Combining Ability and Heterosis for Yield and Yield Components in Maize (Zea mays L.)

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Abstract: The study was conducted at two sites, University of Khartoum the experimental farm, faculty of Agriculture, Shambat and at west of Khartoum state, Elrawkeeb Dry Land Research Station, Sudan, during the summer and winter seasons of 2009 and 2010 respectively. Five inbred lines (2, 3, 6, 277, and 405) were used as lines and two inbred lines namely (66Y and 160) were used as (testers). These lines were crossed together according to line x tester technique to generate 10 F1 hybrids, every genotype was planted in rows with 4 m along, 70cm between rows and 25cm between plants. A line x tester method for estimation the general combining ability (GCA) of parent and specific combining ability (SCA) of their F1-hybrids was used. Genetic components resulting from additive and non-additive type of gene action were also estimated. Heterosis was measured as a deviation from the mid-parents and better-parent. The analysis of variance for combining ability revealed that both GCA and SCA variances were highly significant for most of the studied characters indicating importance of additive as well as non-additive types of gene action in controlling these traits. GCA mean squares for inbred lines were significant (P < 0.01) for all the traits except cob length and number of kernels/row while GCA due to testers was only significant (P<0.05) for 100-kernels weight. Moreover, variances due to SCA were higher in magnitude than GCA for the yield and yield components except cob diameter, number of rows/cob, number of kernels/row and harvest index. SCA to GCA ratios were less than one for most of the traits except cob diameter, number of kernels row/cob, number of kernels/row and harvest index indicating a preponderance of additive over no additive gene action. High positive heterosis for grain yield and its components was found for more than half of the hybrids studied. Crosses involving 160×3 and 66Y×2 produced the highest heterosis. It can be concluded that these parental lines can be desirable parents for hybrids as well as for inclusion in breeding program, since they may contribute favorable alleles in the synthesis of new varieties.

Key words: Maize, General combining ability, Specific combining ability, Heterosis, Grain yield.

INTRODUCTION

Maize (Zea mays L.) is the third most important cereal crop in the world after rice and wheat. It is cultivated in a wider range of environments than wheat and rice because of its greater adaptability (Koutsika-Sotiriou, 1999). Over 70% of maize in Africa is produced by resource poor small-scale farmers (Salasya et al., 1998). The average maize yield in Africa stood at 1.3 t/ha compared to 3.0 t/ha elsewhere (FAO, 2006). The low grain yields can be attributed to a number of constraints which include biotic stress (diseases, pests and lack of suitable varieties), a biotic stresses (low soil fertility and lack of capital to purchase farm inputs) (Salasya et al., 1998). In the Sudan, maize is normally grown as a rain fed crop in Kordofan, Darfur and Southern states or in small-irrigated areas in Northern states (Ahmed and Elhag, 1999). Recently, there has been an increased interest in maize production in the Sudan (Nour et al, 1997). Heterosis and combining ability is prerequisite for developing a good economically viable maize variety. Information on the heterotic patterns and combining ability among maize germplasm is essential in maximizing the effectiveness of hybrid development (Beck et al,1990). In maize, appreciable percentage of heterosis for yield and combining ability were studied by several workers (Roy et al., 1998; Paul et al., 1999 and Rokadia., 2005).

Combining ability studies provide information on the genetic mechanisms controlling the inheritance of quantitative traits and enable the breeders to select suitable parents for further improvement or use in hybrid breeding for commercial purposes. In biometrical genetics two types of combining abilities are considered i.e.
general combining ability (GCA) and specific combining ability (SCA). General combining ability refers to the average performance of the genotype in a series of hybrid combinations and is a measure of additive gene action whereas, specific combining ability is the performance of a parent in a specific cross in relation to general combining ability (Sharief et al., 2009). SCA is due to genes showing non-additive effects (Sprague and Tatum, 1942). Line × tester mating design was developed by Kempthorne (1957), which provides reliable information on the general and specific combining ability effects of parents and their hybrid combinations in applied breeding programs. The design has been widely used in maize breeding by several workers and continues to be applied in quantitative genetic studies in maize due to its significance (Sharma et al., 2004). However, the objective of this study was to evaluate of combining ability and estimate the heterosis for yield and yield components of maize genotypes.

