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# Useful Heterosis and Combining Ability in Maize *(Zea mays L.)* Agronomic and Yield Characters under Well Watering and Water Stress at Flowering

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***Authors' contributions***

*This work was carried out in collaboration between all authors. Author AMMAN designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors MMMA and MAA managed the literature searches. Author ASMY managed the experimental process and performed data analyses. All authors read and approved the final manuscript.*

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## ABSTRACT

Selecting superior parents for hybrid combinations and studying the nature of genetic variation are prerequisites for starting a successful breeding program. The main objective of the present study was to assess performance, useful heterosis and combining ability among maize inbreds under optimum and drought conditions. Six inbreds and their diallel $F_1$'s were evaluated in 2013 and 2014 seasons in two experiments, one under well watering (WW) and one under water stress (WS) at flowering. Data combined across seasons revealed that the inbreds L53, L20 and Sk5 and the crosses L20 × L53, L53 x Sk5 and L53 × Sd7 under WW and WS had the highest grain yield/plant (GYPP) and its components. The largest average heterobeltiosis (236.58%) was shown under WS by GYPP. Maximum GYPP heterobeltiosis reached 736.0% by the cross L28 x Sd7 under WS. The magnitude of general combining ability (GCA) (additive) was higher than specific combining ability (SCA) (non-additive) mean squares for leaf angle (LANG), ears/plant (EPP), rows/ear (RPE), 100-kernels weight (100 KW), kernels/plant (KPP) and barren stalks (BS) under WW and WS, days to

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anthesis (DTA) under WW and anthesis silking interval (ASI) under WS. On the contrary, the magnitude of SCA was higher than GCA mean squares for ear height (EH), kernels/row (KPR) and GYPP, under WW and WS, DTA under WS and ASI under WW. The best inbreds in GCA effects for GYPP and all yield components were L53 followed by L20 and Sk5. The best crosses in SCA effects for the same traits were Sk5 × L18 followed by L20 × L53 and L28 × Sd7 under WW and WS. Mean performance of inbreds and crosses was significantly correlated with GCA and SCA effects, respectively for most studied traits under WW and WS.

*Keywords: Heterobeltiosis; diallel analysis; water stress; rank correlation.*

## 1. INTRODUCTION

Egypt produces about 5.8 million tons of maize (*Zea mays* L.) per year and it is cultivated in approximately 0.75 million hectares [1]. Maize is used primarily for human food, animal feed and poultry industry in Egypt and ranks second to wheat among cereal crops. Maize is a summer season crop in Egypt and depends on flood irrigation from River Nile and its branches and canals. However, the amount of water available for irrigation is reducing, especially at the ends of canals and due to expanding maize cultivation into the deserts and competition with other crops; especially rice. In order to stabilize maize production in Egypt, there is need to develop maize hybrids with drought tolerance.

Maize is a highly water-dependent crop and drought can cause considerable yield reductions throughout the growing cycle and especially during flowering stage [2-5]. Global warming and reduction of current water resources in Egypt will adversely affect maize production in the future. One of the most effective and practical strategies to reduce negative effects of drought to maize production is the development of varieties that have better tolerance to drought stress [6,7]. Several investigations have been undertaken over the years to improve drought tolerance in breeding programs [8-11]. Edmeades et al. [12] demonstrated that germplasm developed from drought tolerant source populations performed significantly better under drought stress compared to conventional populations. Despite the increasing grain yield in Egypt due to the use of single and three-way cross hybrids bred under high inputs, *i.e.* high N fertilizer rate and well irrigation, there is a lack of information on the proper maize breeding procedures for improving drought tolerance.

Heterosis is the genetic expression of the superiority of a hybrid in relation to its parents [13]. The term heterobeltiosis has been suggested to describe the increased performance of the hybrid over the better parent [14]. Heterosis is also modified by the interaction between genotypes and environment [15,16]. Since inbreds are more sensitive to environmental differences, some traits have been found to be more variable among inbreds than among hybrids [17]. Similarly, Betran et al. [18] reported extremely high expression of heterosis in maize under stress, especially under severe drought stress because of the poor performance of inbred lines under these conditions.

Combining ability has been defined as the performance of a line in hybrid combinations [19]. Since the final evaluation of inbred lines can be best determined by hybrid performance, it plays an important role in selecting superior parents for hybrid combinations and in studying the nature of genetic variation [15,20,21]. In general, diallel analysis have been used primarily to estimate general (GCA) and specific (SCA) combining ability effects from crosses of fixed lines [20,22]. Investigators reported more proportional and significant GCA effects for yield, days to silk and plant across locations [23-25]. On the other hand, Singh and Asnani [26] found that both GCA (additive) and SCA (non-additive) effects play an important role in the inheritance of yield and its components. Shewangizaw et al. [27] also reported significant GCA and SCA for most traits, but predominance of non-additive genetic variance in the case of yield. Knowledge about the combining ability of drought tolerant inbreds in diverse environments is essential for plant breeding programs that use this germplasm. The objectives of the present study were to: (i) assess performance, heterosis and combining ability among maize inbreds under optimum and drought conditions for agronomic, yield and yield related traits, (ii) identify suitable parents and hybrids for further breeding studies on improving maize drought tolerance and (iii) analyze correlations among inbred and hybrid *per se* performance, GCA, SCA and heterosis for studied traits.

## 2. MATERIALS AND METHODS

This study was carried out at the Agricultural Experiment and Research Station of the Faculty of Agriculture, Cairo University, Giza, Egypt (30° 02'N latitude and 31° 13'E longitude with an altitude of 22.50 meters above sea level), in 2012, 2013 and 2014 seasons.

### 2.1 Plant Material

Based on the results of previous experiments [28], six maize (*Zea mays* L.) inbred lines in the 8$^{th}$ selfed generation ($S_8$), showing clear differences in performance and GCA for grain yield under WS, were chosen in this study to be used as parents of diallel crosses (Table 1).

### 2.2 Making $F_1$ Diallel Crosses

In 2012 season, all possible diallel crosses (except reciprocals) were made among the six parents, so seeds of 15 direct $F_1$ crosses were obtained. Seeds of the six parents were also increased by selfing in the same season (2012) to obtain enough seeds of the inbreds in the 9$^{th}$ selfed generation ($S_9$).

### 2.3 Evaluation of Parents and $F_1$`s

Two field experiments were carried out in each season of 2013 and 2014 at the Agricultural Experiment and Research Station of the Faculty of Agriculture, Cairo University, Giza. Each experiment included 21 genotypes (15 $F_1$ crosses and their six parents). The first experiment was done under well irrigation by giving all required irrigations, but the second experiment was done under deficit irrigation at flowering stage by skipping the fourth and fifth irrigations. A randomized complete blocks design with three replications was used in each experiment.

