ability (*sca*) effects of 108 $F_1$ hybrids and variances due *gca* and *sca* effects were estimated. Better parent heterosis (BPH) of 108 $F_1$ hybrids was estimated for each of the six characters as following.

$$BPH = \left( \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \right) \times 100$$

Where, $\overline{F_1}$= quantitative trait (QT) mean of $F_1$, $\overline{BP}$ = mean of better parent.

As quantitative traits are correlated either positively or negatively, it is usual to find, for a particular parent and a hybrid, *gca* effect and *sca* effects, BPH, respectively in the desirable direction for some characters and in the undesirable direction for others. Hence, the overall status of parents with respect to their *gca* effects and the hybrids with respect to their *sca* effects and BPH across six characters were determined (Arunachalam and Bandopadhyay, 1979). As per the procedure suggested Arunachalam and Bandopadhyay (1979), the determination of overall status of parents with respect to their *gca* effects and the hybrids with respect to their *sca* effects and BPH across all characters should be based on only significant *gca*, *sca* and heterotic effects. The consideration of only significant *gca*, *sca* and heterotic effects results in loss of information on several parents and crosses. To overcome such shortcoming, we considered the estimates of *gca*, *sca* and heterotic effects irrespective of their statistical significance. The modified procedure is described as under.

The estimates of *gca* effects of parents, *sca* effects and BPH of hybrids were ranked by assigning lowest rank for the parent or the cross which manifested the highest *gca*/*sca* effects and BPH, respectively in desirable direction. The highest rank was assigned for parent or the cross which manifested the lowest *gca*/*sca* effects and BPH, respectively in desirable direction. The rank obtained by parents/hybrids were summed up across all the characters to arrive at a total score for each of the parent/cross. Further, the mean of the total scores of all the parents or crosses across the traits was computed which was used as the final norm to ascertain the status of a parent or a hybrid for their *gca*/*sca* effects and BPH. The

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parent/hybrid whose total rank exceeds the final norm were given low (L) overall *gca*/*sca*/BPH status, respectively. On the other hand, the parent or a hybrid, whose total rank was less than the final norm were given high (H) overall *gca*/*sca*/BPH status, respectively. Based on the overall *gca* status of the parents, crosses were classified into HH (both the parents in a cross with high overall *gca* status), HL (one parent with high and the other with low overall *gca* status) and LL (both the parents with low overall *gca* status) categories.

Genetic divergence between the parents of 108 $F_1$'s was estimated by Mahalanobis $D^2$ statistic (Rao, 1952). The mean (m), lowest, highest and standard deviation of $D^2$ statistic were calculated, and were used to delineate parental divergence into four divergent classes (DC) (Arunachalam and Bandopadhyay, 1984). Divergence classes were defined as follows.

DC 1: $D^2 < (m-s)$
DC 2: $(m-s) < D^2 < m$
DC 3: $m < D^2 < (m+s)$
DC 4: $D^2 > (m+s)$

Where, DC 1 and DC 4 represents the extremely divergent classes in either direction.

The total number of hybrids and those with high overall *sca* and heterotic status falling into each of the four parental divergent classes (DC 1, DC 2, DC 3 and DC 4) and three parental *gca* classes (HH, HL/LH and LL) were counted. Based on this information, given a hybrid with high overall *sca* and heterotic status, conditional probability that it belongs to each of the four parental divergence and three parental *gca* classes were estimated (Arunachalam and Bandopadhyay, 1979; Rao, *et al.*, 2004).

**Results and Discussion**

Significant mean sum of squares due to line effects for ear height, ear length, number of kernel rows, number of kernels row$^{-1}$ and yield plant$^{-1}$, and those due to tester effects and line × tester (L × T) effects for all the traits suggested importance of both *gca* and *sca* effects for these traits were considered for the study (Table 1). The significance of the interaction arising from line effects with seasons for all the traits except for number of kernel rows and L × T interaction effect with the season for all the traits except for anthesis-silking interval (ASI), ear diameter and yield plant$^{-1}$ suggested differential response of the alleles controlling these traits to differences in weather variables that prevailed during experimental period in the three seasons. The significant line effect × year first order interaction suggested the necessity of selecting lines that are relatively more stable across years for their *gca* effects. The significant line × tester × year second-order interaction justifies evaluating hybrids across years to identify stable hybrids. The difference in combining ability of parents and their interaction with seasons have been reported in adzuki bean (Kunkaew, *et al*., 2006) and rajmash (Iqbal, *et al*., 2010) for yield plant$^{-1}$, winter wheat (Gowda, *et al*., 2012) for most traits considered for the study.