**MATERIAL AND METHODS**

Seven inbred lines were used in this study, five inbred lines (2, 3, 6, 277 and 405) were used as lines and two inbred lines namely (66Y and 160) were used as (testers). These lines were crossed together according to line x tester technique (Kempthorne, 1957) to generate 10 F1 hybrids. Field evaluation of 17 genotypes (10 F1 hybrids plus 7 parental inbred lines) was performed in two sites: El Rawakeeb Dry land and Desertification Research station. (National Center for Research, which west of Omdurman city Khartoum state, longitude 32°15’ E, latitude 15°25’ N and 420 meters above the sea level) and the Experimental Farm of the Faculty of Agriculture, University of Khartoum, Shambat (Longitude 32°32’ E., Latitude 15°40´ N, and 380 meters above the sea level) during winter and summer seasons 2009 and 2010 respectively. The genotypes were laid out using spilt-plot design with three replications at the two sites. All recommended cultural practices and operations (planting, irrigation) were conducted. Different plant characters were measured, which included cob length, cob diameter, number of kernels/row, number of kernels/cob, 100 kernels/cob, cob weight, grain yield/plant, grain yield kg/ha and harvest index.

Data from each site was subjected to ANOVA separately to detect the significance of genotypic differences (Gomez and Gomez, 1984) before a combined ANOVA. Combining ability analysis was carried out according to Singh and Chaudhary (1979) based on line x tester general linear model for combined environments;

\[
Y_{ijk} = G + g_i + g_j + s_{ij} + e_{ij}
\]

Where; \(Y_{ijk}\) = performance of the hybrid when \(i\)th line is crossed to \(j\)th tester, \(G\) = overall mean, \(g_i\) = general combining ability of \(i\)th line, \(g_j\) = general combining ability of the \(j\)th tester, \(s_{ij}\) = specific combining ability when \(i\)th line is crossed to \(j\)th tester and \(e_{ij}\) = random error term.

For estimation of combining ability. The pooled data of the four environments were analyzed for general combining ability (GCA) and specific combining ability (SCA) effects, as described by Singh and Chaudhary (1979).

**Estimation of GCA:**

- **Lines** = GCA (line) = \(g_i = \frac{\sum_{r} x_{i..} - \frac{X_{..}}{I}}{I} \)
- **Testers** = GCA (line) = \(g_j = \frac{\sum_{r} x_{..j} - \frac{X_{..}}{I}}{J} \)

**Estimation of SCA effect = \(S_{ij} = x_{ij} - \frac{x_{i..} + x_{..j}}{IJ} \)**

Where:
- \(I\) = number of lines
- \(T\) = number of testers
- \(R\) = number of replications

Proportional contribution of lines, testers and their interaction line × tester to the total variances were calculated as follows:

The contribution due to lines = \(\frac{ss\ due\ to\ lines \times 100}{ss\ due\ to\ crosses}\)
The contribution due to line × tester = \text{ss due to tester interaction} \times 100 \\
\text{Crosses ss due to}

Genetic parameters:

σ²_A = Additive variance:
\sigma^2_1 = \left[ \text{Ms (L)} - \text{Mse} \right] / rt = \frac{1}{2} \sigma^2_A
\sigma^2_2 = \left[ \text{Ms (L)} - \text{Mse} \right] / rL = \frac{1}{2} \sigma^2_A
\sigma^2_A = 2 \sigma^2_L
\sigma^2_A = 2 \sigma^2_t

Additive variance
\sigma^2_A = \frac{2 \sigma^2_L + 2 \sigma^2_t}{2} = \sigma^2_1 + \sigma^2_t
\sigma^2_D = Dominance variance
\sigma^2_{Lt} = \left[ \text{Ms (Lx t)} - \text{Mse} \right] / r = \sigma^2_D