Each experimental plot consisted of one ridge of 4 m long and 0.7 m width, *i.e.* the experimental plot area was 2.8 m$^2$. Seeds were sown in hills at 20 cm apart, thereafter (before the 1$^{st}$ irrigation) were thinned to one plant/hill to achieve a plant density of 76,400 plants/ha, respectively. Sowing date of the two experiments was on May5 and May8 in 2013 and 2014 seasons, respectively. The soil of the experimental site was clayey loam. All other agricultural practices were followed according to the recommendations of ARC, Egypt. The analysis of the experimental soil, as an average of the two growing seasons 2013 and 2014, indicated that the soil is clay loam (4.00% coarse sand, 30.90% fine sand, 31.20% silt, and 33.90% clay), the pH (paste extract) is 7.73, the EC is 1.91 dSm-1, soil bulk density is 1.2 g cm-3, calcium carbonate is 3.47%, organic matter is 2.09%, the available nutrient in mg kg-1are Nitrogen (34.20), Phosphorous (8.86), Potassium (242), hot water extractable B (0.49), DTPA - extractable Zn (0.52), DTPA - extractable Mn (0.75) and DTPA - extractable Fe (3.17). Meteorological variables in the 2013 and 2014 growing seasons of maize were obtained from Agro-meteorological Station at Giza, Egypt. For May, June, July and August, mean temperature was 27.87, 29.49, 28.47 and 30.33℃, maximum temperature was 35.7, 35.97, 34.93 and 37.07℃ and relative humidity was 47.0, 53.0, 60.33 and 60.67%, respectively, in 2013 season. In 2014 season, mean temperature was 26.1, 28.5, 29.1 and 29.9℃, maximum temperature was 38.8, 35.2, 35.6 and 36.4℃ and relative humidity was 32.8, 35.2, 35.6 and 36.4%, respectively. Precipitation was nil in all months of maize growing season for both seasons. Sibbing was carried out in each entry for the purpose of determining the grain contents of protein, oil and starch.

### 2.4 Data Recorded

Days to 50% anthesis (DTA) (as number of days from planting to anthesis of50% of plants per plot). Anthesis-silking interval (ASI) (as number of days between 50% silking and 50% anthesis of plants per plot). Plant height (PH) (cm) (measured from ground surface to the point of flag leaf insertion for five plants per plots). Ear height (EH) (cm) measured from ground surface to the base of the top most ear relative to the plant height for five plants per plots. Barren stalks (BS) (%) measured as percentage of plants bearing no ears relative to the total number of plants in the plot (an ear was considered fertile if it had one or more grains on the rachis). Leaf angle (LANG) (°) measured as the angle between stem and blade of the leaf just above ear leaf, according to Zadoks et al. [29]. Ears per plant (EPP) calculated by dividing number of ears per plot on number of plants per plot. Rows per ear (RPE) using 10 random ears/plot at harvest. Kernels per row (KPR) using the same 10 random ears/plot. Kernels per plant (KPP) calculated as: number of ears per plant × number of rows per ear × number of kernels per row. 100-kernel weight (100-KW) (g) adjusted at 15.5% grain moisture, using shelled grains of each plot. Grain yield/plant (GYPP) (g) estimated by dividing the grain yield per plot (adjusted at 15.5% grain moisture) on number of plants/plot at harvest.

### 2.5 Biometrical and Genetic Analyses

Analysis of variance of the RCBD was performed on the basis of individual plot observation using GENSTAT $10^{th}$ addition windows software. Combined analysis of variance across the two seasons was also performed if the homogeneity test was non-significant. Least significant differences (LSD) values were calculated to test the significance of differences between means according to Steel et al. [30]. Diallel crosses were analyzed to obtain general (GCA) and specific (SCA) combining ability variances and effects for studied traits according to Griffing [31] Model I (fixed effect) Method 2. The significance of the various statistics was tested by "t" test, where "t" is a parameter value divided by its standard error. However, for making comparisons between different effects, the critical difference (CD) was calculated using the corresponding comparison as follows: CD = SE × t (tabulated).

Heterobeltiosis was calculated as a percentage of $F_1$ relative to the better-parent (BP) values as follows: Heterobeltiosis (%) = $100[(\overline{F}_1-\overline{BP})/\overline{BP}]$ Where: $\overline{F}_1$= mean of an $F_1$ cross and $\overline{BP}$= mean of the better parent of this cross. The significance of heterobeltiosis was determined as the least significant differences (LSD) at 0.05 and 0.01 levels of probability according to Steel et al. [30] using the following formula: $LSD_{0.05} = t_{0.05}(edf) \times SE$, $LSD_{0.01} = t_{0.01}(edf) \times SE$, Where: *edf*= the error degrees of freedom, SE**=** the standard error, SE for heterobeltiosis $=(2MS_e/r)^{1/2}$ Where: $t_{0.05}$ and $t_{0.01}$ are the tabulated values of '*t*' for the error degrees of freedom at 0.05 and 0.01 levels of probability, respectively. $MS_e$: The mean squares of the experimental error from the analysis of variance Table. *r*: Number of replications.

Rank correlation coefficients were calculated between *per se* performance of inbred lines and their GCA effects; between *per se* performance of $F_1$ crosses and their SCA effects and between SCA effects and heterobeltiosis of $F_1$ crosses for studied traits under WW and WS conditions by using SPSS 17 computer software and the significance of the rank correlation coefficient was tested according to Steel et al. [30]. The correlation coefficient ($r_s$) was estimated for each pair of any two parameters as follows: $r_s = 1 - (6 \sum d_i^2)/(n^3-n)$, Where, $d_i$ is the difference between the ranks of the $i^{th}$ genotype for any two parameters, n is the number of pairs of data. The hypothesis Ho: $r_s = 0$ was tested by the r-test with (n-2) degrees of freedom.

## 3. RESULTS AND DISCUSSION

### 3.1 Analysis of Variance

Combined analysis of variance of a randomized complete blocks design for 12 traits of 21 maize genotypes under two environments (WW and WS) across two seasons is presented in Table 2. Mean squares due to parents and $F_1$ crosses under both environments were highly significant for all studied traits, except ASI of parents and $F_1$'s under WW and parents under WS, indicating the significance of differences among studied parents and among $F_1$ diallel crosses in the majority of cases.