It has been generally reported that in relatively selected material non-additive gene action was more important than additive gene action (Spargue and Tatum, 1942). Predominance of *sca* variance for most of the traits in all seasons indicated greater importance of non-additive (non-fixable) mode of action of genes controlling these traits. Similar study confirms the findings of the workers Divan *et al.,* (2013) and Kanagarasu *et al.,* (2010).

Predominance of dominant action of genes renders selection in early generation ineffective. One or two cycles of bi-parental mating in $F_2$ generation not only reduce dominance gene effects but also converts un-exploited potential variability into exploitable free variability [Bos, 1977 and Stam,1977) which enables rapid genetic gain from selection. This is because, probability of genes being in dispersion phase (which results in reduction in trait mean) minimized by $F_2$ inter-se mating (Roy, 2000).

Both lines and testers differed widely in their abilities to combine in the cross combinations for all the traits. The differences in *gca* effects are attributable to differences in frequencies of genes with the additive effects (Falconer and Mackay, 1996). The differences in gene frequencies among the lines and testers suggested their significant genotypic differences, thus justifying their selection for the present study. As expected, different lines and testers were desirable general combiner in both direction and magnitude for different traits. Thus, no single line or tester was desirable combiner for all the traits. As it is true with respect to lines and testers for *gca* effects, the hybrids differed significantly for their *sca* and better parent heterotic effects. These results indicated that while performance of a few hybrids is attributable only to their parental genes with additive effects, which of other hybrids is attributable to non-additive effects of their parental genes in addition to their additive effects (Arunachalam, 1976). It should however, be noted that the estimates of *gca* and *sca* effects are relative to and are dependant on particular set of parents included in the experiment.

Similar to lines and testers with respect to their *gca* effects, the different hybrids displayed desirable *sca* and heterotic effects for different traits. For instance, lines such as MAI 1-21-4, MAI 3-2-4-1 and MAI 1-17-2 were desirable general combiners for ASI, MAI 1-41-3, MAI 1-91-3 and MAI 1-17-2 were desirable general combiners for yield plant$^{-1}$ (Table 2). Similarly, hybrids such as MAI 1-31-2 × NAI 137, MAI 1-21-4 × CM 202 and MAI 1-41-3 × NAI 137 were desirable specific combinations for ASI, MAI 1-58-3 × NAI 137, MAI 3-2-5 × MAI 105 and MAI 1-17-2 × MAI 105 were desirable specific combinations for yield plant$^{-1}$ (Table 3). These results lend support to the use of the method suggested (Seyoum, *et al*., 2016) to determine *gca* status of parents, and *sca* and heterotic status of hybrid across the six traits considered for the study.

Fourteen of the 27 lines and two of the four testers displayed high overall *gca* status and the remaining exhibited low overall *gca* status (Table 4). Similarly, 50% of the hybrids displayed high overall *sca* and heterotic status (Table 5, 6). The similar results of parents with high and low overall *gca* status and hybrids with low and high *sca* and heterotic status have also been reported in maize (Kambegowda, *et al*., 2013). The lines and testers with overall high *gca* status could be preferentially used to develop hybrids from which it is more likely to derive high frequency of superior inbred lines. Similarly, the hybrids with high overall *sca* status are suggested for preferential use in deriving desirable inbred lines.