Average degree of dominance (\bar{a}) was calculated according to the following equation:

\bar{a} = \sqrt{\frac{2\sigma^2_D}{\sigma^2_A}}

if \bar{a} = 0 no dominance
if \bar{a} = <1> 0 partial dominance
if \bar{a} = 1 complete dominance
if \bar{a} > 1 over dominance

Variance of general and specific combing ability was estimated according to (Singh and Chaudhary, 1979)

Heterosis: Using means computed from the combined analysis, percentage heterosis based on mid-parent(mp) and better parent (BP) values were been calculated according to the formula, using the following formula described by Davis(1978) as follows:

Mid-parent heterosis (Mp) = \left( \frac{F_1 - ((P_1 + P_2)/2)}{(P_1 + P_2)/2} \right) \times 100

Better-parent heterosis (Bp) = \left( \frac{F_1 - BP}{BP} \right) \times 100

Where: F_1= the mean of F_1 hybrid
P_1, P_2 and BP = means of the first, the second and better parent respectively.

RESULTS AND DISCUSSION

In the present study, mean squares due to lines were larger than due to tester (Table.1), indicating greater diversity among lines for most of the characters under study. Most of parental lines related to 160 and few of the 66Y revealed positive (GCA) (Table.2). Nevertheless, parental lines 2 and 6 were found most attractive general combiners. These parental lines can be desirable parents for hybrids as well as for inclusion in breeding program, since they may contribute favorable alleles in the synthesis of new varieties. Among the testers, the highest GCA values for grain yield (kg/ha) was revealed by tester 160. These results indicated that these inbred line (160) could be considered as good combiner for improving these traits. On the other hand, the analysis of variance for combining ability revealed that both GCA and SCA variances were highly significant for characters studied (Table.1), indicating importance of additive as well as non- additive types of gene action in controlling the traits. Furthermore, variances due to GCA were higher in magnitude than SCA for cob diameter, number of row/cob, number of kernels/row and harvest index (Table.1). Indicating importance of additive type of gene action for these traits. Similar finding were reported by, Seldom (1994), Mathur et al., (1998), Ogunbodede et al. (2000) and Ismail (2004). On the other hand, cob length, number of kernels/cob, 100-kernels/cob, grain yield/plant and grain yield kg/ha only SCA variance was significant and also ratio of GCA/SCA was less than unity indicating the involvement of non-additive (Table.4). This suppresses the findings of Mohammad (1993) and Dehghanapour et al. (1997). Further more, in the present studies, the hybrids different widely and estimate of SCA effects showed that, the hybrids 160x3, 160x6, 66x277 and 66x405 were significantly superior to others in their specific combing ability for grain yield kg/ha (Table.3). These crosses could be selected and used inbreeding programs for improving these traits.

Table.4 indicates the value of additive gene effects was more than the value of dominance gene for cob diameters, number of rows/cob and number of kernels/rows, while the value of dominance gene effects was higher than the value of additive gene effects for cob length, number of kernels/cob, 100- kernels weight, grain yield/plant, grain yield kg/ha and harvest index. The average degree of dominance was more than one for
number of kernels row/cob and number of kernels/row indicating this trait under control of the over dominance gene effect, whereas cob length, 100- kernels weight, grain yield kg/ha under control of complete dominance.

In the present study the results showed that, Heterosis estimates for most of the hybrids had positive mid-parents (MP %) and better parents (BP %) heterosis value for the yield and its component (Table 5). However, large number of hybrids showed superiority over their parents for various traits indicating the existence of substantial heterosis in the hybrids and the potential of these inbred lines for hybrid development. However, the ranges of heterotic responses observed in this study were on average higher than that reported by Gissa et al. (2007) for maize inbred lines. However, Tollenaar et al. (2004) observed higher mean grain yield MP of 167% and Betran et al. (2003) reported MP and BP of 157 and 126%, respectively, compared to 130.92 % and 125.28%, observed in this study. The extent of heterotic response of the F_1 hybrids largely depends on the breeding value and genetic diversity of the parents included in crosses, and on the environmental conditions under which hybrids are grown (Hallauer and Miranda, 1988; Young and Virmani, 1990; Glover et al., 2005).