Mean squares due to parents *vs.* $F_1$ crosses were highly significant for all studied traits under both environments, except for ASI under WW and WS and BS under WW, suggesting the presence of significant average heterosis for most studied cases. Mean squares due to the interactions parents × years (P × Y) and crosses × years ($F_1$ × Y) were significant or highly significant for all studied traits under both environments, except ASI under WW for P x Y, PH under WW and WS for P×Y and WS for $F_1$×Y, EPP under WW for P×Y, RPE under WW for P x Y and WS for $F_1$ x Y, KPP under WW for P x Y for $F_1$ x Y, 100KW under WS for P x Y and KPP under WW for P x Y. Mean squares due to parents *vs.* crosses × years were significant or highly significant in 13 out of 24 cases; nine of them were expressed in WS environment for ASI, BS, LANG, EPP, RPE, KPR, KPP, 100-KW, and GYPP traits. This indicates that heterosis differ from season to season in these cases. It is observed from Table 2 that under both environments (24 cases), the largest contributor to total variance was parents vs. $F_1$'s (heterosis) variance for 14 cases, followed by $F_1$ crosses (7 cases) and parents (3 cases). Similar conclusion was reported by Al-Naggar et al. [2,32-35].

### 3.2 Mean Performance

Mean grain yield per plant and per hectare across years under the two environments (WW and WS) for each inbred and hybrid is presented in Table 3. In general, GYPP of the three inbreds

L53, L20 and Sk5 was higher than that of the three other three inbreds (L18, L28 and Sd7) under both environments (WW and WS). This means that the inbreds Sk5, L20 and Sk5 could be considered tolerant to WS, while inbreds Sk5, L20 and Sk5 are sensitive. The highest GYPP of all inbreds was achieved under WW environment because of the optimum irrigation. The inbred L53 showed the highest mean for GYPP under both environments. The inbred L20 was the second highest for grain yield, while inbred Sk5 came in the third rank. On the contrary, the inbred Sd7 exhibited the lowest mean for GYPP under both environments. The rank of inbreds under WW for GYPP was similar to that under WS environment, indicating less effect of interaction between inbreds and irrigation regime on these traits. The superiority of L53 in GYPP over other inbreds was associated with superiority in all studied yield components, but had the tallest plant and the highest ear position under WS and non-stress conditions.

**Table 1. Designation, origin and most important traits of six inbred lines (L) used for making diallel crosses of this study**

| Entry designation | Origin | Institution (country) | Prolificacy | Productivity under water stress | Leaf Angle |
|---|---|---|---|---|---|
| L20-Y | SC 30N11 | Pion. Int.Co. | Prolific | High | Erect |
| L53-W | SC 30K8 | Pion. Int.Co. | Prolific | High | Erect |
| Sk 5-W | Teplacinco - 5 | ARC-Egypt | Prolific | High | Erect |
| L18-Y | SC 30N11 | Pion. Int.Co. | Prolific | Low | Wide |
| L28-Y | Pop 59 | ARC-Thailand | Non-Prolific | Low | Wide |
| Sd 7-W | A.E.D. | ARC-Egypt | Non-Prolific | Low | Erect |

*ARC = Agricultural Research Center, Pion. Int. Co. = Pioneer International Company in Egypt, SC = Single cross, A.E.D. = American Early Dent; an old open-pollinated variety, W = White grains and Y = Yellow grains*

**Table 2. Combined analysis of variance of RCBD across two years for studied traits of six parents (P) and 15 $F_1$ crosses (F) and their interactions with years (Y) under water stress (WS) and non-stress (WW) conditions**

| SOV | df | % Sum of squares | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | WW | WS | WW | WS | WW | WS | WW | WS |
| | | DTA | | ASI | | PH | | EH | |
| P | 5 | 7.84** | 9.71** | 2.50 | 2.94 | 13.22** | 13.53** | 15.48** | 14.10** |
| $F_1$ | 14 | 3.95* | 37.40** | 14.83 | 18.45** | 21.97** | 10.03** | 25.23** | 24.70** |
| P vs $F_1$ | 1 | 29.35** | 5.49** | 2.42 | 1.11 | 58.93** | 72.77** | 50.17** | 47.19** |
| P × Y | 5 | 7.58** | 2.72** | 1.61 | 8.56* | 0.26 | 0.26 | 0.46 | 0.69 |
| $F_1$ × Y | 14 | 1.97 | 34.99** | 15.00* | 18.73** | 0.41* | 0.47 | 1.77** | 2.60** |
| P vs $F_1$ × Y | 1 | 0.27 | 0.65 | 2.18 | 5.45** | 0.07 | 0.01 | 0.02 | 0.02 |
| | | BS% | | LANG | | EPP | | RPE | |
| P | 5 | 9.11* | 7.05** | 19.35** | 24.31** | 17.23** | 3.93 | 28.95** | 19.45** |
| $F_1$ | 14 | 17.60** | 6.42** | 50.17** | 19.93** | 27.41** | 22.58** | 28.54** | 17.92** |
| P vs $F_1$ | 1 | 0.04 | 36.81** | 6.12** | 7.24** | 3.82** | 8.61** | 7.44** | 10.42** |
| P × Y | 5 | 9.11* | 3.09* | 2.65** | 5.24** | 2.07 | 11.95** | 3.73** | 14.41* |
| $F_1$ × Y | 14 | 19.56** | 5.49* | 10.12** | 14.57** | 7.97* | 14.78** | 4.68* | 2.24 |
| P vs $F_1$ × Y | 1 | 0.33 | 18.62** | 0.40* | 1.58** | 2.81* | 4.32** | 0.09 | 1.55* |
| | | KPR | | KPP | | 100-KW | | GYPP | |
| P | 5 | 5.85** | 13.92** | 9.69** | 4.69** | 11.75** | 15.20** | 5.50** | 3.71** |
| $F_1$ | 14 | 10.66** | 9.68** | 6.63** | 11.27** | 16.33** | 13.54** | 9.66** | 17.83** |
| P vs $F_1$ | 1 | 65.45** | 59.17** | 59.24** | 51.92** | 45.48** | 16.00** | 75.18** | 70.56** |
| P × Y | 5 | 1.64* | 2.11* | 0.74 | 5.34** | 4.11** | 0.65 | 0.37** | 0.18* |
| $F_1$ × Y | 14 | 1.84** | 1.19* | 5.21** | 5.56** | 4.20** | 11.18** | 1.91** | 1.95** |
| P vs $F_1$ × Y | 1 | 0.90** | 1.06** | 0.001* | 1.94** | 2.09** | 1.82** | 0.01 | 0.17** |

** and ** significant at 0.05 and 0.01 probability levels, respectively, WW = Well watering, WS = Water stress, DTA = Days to 50% anthesis, ASI = Anthesis silking interval, RH = Plant height, EH = Ear height, BS = Barren stalks, LANG = Leaf angle, EPP = Ears per plant, RPE = Rows per ear, KPR = Kernels per row, KPP = Kernels per plant, 100-KW = 100 Kernel weight, GYPP = Grain yield per plant.*