The number of hybrids with high (H) overall *sca* status was more in HL than either in HH or LL category. Also, the number of overall heterotic crosses was more in HL than either in HH or LL category. It may be argued that the frequency of hybrids with high overall *sca* and heterotic status could be biased due to varying number of crosses under each category. To take into consideration, the unequal number of crosses in different categories and conditional probability of a heterotic cross found in HH, HL or LL category was computed manually as the ratio of number of heterotic crosses belonging to HH, HL or LL category to the total number of heterotic crosses. The conditional probability is independent of number of crosses under each category. It was interesting to note that given a heterotic cross, the probability of finding it to be a H × L combination was higher than the probability of finding it to be either H × H or L × L combination. Also, given a cross with high *sca* status, the probability of finding it to be a H × L combination was higher than the probability of finding it to be either H × H or L × L combination (Table 7).

Thus, the present study indicated requirement of parents with contrasting *gca* effects to realize higher frequency of heterotic hybrids. The results of the present investigation are adequately supported by the studies of similar nature in pearl millet (Reddy and Arunachalam, 1981) and maize (Kambegowda, *et al*., 2013).

The superiority of H × L crosses in producing high magnitude of heterosis over number of characters, is of practical utility to a breeder. It is worthwhile to initiate H × L type of crosses for realizing hybrids with high heterosis to optimize resources. The support for the utility of CA as one of the criterion for choosing the parents comes from the theoretical results which have indicated higher heterosis in the hybrids derived from parents differing in the frequencies of the genes (Cress, 1966). The parental differences in combining abilities are attributed to differences in gene frequency (Falconer and Mackay, 1996).

The number of hybrids with high (H) overall *sca* status was more in moderately divergent classes (DC 3 and DC 2) than either in DC 1 or DC 4 class. The number of overall heterotic crosses was more in DC 2 than either in DC 4 or DC 1. To normalize unequal number of crosses in different divergent classes, conditional probability of a heterotic cross has been found in DC 1, DC 2, DC 3 or DC 4 divergent classes. Given a heterotic cross, the conditional probability of finding it to be in DC 2 class was higher than the probability of finding it to be either in DC 4 or DC 1. Similarly, given a cross with high *sca* status, the probability of finding it to be in DC 3 and DC 2 was higher than the probability of finding it to be either in DC 4 or DC 1 class (Table 8).

The study suggested that it is likely to realize high frequency of heterotic hybrids from parents with intermediate genetic divergence quantified as DC 2 and DC 3 classes. Thus, there is existence of limit to parental divergence and it should neither be too small nor very large for realizing higher frequencies of heterotic hybrids. Choosing the parents with moderate divergence is likely to result in high frequency of heterotic hybrids as shown in triticale (Srivastava and Arunachalam, 1977) and chilli

(Krishnamurthy, *et al.*, 2013). It is hence, desirable to involve parents with intermediate genetic divergence and contrasting *gca* effects to recover higher frequency of heterotic hybrids for economic traits in maize.

The high predictive power of parental *gca* effects on hybrid heterosis would save substantial resources and time and thus help enhance the pace and efficiency of maize breeding. The hybrids involving parents contrasting for overall *gca* status and/or those involving parents with intermediate genetic divergence were more frequently heterotic than those involving comparable *gca* status with extreme genetic divergence. Thus, there exists a limit to parental divergence and contrasting *gca* effects to recover higher frequency of heterotic hybrids for economic traits in maize.

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**Table 1. Analysis of variance of combining ability for quantitative traits in Maize**