<table>
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<th>Table 1: Mean squares from Line × Tester analysis of variance thirteen maize genotypes evaluated for different characters across during (Elrawkeeb - summer 2009, Shambat –summer 2009, Shambat- winter 2009 and Shambat- winter 2010).</th>
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<td>S.V</td>
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<td>Rep</td>
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<td>Line (L)</td>
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<td>Tester (T)</td>
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<td>Line × Tester</td>
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<tr>
<td>Crosses</td>
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<td>Error</td>
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* and **Significance at p=0.05 and p=0.01, respectively.

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<tr>
<th>Table 2: Estimation of general combing ability effects of testers and lines genotypes for different characters across four environments (Elrawkeeb - summer 2009, Shambat –summer 2009, Shambat- winter 2009 and Shambat- winter 2010).</th>
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<tbody>
<tr>
<td>S.V</td>
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<td>Testers</td>
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Table 4: Percentages contribution of lines, testers and lines × testers to total variation among crosses for different characters and genetic parameters values for studied characters.

<table>
<thead>
<tr>
<th>Characters</th>
<th>GCA Contribution due to lines</th>
<th>GCA Contribution due to Tester</th>
<th>GCA Contribution due to Lines × Tester</th>
<th>SCA Contribution due to lines</th>
<th>SCA Contribution due to Tester</th>
<th>SCA Contribution due to Lines × Tester</th>
<th>Genetic parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cob length (cm)</td>
<td>18.26</td>
<td>6.64</td>
<td>75.10</td>
<td>0.33</td>
<td>0.27</td>
<td>0.33</td>
<td>1.29</td>
</tr>
<tr>
<td>Cob diameter (mm)</td>
<td>52.32</td>
<td>0.77</td>
<td>47.00</td>
<td>1.13</td>
<td>1.50</td>
<td>1.38</td>
<td>1.47</td>
</tr>
<tr>
<td>Cob weight (g)</td>
<td>34.13</td>
<td>0.04</td>
<td>65.83</td>
<td>0.52</td>
<td>0.01</td>
<td>0.00</td>
<td>#</td>
</tr>
<tr>
<td>No. of rows per cob</td>
<td>43.76</td>
<td>12.84</td>
<td>43.40</td>
<td>1.30</td>
<td>0.26</td>
<td>0.20</td>
<td>1.60</td>
</tr>
<tr>
<td>No. of kernels/ cob</td>
<td>57.03</td>
<td>4.96</td>
<td>38.01</td>
<td>1.63</td>
<td>0.80</td>
<td>0.19</td>
<td>2.88</td>
</tr>
<tr>
<td>100- kernels weight (g)</td>
<td>35.30</td>
<td>11.59</td>
<td>53.11</td>
<td>0.88</td>
<td>380.15</td>
<td>531.68</td>
<td>1.20</td>
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<tr>
<td>Harvest index (%)</td>
<td>50.84</td>
<td>0.63</td>
<td>48.53</td>
<td>1.06</td>
<td>13.79</td>
<td>13.15</td>
<td>1.45</td>
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Table 5: Magnitude of heterosis for the different characters in 13 maize hybrids expressed as percentage of increase over and decrease under mid-parent (MP%) or better parent (BP%) evaluated a cross four environments Elraweek - summer 2009, Shambat - summer 2009, Shambat- winter 2009 and Shambat- winter 2010.

Conclusions:

It can be concluded that, high positive heterosis for grain yield and its components was found for more than half of the hybrids studied. However, these results indicated that these crosses could be selected and used in breeding programs for improving these traits. The analysis of variance for combining ability revealed that both general combining ability (GCA) and specific combining ability (SCA) variances were highly significant for characters studied indicating importance of additive as well as non-additive types of gene action in controlling these traits. Moreover, variances due to SCA were higher in magnitude than GCA for the yield and yield components except cob diameter, number of row/cob, number of kernels/row and harvest index.

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