**Table 3. Means of studied agronomic and yield traits of each inbred and hybrid under water stress (WS) and well watering (WW) across two seasons**

| Genotypes | WW | WS | WW | WS | WW | WS | WW | WS |
|---|---|---|---|---|---|---|---|---|
| | DTA | | ASI | | PH | | EH | |
| | | | | Inbreds | | | | |
| L20 | 59.67 | 61.67 | 2.33 | 3.25 | 194.17 | 174.50 | 72.30 | 65.67 |
| L53 | 63.33 | 65.83 | 2.83 | 2.67 | 233.67 | 192.17 | 99.25 | 88.17 |
| Sk5 | 61.00 | 64.83 | 2.67 | 2.67 | 174.67 | 168.67 | 72.25 | 74.98 |
| L18 | 64.58 | 65.83 | 2.67 | 3.17 | 178.33 | 158.17 | 66.33 | 67.08 |
| L28 | 60.00 | 61.33 | 2.67 | 2.67 | 182.83 | 175.83 | 56.70 | 52.78 |
| Sd7 | 64.08 | 65.67 | 3.00 | 3.42 | 202.33 | 184.67 | 87.76 | 72.14 |
| | | | | $F_1$ crosses | | | | |
| L20 X L53 | 58.00 | 59.50 | 2.00 | 2.67 | 216.00 | 222.50 | 78.17 | 83.05 |
| L20 XSK5 | 59.00 | 60.83 | 2.33 | 3.00 | 243.33 | 236.33 | 105.12 | 100.21 |
| L20 X L18 | 60.00 | 61.50 | 2.00 | 2.58 | 247.17 | 240.17 | 110.65 | 105.92 |
| L20 X L28 | 59.00 | 61.00 | 2.50 | 2.73 | 240.17 | 235.67 | 104.42 | 102.17 |
| L20 X Sd7 | 59.17 | 61.00 | 2.83 | 2.85 | 242.17 | 236.83 | 107.28 | 103.89 |
| L 53 X Sk5 | 59.00 | 60.00 | 2.00 | 3.00 | 224.00 | 229.50 | 93.82 | 92.78 |
| L53 X L18 | 60.50 | 62.00 | 2.00 | 2.93 | 267.00 | 248.83 | 117.27 | 114.56 |
| L53 X L28 | 59.00 | 60.83 | 2.00 | 2.50 | 238.00 | 232.00 | 99.50 | 98.49 |
| L53 X Sd7 | 59.00 | 60.08 | 2.00 | 2.92 | 234.00 | 231.00 | 96.66 | 96.06 |
| Sk5 X L18 | 59.00 | 61.00 | 2.08 | 2.55 | 238.67 | 233.83 | 103.06 | 100.40 |
| Sk5 X L28 | 59.75 | 61.50 | 2.25 | 2.50 | 245.17 | 238.33 | 109.09 | 104.60 |
| Sk5 X Sd7 | 60.00 | 61.50 | 2.17 | 3.00 | 255.17 | 246.33 | 113.83 | 110.87 |
| L18 X L28 | 61.50 | 63.08 | 2.67 | 3.08 | 273.00 | 254.67 | 125.33 | 120.36 |
| L18 X Sd7 | 60.00 | 61.50 | 2.00 | 3.00 | 251.17 | 243.17 | 113.08 | 108.83 |
| L28 X Sd7 | 59.83 | 61.50 | 2.17 | 3.00 | 247.33 | 240.33 | 105.84 | 105.46 |
| | BS | | LANG | | EPP | | RPE | |
| | | | | Inbreds | | | | |
| L20 | 9.22 | 7.37 | 23.33 | 25.50 | 1.34 | 1.10 | 15.30 | 14.06 |
| L53 | 12.24 | 10.02 | 23.83 | 25.17 | 1.39 | 1.25 | 15.97 | 14.97 |
| Sk5 | 9.43 | 15.66 | 19.67 | 24.00 | 1.25 | 1.13 | 14.23 | 13.73 |
| L18 | 12.06 | 11.15 | 31.33 | 31.00 | 1.15 | 1.16 | 12.92 | 13.04 |
| L28 | 7.46 | 11.87 | 35.00 | 32.67 | 1.09 | 1.10 | 12.55 | 12.31 |
| Sd7 | 9.22 | 14.53 | 26.50 | 26.83 | 1.18 | 1.16 | 13.30 | 11.67 |
| | | | | $F_1$ crosses | | | | |
| L20 X L53 | 6.13 | 5.53 | 20.17 | 24.67 | 1.47 | 1.48 | 16.58 | 16.10 |
| L20 XSK5 | 10.50 | 13.20 | 28.33 | 30.67 | 1.29 | 1.25 | 14.83 | 14.04 |
| L20 X L18 | 10.36 | 14.29 | 29.83 | 33.67 | 1.20 | 1.15 | 14.22 | 13.58 |
| L20 X L28 | 9.55 | 12.50 | 27.50 | 31.00 | 1.23 | 1.21 | 14.90 | 14.11 |
| L20 X Sd7 | 9.78 | 13.19 | 28.33 | 31.83 | 1.21 | 1.20 | 14.83 | 14.00 |
| L 53 X Sk5 | 8.45 | 8.01 | 24.67 | 26.83 | 1.32 | 1.35 | 15.80 | 15.00 |
| L53 X L18 | 11.00 | 16.37 | 32.33 | 35.50 | 1.13 | 1.09 | 13.80 | 13.00 |
| L53 X L28 | 8.71 | 10.64 | 25.83 | 29.00 | 1.29 | 1.29 | 15.00 | 14.61 |
| L53 X Sd7 | 8.71 | 9.27 | 25.33 | 27.83 | 1.30 | 1.31 | 15.36 | 14.80 |
| Sk5 X L18 | 9.39 | 11.37 | 27.00 | 30.33 | 1.26 | 1.23 | 14.90 | 14.20 |
| Sk5 X L28 | 10.26 | 13.65 | 29.50 | 32.83 | 1.20 | 1.18 | 14.50 | 13.91 |
| Sk5 X Sd7 | 10.77 | 15.60 | 31.00 | 34.67 | 1.18 | 1.12 | 13.80 | 13.21 |
| L18 X L28 | 15.76 | 22.43 | 35.17 | 38.67 | 1.08 | 1.04 | 12.44 | 12.23 |
| L18 X Sd7 | 10.56 | 14.84 | 30.33 | 34.33 | 1.19 | 1.14 | 13.90 | 13.37 |
| L28 X Sd7 | 9.67 | 11.41 | 28.50 | 32.00 | 1.20 | 1.19 | 14.40 | 14.18 |
| | KPP | | KPR | | 100-KW | | GYPP (g) | |
| | | | | Inbreds | | | | |
| L20 | 681.12 | 504.14 | 37.38 | 32.02 | 34.09 | 30.09 | 106.58 | 57.74 |
| L53 | 755.07 | 670.36 | 42.37 | 39.40 | 35.41 | 33.40 | 132.05 | 85.54 |
| Sk5 | 575.11 | 454.19 | 33.72 | 30.70 | 31.69 | 28.95 | 77.56 | 46.87 |
| L18 | 492.13 | 423.87 | 29.08 | 28.17 | 26.35 | 27.66 | 46.69 | 34.79 |
| L28 | 458.08 | 390.20 | 28.22 | 26.12 | 25.55 | 25.46 | 44.37 | 21.20 |