| Source of variation | DF | ASI | Ear ht | EL | ED | no. k rows | no. k $row^{-1}$ | yield $plant^{-1}$(g) |
|---|---|---|---|---|---|---|---|---|
| Replicates | 1 | 1.84 | 744.42 | 49.86* | 4.55 | 3.13 | 65.20* | 20739.26 |
| Seasons | 2 | 21.92** | 13230.16** | 40.69** | 0.01 | 123.39** | 803.28** | 300732.40** |
| Rep * season | 2 | 0.27 | 1.19 | 2.77 | 0.20 | 0.78 | 0.33 | 3650.13 |
| Crosses | 107 | 2.14** | 436.37** | 11.96** | 3.32** | 8.54** | 55.01** | 10109.74** |
| Line effect | 26 | 2.49 | 739.64** | 20.47** | 4.64 | 14.00** | 83.50* | 9828.41 |
| Tester effect | 3 | 0.09 | 738.34 | 18.42 | 3.98 | 17.60* | 97.55 | 42698.01** |
| Line * Tester effect | 78 | 2.11** | 323.67** | 8.87** | 2.86** | 6.37** | 43.87** | 8950.13** |
| Season * Crosses | 214 | 1.08 | 150.68** | 4.62** | 1.14 | 2.13** | 18.27** | 2562.23 |
| Season* Line effect | 52 | 1.70** | 287.66** | 6.32** | 1.59* | 2.20 | 27.48** | 3802.70** |
| Season * Tester effect | 6 | 1.07 | 256.78* | 12.21** | 1.43 | 1.46 | 8.28 | 5433.46* |
| Season * L * T effect | 156 | 0.87 | 100.94* | 3.76** | 0.99 | 2.13** | 15.59** | 2038.31 |
| Pooled Error | 321 | 0.92 | 79.26 | 1.46 | 1.52 | 1.34 | 10.07 | 2424.36 |
| $\sigma^2$GCA | | 0.00 | 7.09 | 0.19 | 0.03 | 0.16 | 0.87 | 256.33 |
| $\sigma^2$SCA | | 0.20 | 40.73 | 1.24 | 0.22 | 0.84 | 5.63 | 1087.63 |
| $\sigma^2$GCA/SCA | | 0.02 | 0.17 | 0.16 | 0.13 | 0.19 | 0.15 | 0.24 |

*Significant at P = 0.05 **Significant at P = 0.01
DF=degrees of freedom, ASI=anther silk interval, Ear ht= ear height, EL = ear length, ED= ear diameter, no. k rows=number of kernel rows, no. k $row^{-1}$= number of kernels per row

**Table 2. Top three desirable general combiners for quantitative traits in maize**

| | Desirable general combiners | | | |
|---|---|---|---|---|
| **Traits** | **Lines** | **Estimates of gca** | **Testers** | **Estimates of gca** |
| ASI | MAI 1-21-4 | -0.56** | CM500 | -0.04 |
| | MAI 3-2-4-1 | -0.56** | CM202 | 0.01 |
| | MAI 1-17-2 | -0.47* | | |
| ear ht | MAI 1-97-3 | 8.19** | MAI105 | 2.42** |
| | MAI 1-5-2 | 7.17** | CM500 | 0.73 |
| | MAI 1-1-1 | 6.67** | | |
| EL | MAI 1-17-11 | 1.78** | CM202 | 0.37** |
| | MAI 1-48-1 | 1.64** | NAI137 | 0.21* |
| | MAI 2-16-3-1 | 1.49** | | |
| ED | MAI 1-22-1 | 0.90** | MAI105 | 0.17 |
| | MAI 1-108-2 | 0.73** | CM202 | 0.08 |
| | MAI 1-22-3 | 0.57* | | |
| no. k rows | MAI 1-22-3 | 1.50** | MAI105 | 0.46** |
| | MAI 4-10-3 | 1.18** | CM202 | 0.03 |
| | MAI 1-5-2 | 0.96** | | |
| no. k/row | MAI 4-10-3 | 3.26** | NAI137 | 0.85** |
| | MAI 1-108-2 | 3.26** | CM202 | 0.47 |
| | MAI 2-16-3-1 | 2.91** | | |
| yield plant$^{-1}$ (g) | MAI 1-41-3 | 41.24** | MAI105 | 16.99** |
| | MAI 1-97-3 | 27.27** | CM202 | 7.23 |
| | MAI 1-17-11 | 23.70* | | |

*Significant at P = 0.05 **Significant at P = 0.01
DF=degrees of freedom, ASI=anther silk interval, Ear ht= ear height, EL = ear length, ED= ear diameter, no. k rows=number of kernel rows, no. k row$^{-1}$= number of kernels per row

**Table 3. Top three desirable specific combinations based on *sca* effects and better parent heterosis (BPH) for quantitative traits in maize**

| Traits | Crosses | Estimates of *sca* | Crosses | Estimates of BPH |
|---|---|---|---|---|
| **ASI** | MAI1-31-2×NAI137 | -1.27** | MAI1-21-4×CM202 | -86.21** |
| | MAI1-21-4×CM202 | -1.21** | MAI1-31-2×NAI137 | -60** |
| | MAI1-41-3×NAI137 | -0.85* | MAI1-37-3×CM500 | -55.56** |
| **Ear ht** | MAI1-91-3×CM500 | 17.05** | MAI3-13-6×CM202 | 41.13** |
| | MAI3-13-6×CM202 | 14.32** | MAI1-17-11×NAI137 | 30.94** |
| | MAI1-37-3×MAI105 | 13.31** | MAI1-8-3×MAI105 | 28.76** |
| **EL** | MAI1-17-2×NAI137 | 2.53** | MAI4-10-3×CM202 | 41.71** |
| | MAI1-22-3×NAI137 | 2.44** | MAI1-48-1×NAI137 | 37.32** |
| | MAI3-2-4-1×MAI105 | 2.01** | MAI4-10-3×CM500 | 36.53** |
| **ED** | MAI1-22-1×CM500 | 3.79** | MAI1-22-1×CM500 | 40.5** |
| | MAI4-10-3×MAI105 | 1.03* | MAI1-108-2×CM202 | 20.82** |
| | MAI3-2-4-1×CM202 | 0.90 | MAI3-2-4-1×CM202 | 19.33** |
| **no. k rows** | MAI4-10-3×CM500 | 4.56** | MAI4-10-3×CM500 | 36.91** |
| | MAI1-22-3×CM202 | 2.40** | MAI1-17-2×NAI137 | 21.21** |
| | MAI1-41-3×MAI105 | 2.32** | MAI1-5-2×NAI137 | 19.08** |
| **no. k/row** | MAI1-37-3×MAI105 | 6.76** | MAI4-10-3×NAI137 | 60.34** |
| | MAI2-9-1-2×CM500 | 4.03** | MAI4-10-3×CM500 | 46.96** |
| | MAI1-5-2×NAI137 | 4.02** | MAI3-2-5×NAI137 | 45.13** |
| **Yield plant$^{-1}$ (g)** | MAI1-58-3×NAI137 | 83.52** | MAI1-17-11×CM202 | 251.93** |
| | MAI3-2-5×MAI105 | 78.20** | MAI3-2-5×CM202 | 248.39** |
| | MAI1-17-2×MAI105 | 69.62** | MAI1-48-1×CM202 | 220.74** |

*Significant at P = 0.05 **Significant at P = 0.01
DF=degrees of freedom, ASI=anther silk interval, Ear ht= ear height, EL = ear length, ED= ear diameter, no. k rows=number of kernel rows, no. k row$^{-1}$= number of kernels per row

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**Table 4. Overall general combining ability status of parent in maize**

| Lines[a] | Overall rank | Overall gca status |
|---|---|---|
| MAI 1-1-1 | 127 | L |
| MAI 1-5-2 | 131 | L |
| MAI 1-8-3 | 67 | H |
| MAI 1-17-2 | 60 | H |
| MAI 1-17-11 | 131 | L |
| MAI 1-21-4 | 92 | H |
| MAI 1-22-1 | 104 | L |
| MAI 1-22-3 | 84 | H |
| MAI 1-31-2 | 86 | H |
| MAI 1-37-3 | 86 | H |
| MAI 1-41-3 | 50 | H |
| MAI 1-48-1 | 137 | L |
| MAI 1-77-1-1 | 119 | L |
| MAI 1-91-3 | 93 | H |
| MAI 1-97-3 | 121 | L |
| MAI 1-98-3 | 94 | H |
| MAI 1-108-2 | 126 | L |
| MAI 2-4-1-1 | 74 | H |
| MAI 2-9-1-2 | 64 | H |
| MAI 3-2-4-1 | 80 | H |
| MAI 3-2-5 | 99 | L |
| MAI 3-13-6 | 102 | L |
| MAI 4-5-2 | 83 | H |
| MAI 4-10-3 | 101 | L |
| MAI 1-17-13 | 125 | L |
| MAI 1-58-3 | 134 | L |
| MAI 2-16-3-1 | 76 | H |
| Testers[b] | | |
| CM500 | 22 | L |
| CM202 | 14 | H |
| MAI105 | 13 | H |
| NAI137 | 21 | L |