| Genotypes | WW | WS | WW | WS | WW | WS | WW | WS |
|---|---|---|---|---|---|---|---|---|
| Sd7 | 524.59 | 338.11 | 30.88 | 24.96 | 28.09 | 24.37 | 55.10 | 13.21 |
| | | | | $F_1$ crosses | | | | |
| L20 X L53 | 1001.41 | 914.82 | 54.03 | 50.88 | 40.60 | 37.02 | 277.36 | 242.72 |
| L20 XSK5 | 851.19 | 770.97 | 46.54 | 43.28 | 35.75 | 31.67 | 221.68 | 166.82 |
| L20 X L18 | 800.63 | 694.53 | 44.57 | 42.04 | 35.43 | 31.87 | 219.17 | 182.09 |
| L20 X L28 | 829.05 | 748.89 | 45.74 | 43.82 | 36.31 | 33.21 | 232.77 | 171.71 |
| L20 X Sd7 | 818.54 | 734.12 | 45.49 | 43.12 | 35.92 | 32.72 | 226.70 | 179.94 |
| L 53 X Sk5 | 903.14 | 846.61 | 48.48 | 45.46 | 38.08 | 34.95 | 245.53 | 202.98 |
| L53 X L18 | 743.15 | 635.25 | 42.54 | 39.42 | 33.91 | 29.89 | 197.48 | 138.90 |
| L53 X L28 | 862.10 | 775.94 | 46.94 | 44.76 | 37.23 | 33.77 | 237.53 | 171.64 |
| L53 X Sd7 | 885.44 | 810.39 | 47.67 | 45.11 | 37.63 | 34.27 | 240.96 | 197.33 |
| Sk5 X L18 | 844.80 | 762.38 | 46.26 | 44.28 | 36.74 | 33.42 | 234.83 | 183.68 |
| Sk5 X L28 | 806.15 | 722.57 | 45.12 | 42.53 | 35.57 | 32.39 | 223.20 | 177.24 |
| Sk5 X Sd7 | 773.02 | 659.12 | 43.39 | 40.63 | 34.56 | 30.57 | 207.22 | 147.71 |
| L18 X L28 | 667.98 | 543.51 | 40.64 | 37.13 | 31.78 | 27.30 | 171.09 | 123.96 |
| L18 X Sd7 | 777.86 | 674.35 | 43.79 | 41.14 | 34.84 | 31.21 | 213.29 | 154.19 |
| L28 X Sd7 | 811.27 | 713.85 | 45.96 | 43.61 | 36.28 | 33.45 | 227.64 | 177.24 |

*WW = Well watering, WS = Water stress, DTA = Days to 50% anthesis, ASI = Anthesis silking interval, RH = Plant height, EH = Ear height, BS = Barren stalks, LANG = Leaf angle, EPP = Ears per plant, RPE = Rows per ear, KPR = Kernels per row, KPP = Kernels per plant, 100-KW = 100 Kernel weight, GYPP = Grain yield per plant*

The highest GYPP in this experiment (277.36 g) was recorded by the cross L20 × L53 under well watered environment (WW) followed by the crosses L53 x Sk5 (245.53g), L53 × Sd7 (240.96 g). The same crosses were also the highest yielders under WS with the same order. These crosses could therefore be considered responsive to optimum irrigation and tolerant to deficit irrigation. The superiority of these crosses in GYPP to other studied $F_1$'s was also expressed in all studied yield components, namely EPP, RPE, KPR, KPP, and 100-KW as well as in the shortest plant and lowest EH, narrowest LANG, lowest barrenness and the earliest in DTA under both WS and non-stress conditions. On the contrary, the cross L18 x L28 showed the lowest GYPP, EPP, RPE, KPR, KPP and 100-KW, the tallest plant, the highest EH, the widest LANG and the latest in anthesis.

## 3.3 Heterobeltiosis

Estimates of BP heterosis (heterobeltiosis) across all $F_1$ crosses, maximum values and number of crosses showing significant favorable heterobeltiosis for all studied traits under the two environments (WW and WS) across 2011 and 2012 years are presented in Table 4. Favorable heterobeltiosis in the studied crosses was considered negative for DTA, ASI, PH, EH, LANG and BS and positive for the rest of studied traits under both environments. In general, the highest average significant and positive (favorable) heterobeltiosis was shown by grain yield per plant (151.79 and 236.58%) under WW and WS, respectively. The highest heterobeltiosis expressed by grain yield in maize was previously reported by several investigators [3,32,34,36,37]. On the contrary, the lowest average significant (favorable) heterobeltiosis was shown by RPE (-1.59 and 0.00%) under WW and WS, respectively. The traits PH, EP, BS, LANG under all environments, ASI, EPP and RPE under WS showed on average unfavorable heterobeltiosis. However, some crosses showed significant favorable heterobeltiosis in these cases. In general, WW environment, where irrigation was optimum, showed the largest number of crosses and significant favorable heterobeltiosis for studied traits. For GYPP, the WS environment (the stressed environment) showed generally the highest maximum heterobeltiosis (736.00%).

The reason for getting the highest average heterobeltiosis estimates under WS environment could be attributed to the large reduction in grain yield and its components of the parental inbreds compared to that of $F_1$ crosses due to severe stress of water deficit at flowering stage (Table 3). In general, maize hybrids typically yield two to three times as much as their parental inbred lines. However, since a cross of two extremely low yielding lines can give a hybrid with high heterosis, a superior hybrid is not necessarily associated with high heterosis [38]. This author suggested that a cross of two high yielding inbreds might exhibit less heterosis but nevertheless produce a high yielding hybrid. Besides, a hybrid is superior not only due to heterosis but also due to other heritable factors that are not influenced by heterosis. Since inbreds are more sensitive to environmental differences, some traits have been found to be more variable among inbreds than among hybrids [17]. Similarly, Betran et al. [18] reported extremely high expression of heterosis in maize under stress, especially under severe drought stress because of the poor performance of inbred lines under these conditions On the contrary, the WW environment (non-stressed) showed the lowest average favorable heterobeltiosis for all studied traits, except for 100-KW (Table 4).

The largest significant favorable heterobeltiosis for GYPP in this study (736.00%) was shown by the cross (L28 × Sd7) under WS environment (Table 5). This cross showed also the highest significant and favorable heterobeltiosis under WS for the yield components RPE (15.17%), 100-KW (31.91), KPR (66.96%) and KPP (82.95%). Under WW and WS environments, the highest estimates of GYPP heterobeltiosis were generally obtained by the cross (L28 × Sd7) followed by the crosses L18 × Sd7 and L18 × L28. These crosses could therefore be recommended for commercial application under high plant density and WS conditions and as good genetic material for maize breeding programs. Some crosses showed significant and favorable estimates of heterobeltiosis for DTA (7 and 9 crosses), ASI (5 and 0 crosses), EPP (1 and 5 crosses) and RPE (4 and 2 crosses) under WW and WS, respectively (Tables 4 and 5).

In this respect, Bolanos and Edmeades [39] reported that short ASI in hybrids and subsequently better pollination should not be discarded as an explanation of heterosis in grain number. It is a trait used mostly in screening genotypes for tolerance to abiotic stresses especially for drought, low-N and high plant density [33,36,40-43].

## 3.4 Combining Ability Variances

Estimates of variances due to general (GCA) and specific (SCA) combining ability of the diallel crosses of maize for combined data across two seasons under WS and non-stress conditions are presented in Table 6. Mean squares due to GCA and SCA were significant (P≤ 0.01 or 0.05) for most studied traits under both environments (36 out of 48 cases), suggesting that both additive and non-additive gene effects play important roles in controlling the inheritance of these traits under both environments. A similar conclusion was reported by several investigators [44-49]. In the present study under both environments, the magnitude of GCA mean squares was higher than SCA mean squares (the ratio of GCA/SCA mean squares was higher than unity) for the traits LANG, EPP, RPE, 100KW, KPP and BS under WW and WS, DTA under WW and ASI under WS; *i.e.* 14 out of 24 cases, suggesting the existence of a greater portion of additive and additive x additive than non-additive variance in controlling the inheritance of these traits under respective environments. These results are in agreement with those reported by several investigators [33-35,46,50-53].

**Table 4. Estimates of average (Aver) and maximum (Max) heterobeltiosis (%) and number (No.) of crosses showing significant favorable heterobeltiosis for studied traits under well (WW) and water stress (WS) environments across two seasons**

| Parameter | WW | WS | WW | WS | WW | WS | WW | WS |
|---|---|---|---|---|---|---|---|---|
| | DTA | | ASI | | PH | | EH | |
| Aver. | -2.07 | -2.89 | -13.63 | 2.31 | 34.75 | 41.82 | 61.92 | 66.54 |
| Max. | 2.5 | 2.85 | 21.43 | 15.62 | 53.08 | 61.01 | 121.05 | 128.03 |
| Min. | -6.84 | -8.5 | -29.41 | -18.42 | 11.24 | 25.09 | 8.11 | 23.74 |
| No. | 7 | 9 | 5 | 0 | 0 | 0 | 0 | 0 |
| | BS | | LANG | | EPP | | RPE | |
| Average | 15.23 | 32.89 | 23.51 | 24.17 | -5.07 | 2.63 | -1.59 | 0.00 |
| Max | 111.3 | 101.13 | 57.63 | 44.44 | 6.25 | 17.86 | 8.27 | 15.17 |
| Min | -33.48 | -24.97 | -13.57 | -1.99 | -18.35 | -12.68 | -13.57 | -13.14 |
| No. | 0 | 0 | 1 | 0 | 1 | 5 | 4 | 2 |
| | KPR | | KPP | | 100-KW | | GYPP | |
| Average | 25.57 | 31.38 | 28.44 | 41.42 | 10.73 | 7.66 | 151.79 | 236.58 |
| Max | 48.82 | 66.96 | 54.65 | 82.95 | 29.15 | 31.41 | 313.14 | 736.00 |
| Min | 0.39 | 0.04 | -1.58 | -5.24 | -4.24 | -10.5 | 49.55 | 62.37 |
| No. | 14 | 14 | 14 | 14 | 12 | 11 | 15 | 15 |

*WW = Well watering, WS = Water stress, DTA = Days to 50% anthesis, ASI = Anthesis silking interval, RH = Plant height, EH = Ear height, BS = Barren stalks, LANG = Leaf angle, EPP = Ears per plant, RPE = Rows per ear, KPR = Kernels per row, KPP = Kernels per plant, 100-KW = 100 Kernel weight, GYPP = Grain yield per plant*

**Table 5. Estimates of heterobeltiosis (%) for selected traits of diallel $F_1$ crosses under six environments combined across 2013 and 2014 seasons**

| Cross | WW | WS | WW | WS | WW | WS | WW | WS |
|---|---|---|---|---|---|---|---|---|
| | DTA | | ASI | | EPP | | RPE | |
| L20 X L53 | -2.79** | -3.51** | -14.29 | 0.00 | 6.25** | 17.86** | 3.83* | 7.57** |
| L20 XSK5 | -1.12 | -1.35** | 0.00 | 12.50 | -4.26* | 11.04** | -3.05 | -0.08 |
| L20 X L18 | 0.56 | -0.27 | -14.29 | -18.42 | -10.69** | -1.43 | -7.04** | -3.40 |
| L20 X L28 | -1.12 | -0.54 | 7.14 | 2.50 | -8.83** | 9.73** | -2.61 | 0.39 |
| L20 X Sd7 | -0.84 | -1.08* | 21.43 | -12.31 | -10.00** | 3.13 | -3.07 | -0.40 |
| L 53 X Sk5 | -3.28** | -7.46** | -25.00* | 12.50 | -5.18* | 7.86* | -1.04 | 0.22 |
| L53 X L18 | -4.47** | -5.82** | -25.00* | 10.00 | -18.35** | -12.68** | -13.57** | -13.14** |
| L53 X L28 | -1.67* | -0.82 | -25.00* | -6.25 | -6.92** | 2.67 | -6.05** | -2.37 |
| L53 X Sd7 | -6.84** | -8.50** | -29.41* | 9.37 | -6.42** | 4.64** | -3.83* | -1.11 |
| Sk5 X L18 | -3.28** | -5.91** | -21.88 | -4.38 | 0.55 | 6.04 | 4.68** | 3.40 |
| Sk5 X L28 | -0.42 | 0.27 | -15.63 | -6.25 | -4.00 | 4.63 | 1.87 | 1.29 |
| Sk5 X Sd7 | -1.64* | -5.14** | -18.75 | 12.50 | -5.21* | -3.28 | -3.04 | -3.80** |
| L18 X L28 | 2.50** | 2.85** | 0.00 | 15.62 | -6.05* | -10.42** | -3.68 | -6.18** |
| L18 X Sd7 | -6.37** | -6.35** | -25.00* | -5.26 | 1.37 | -2.47 | 4.51* | 2.51 |
| L28 X Sd7 | -0.28 | 0.27 | -18.75 | 12.50 | 1.65 | 2.07 | 8.27** | 15.17** |
| | KPR | | KPP | | 100-KW | | GYPP | |
| L20 X L53 | 27.51** | 29.13** | 32.62** | 36.47** | 14.66** | 10.83** | 110.04** | 183.73** |
| L20 XSK5 | 24.50** | 35.19** | 24.97** | 52.93** | 4.88 | 5.27* | 107.99** | 188.90** |
| L20 X L18 | 19.25** | 31.32** | 17.55** | 37.76** | 3.93 | 5.93* | 105.63** | 215.33** |
| L20 X L28 | 22.37** | 36.86** | 21.72** | 48.55** | 6.51* | 10.38** | 118.39** | 197.36** |
| L20 X Sd7 | 21.72** | 34.67** | 20.17** | 45.62** | 5.36* | 8.77** | 112.69** | 211.62** |
| L 53 X Sk5 | 14.42** | 15.37** | 19.61** | 26.29** | 7.54** | 4.63* | 85.93** | 137.29** |
| L53 X L18 | 0.39 | 0.04 | -1.58 | -5.24 | -4.24 | -10.50** | 49.55** | 62.37** |
| L53 X L28 | 10.79** | 13.61** | 14.17** | 15.75** | 5.14* | 1.11 | 79.87** | 100.64** |
| L53 X Sd7 | 12.50** | 14.48** | 17.27** | 20.89** | 6.26* | 2.60 | 82.47** | 130.68** |
| Sk5 X L18 | 37.19** | 44.23** | 46.89** | 67.85** | 15.93** | 15.46** | 202.76** | 291.88** |
| Sk5 X L28 | 33.81** | 38.53** | 40.17** | 59.09** | 12.24** | 11.89** | 187.76** | 278.14** |
| Sk5 X Sd7 | 28.69** | 32.34** | 34.41** | 45.12** | 9.05** | 5.61* | 167.16** | 215.14** |
| L18 X L28 | 39.75** | 31.83** | 35.73** | 28.23** | 20.58** | -1.31 | 266.42** | 256.34** |
| L18 X Sd7 | 41.79** | 46.07** | 48.28** | 59.09** | 24.03** | 12.81** | 287.11** | 343.24** |
| L28 X Sd7 | 48.82** | 66.96** | 54.65** | 82.95** | 29.15** | 31.41** | 313.14** | 736.00** |