[a] final norm: 98 H=High overall gca status
[b] final norm: 17.5 L=Lower overall gca status

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**Table 5. Overall specific combining ability status of crosses in maize**

| Lines | Testers | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | CM500 (L) | | CM202 (H) | | MAI105 (H) | | NAI137 (L) | |
| | Total score | status | Total score | status | Total score | status | Total score | status |
| MAI 1-1-1 (L) | 232 | H | 396 | L | 529 | L | 348 | H |
| MAI 1-5-2 (L) | 442 | L | 591 | L | 313 | H | 193 | H |
| MAI 1-8-3 (H) | 462 | L | 390 | L | 264 | H | 335 | H |
| MAI 1-17-2 (H) | 522 | L | 438 | L | 366 | H | 280 | H |
| MAI 1-17-11 (L) | 448 | L | 304 | H | 318 | H | 376 | H |
| MAI 1-21-4 (H) | 234 | H | 348 | H | 505 | L | 473 | L |
| MAI 1-22-1 (L) | 280 | H | 593 | L | 360 | H | 353 | H |
| MAI 1-22-3 (H) | 405 | L | 435 | L | 564 | L | 202 | H |
| MAI 1-31-2 (H) | 468 | L | 416 | L | 485 | L | 211 | H |
| MAI 1-37-3 (H) | 297 | H | 420 | L | 317 | H | 508 | L |
| MAI 1-41-3 (H) | 463 | L | 377 | H | 349 | H | 359 | H |
| MAI 1-48-1 (L) | 474 | L | 296 | H | 374 | H | 374 | H |
| MAI 1-77-1-1 (L) | 561 | L | 249 | H | 344 | H | 319 | H |
| MAI 1-91-3 (H) | 411 | L | 364 | H | 431 | L | 322 | H |
| MAI 1-97-3 (L) | 468 | L | 233 | H | 311 | H | 479 | L |
| MAI 1-98-3 (H) | 339 | H | 434 | L | 307 | H | 424 | L |
| MAI 1-108-2 (L) | 358 | H | 304 | H | 435 | L | 426 | L |
| MAI 2-4-1-1 (H) | 546 | L | 274 | H | 175 | H | 492 | L |
| MAI 2-9-1-2 (H) | 285 | H | 517 | L | 270 | H | 494 | L |
| MAI 3-2-4-1 (H) | 533 | L | 233 | H | 378 | H | 418 | L |
| MAI 3-2-5 (L) | 360 | H | 150 | H | 440 | L | 535 | L |
| MAI 3-13-6 (L) | 311 | H | 253 | H | 557 | L | 363 | H |
| MAI 4-5-2 (H) | 329 | H | 539 | L | 492 | L | 129 | H |
| MAI 4-10-3 (L) | 299 | H | 462 | L | 370 | H | 483 | L |
| MAI 1-17-13 (L) | 251 | H | 359 | H | 527 | L | 345 | H |
| MAI 1-58-3 (L) | 439 | L | 390 | L | 480 | L | 229 | H |
| MAI 2-16-3-1 (H) | 231 | H | 461 | L | 169 | H | 628 | L |

Final norm: 381.5
H=High overall gca status
L=Lower overall gca status

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**Table 6. Overall heterosis status of crosses in maize**