*WW = Well watering, WS = Water stress, DTA = Days to 50% anthesis, ASI = Anthesis silking interval, RH = Plant height, EH = Ear height, BS = Barren stalks, LANG = Leaf angle, EPP = Ears per plant, RPE = Rows per ear, KPR = Kernels per row, KPP = Kernels per plant, 100-KW = 100 Kernel weight, GYPP = Grain yield per plant*

On the contrary, the magnitude of SCA mean squares was higher than GCA mean squares (the GCA/SCA ratio was less than unity) for the traits, PH, EH, KPR, GYPP, under both WW and WS, DTA under WS and ASI under WW environment, indicating the predominance of non-additive variance (dominance and epistasis) in controlling these traits under respective environments. A similar conclusion was reported by several investigators [33-37,54-56].

Results in Table 6 indicate that mean squares due to the SCA × year and GCA x year interactions were highly significant for all studied traits under both environments, except for BS under WW and EPP under WW and WS for GCA x year, indicating that additive and non-additive variances for most studied traits under both environments were affected by years. But for EPP under both environments and BS under WW, additive and non-additive variances were not affected by years.

The mean squares due to SCA × year was higher than GCA × year for 14 out of 24 cases, namely PH and RPE under both environments, DTA, ASI, LANG, KPR, KPP, 100KW, GYPP and GYPH under WW and BS and EPP under WS (Table 6), suggesting that SCA (non-additive variance) is more affected by years than GCA (additive and additive x additive) for these cases. On the contrary, mean squares due to GCA × year was higher than SCA × year in the rest of cases, indicating that GCA variance is more affected by years than SCA variance for these cases.

**Table 6. Mean squares due to general (GCA) and specific (SCA) combining ability and their interactions with years (Y) for studied characters under six environments combined across 2013 and 2014 seasons**

| Parameter | WW | WS | WW | WS | WW | WS | WW | WS |
|---|---|---|---|---|---|---|---|---|
| | **DTA** | | **ASI** | | **PH** | | **EH** | |
| GCA | 23.90* | 16.91* | 0.23 | 0.66 | 976.55 | 251.04 | 455.50 | 337.90 |
| SCA | 16.77** | 23.76** | 0.85 | 0.30 | 6058** | 7225** | 2520** | 2486** |
| GCA/SCA | 1.43 | 0.71 | 0.27 | 2.20 | 0.16 | 0.03 | 0.20 | 0.14 |
| GCA×Y | 2.72** | 3.42** | 0.66** | 0.42* | 577.80** | 378.34** | 280.3** | 114.9** |
| SCA×Y | 1.37** | 5.44** | 0.37** | 0.66** | 323.73** | 168.13** | 126.9** | 216.2** |
| GCA×Y/SCA×Y | 1.98 | 0.63 | 1.76 | 0.63 | 1.78 | 2.25 | 2.20 | 0.53 |
| | **BS** | | **LANG** | | **EPP** | | **RPE** | |
| GCA | 25.05* | 123.13* | 263.1* | 190.06** | 0.17** | 0.10* | 21.40* | 14.86* |
| SCA | 21.33** | 66.18* | 50.8* | 62.42 | 0.02 | 0.05 | 2.35 | 3.60* |
| GCA/SCA | 1.17 | 1.86 | 5.20 | 3.04 | 9.27 | 2.13 | 9.09 | 4.13 |
| GCA×Y | 4.27 | 26.00** | 46.3** | 9.12** | 0.01 | 0.14 | 2.28** | 1.50** |
| SCA×Y | 5.32 | 22.95** | 18.0** | 41.15** | 0.02 | 0.02 | 1.20** | 1.10** |
| GCA×Y/SCA×Y | 0.80 | 1.13 | 2.60 | 0.22 | 0.75 | 5.89 | 1.89 | 1.37 |
| | **KPR** | | **KPP** | | **100-KW** | | **GYPP** | |
| GCA | 259.57** | 221.6** | 139470** | 151089** | 130.19** | 90.43** | 12189** | 9558** |
| SCA | 279.75** | 321.0** | 114543** | 146868** | 71.88** | 50.94** | 39215** | 32244** |
| GCA/SCA | 0.93 | 0.69 | 1.22 | 1.00 | 1.81 | 1.78 | 0.30 | 0.30 |
| GCA×Y | 23.47** | 11.4** | 10640** | 10902** | 9.47** | 5.79** | 1067** | 632** |
| SCA×Y | 17.02** | 18.6** | 9869** | 13394** | 6.05** | 12.75** | 797.8** | 1206** |
| GCA×Y/SCA×Y | 1.38 | 0.61 | 1.08 | 0.81 | 1.57 | 0.45 | 1.30 | 0.52 |