| Lines | Testers | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | CM500 (L) | | CM500 (L) | | CM500 (L) | | CM500 (L) | |
| | Total score | Status | Total score | Status | Total score | Status | Total score | Status |
| MAI 1-1-1 (L) | 278 | H | 309 | H | 525 | L | 213 | H |
| MAI 1-5-2 (L) | 395 | L | 427 | L | 415 | L | 197 | H |
| MAI 1-8-3 (H) | 509 | L | 403 | L | 392 | L | 392 | L |
| MAI 1-17-2 (H) | 464 | L | 420 | L | 432 | L | 300 | H |
| MAI 1-17-11 (L) | 468 | L | 348 | H | 426 | L | 334 | H |
| MAI 1-21-4 (H) | 307 | H | 297 | H | 497 | L | 360 | H |
| MAI 1-22-1 (L) | 398 | L | 583 | L | 469 | L | 353 | H |
| MAI 1-22-3 (H) | 471 | L | 456 | L | 547 | L | 310 | H |
| MAI 1-31-2 (H) | 487 | L | 325 | H | 597 | L | 206 | H |
| MAI 1-37-3 (H) | 331 | H | 414 | L | 393 | L | 387 | L |
| MAI 1-41-3 (H) | 391 | L | 362 | H | 336 | H | 310 | H |
| MAI 1-48-1 (L) | 322 | H | 181 | H | 330 | H | 246 | H |
| MAI 1-77-1-1 (L) | 569 | L | 264 | H | 501 | L | 308 | H |
| MAI 1-91-3 (H) | 351 | H | 356 | H | 522 | L | 291 | H |
| MAI 1-97-3 (L) | 389 | L | 297 | H | 374 | H | 365 | H |
| MAI 1-98-3 (H) | 629 | L | 663 | L | 582 | L | 602 | L |
| MAI 1-108-2 (L) | 350 | H | 278 | H | 402 | L | 260 | H |
| MAI 2-4-1-1 (H) | 507 | L | 332 | H | 284 | H | 435 | L |
| MAI 2-9-1-2 (H) | 454 | L | 530 | L | 426 | L | 518 | L |
| MAI 3-2-4-1 (H) | 439 | L | 254 | H | 442 | L | 310 | H |
| MAI 3-2-5 (L) | 329 | H | 181 | H | 430 | L | 364 | H |
| MAI 3-13-6 (L) | 357 | H | 256 | H | 528 | L | 274 | H |
| MAI 4-5-2 (H) | 343 | H | 381 | H | 531 | L | 134 | H |
| MAI 4-10-3 (L) | 243 | H | 310 | H | 355 | H | 264 | H |
| MAI 1-17-13 (L) | 307 | H | 257 | H | 553 | L | 277 | H |
| MAI 1-58-3 (L) | 409 | L | 313 | H | 528 | L | 277 | H |
| MAI 2-16-3-1 (H) | 304 | H | 351 | H | 306 | H | 443 | L |

Final norm: 381.5
H=High overall gca status
L=Lower overall gca status

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**Table 7. Distribution of crosses with high overall *sca* and heterotic status in relation to overall parental *gca* status in maize *HH* both the parents are high in their overall general combining ability**

| Parental *gca* status of crosses | Number of crosses | | | Conditional probability that a cross with high *sca* status is found in the category | Conditional probability that a cross with high heterotic status is found in the category |
|---|---|---|---|---|---|
| | Under the category | With high (H) overall *sca* status | With high (H) overall heterotic status | | |
| H × H | 28 | 14 | 11 | 0.24 | 0.19 |
| H × L/L × H | 54 | 28 | 27 | 0.48 | 0.47 |
| L × L | 26 | 16 | 20 | 0.28 | 0.34 |

*HL/LH* one parent is high and other one is low in their overall general combining ability
*LL* both the parents are low in their general combining ability

**Table 8. Distribution of crosses with high overall *sca* and heterotic status in relation to parental genetic divergence classes in maize**

| Parental divergence class | Number of crosses | | | Conditional probability that a cross with high *sca* status is found in the catogory | Conditional probability that a cross with high heterotic status is found in the catogory |
|---|---|---|---|---|---|
| | Under the category | With high (H) overall *sca* status | With high (H) heterotic status | | |
| DC 1 | 31 | 18 | 18 | 0.31 | 0.31 |
| DC 2 | 47 | 25 | 24 | 0.43 | 0.41 |
| DC 3 | 22 | 11 | 13 | 0.19 | 0.23 |
| DC 4 | 8 | 4 | 3 | 0.07 | 0.05 |