*WW = Well watering, WS = Water stress, DTA = Days to 50% anthesis, ASI = Anthesis silking interval, RH = Plant height, EH = Ear height, BS = Barren stalks, LANG = Leaf angle, EPP = Ears per plant, RPE = Rows per ear, KPR = Kernels per row, KPP = Kernels per plant, 100-KW = 100 Kernel weight, GYPP = Grain yield per plant, * and ** indicate significance at 0.05 and 0.01 probability levels, respectively*

## 3.5 GCA Effects of Inbreds

Estimates of general combining ability (GCA) effects of parental inbreds for studied traits under the two environments (WW and WS) across two seasons are presented in Table 7. The best parental inbreds were those showing negative and significant GCA effects for DTA, ASI, PH, EH, BS and LANG and those of positive and significant GCA effects for EPP, RPE, KPR, KPP, 100-KW and GYPP traits. For GYPP, the best inbred in GCA effects was L53 in both environments (E1 through WW and WS) followed by L20 and Sk5. These best general combiners for grain yield and its components (L53, L120 and Sk5) were also the best ones in *per se* performance for the same traits under the respective environments (Table 3). On the contrary, the inbred lines L18, L28 and Sd7 were the worst in GCA effects for GYPP and its components (Table 7) and the worst in *per se* performance for the same traits under the two environments (Table 3). Superiority of the inbreds L53, L20 and Sk5 in GCA effects for GYPP was associated with their superiority in GCA effects for most studied traits.

The inbreds L53 and L20 under WW and WS environments and SK5 under WS were also the best general combiners for low DTA*, i.e.* the best in producing good hybrid combinations for earliness under both environments. The inbred L53 was also the best general combiner for short ASI under WW and WS environments. Inbreds L53 and L20 were the best general combiners under both environments for the eight traits PH, BS, LANG, RPE, KPR, KPP and 100KW. Inbred Sk5 was also the best general combiner under WW and WS for PH, under WS for EH, under WW for RPE and KPP. For more ears/plant (EPP), the inbred L53 under WW and WS were the best general combiners. In previous studies [31,32,34] the inbred lines L53, L20 and Sd5 were also the best general combiners for GYPP under high and low plant densities. Previous studies proved that positive GCA effects for EPP and kernels/plant and negative GCA effects for DTA, BS, and LANG traits are a good indicator of high density and/or drought stress tolerance [56,57,31,32,34].

**Table 7. Estimates of general combining ability (GCA) effects of parents for studied characters under six environments combined across 2013 and 2014 seasons**

| | WW | WS | WW | WS | WW | WS | WW | WS |
|---|---|---|---|---|---|---|---|---|
| | **DTA** | | **ASI** | | **PH** | | **EH** | |
| L20 | -0.61** | -1.81** | 0.17 | 0.03 | -7.99** | -3.79** | -5.52** | -5.21** |
| L53 | -0.52** | -0.79** | -0.25** | -0.33** | -10.44** | -6.13** | -10.57** | -8.44** |
| Sk5 | -0.21 | -1.56** | -0.04 | 0.11 | -3.61** | -1.25* | -0.7 | -2.52** |
| L18 | 0.85** | 2.13** | -0.06 | 0.07 | 14.06** | 6.79** | 10.42** | 9.09** |
| L28 | 0.38** | 1.90** | 0.15 | -0.01 | 5.72** | 2.92** | 4.12** | 4.26** |
| Sd7 | 0.1 | 0.15 | 0.04 | 0.13 | 2.26** | 1.46** | 2.25** | 2.82** |
| SE $g_i$-$g_j$ | 0.24 | 0.19 | 0.19 | 0.19 | 1.0 | 0.85 | 0.87 | 1.11 |
| | **BS** | | **LANG** | | **EPP** | | **RPE** | |
| L20 | -0.89* | -1.37* | -1.78** | -2.03** | 0.05 | 0.03 | 0.57** | 0.44** |
| L53 | -1.72** | -2.86** | -3.24** | -3.49** | 0.08* | 0.10* | 0.86** | 0.80** |
| Sk5 | -0.12 | -0.33 | -0.2 | -0.57** | 0.02 | 0.01 | 0.19* | 0.04 |
| L18 | 1.80** | 3.19** | 3.35** | 3.72** | -0.08* | -0.09* | -0.96** | -0.81** |
| L28 | 1.02* | 0.9 | 1.31** | 1.51** | -0.05 | -0.03 | -0.46** | -0.32** |
| Sd7 | -0.09 | 0.48 | 0.56* | 0.85** | -0.03 | -0.02 | -0.20* | -0.15 |
| SE $g_i$-$g_j$ | 0.64 | 0.95 | 0.42 | 0.26 | 0.50 | 0.71 | 0.12 | 0.12 |
| | **KPR** | | **KPP** | | **100-KW** | | **GYPP** | |
| L20 | 1.83** | 1.49** | 43.89** | 32.39** | 0.95** | 1.19** | 13.05** | 13.85** |
| L53 | 2.65** | 2.94** | 67.50** | 65.49** | 1.81** | 2.18** | 18.35** | 18.16** |
| Sk5 | 0.18 | 0.12 | 13.27* | 8.59 | 0.12 | -0.07 | 1.74 | 3.54 |
| L18 | -2.81** | -3.03** | -72.71** | -67.34** | -1.88** | -2.52** | -22.40** | -21.66** |
| L28 | -1.16** | -0.93** | -37.17** | -21.77** | -0.76** | -0.40** | -8.31** | -9.93** |
| Sd7 | -0.69** | -0.59 | -14.78* | -17.35** | -0.24 | -0.38** | -2.42 | -3.96 |
| SE gi-gj | 0.35 | 0.48 | 9.64 | 8.94 | 0.31 | 0.14 | 3.08 | 3.61 |

*WW = well watering, WS = water stress, and * and ** significant at 0.05 and 0.01 probability levels, respectively*

### 3.6 SCA Effects of $F_1$ Crosses

Estimates of specific combining ability effects (SCA) of $F_1$ diallel crosses for studied traits under WW and WS environments are presented in Table 8. The best crosses in SCA effects were considered those exhibiting significant and negative SCA effects for DTA, ASI, PH, EH, LANG and BS and significant and positive SCA effects for the rest of studied traits. For GYPP, the largest positive (favorable) and significant SCA effects were recorded by the cross Sk5 × L18 followed by L20 × L53, L28 × Sd7 and L20 × L18 under the two environments (Table 8). The above crosses may be recommended for maize breeding programs for the improvement of tolerance to drought [58-60].

For RPE, KPR, KPP and 100KW, the largest positive and significant SCA effects were exhibited by the cross Sk5 × L18 followed by L20 x L53, L28 x Sd7 and L18 x Sd7 under both environments. For EPP, the highest positive, but not significant SCA effects were exhibited by the crosses Sk5 x L18 and L20 x L53 under both environments. For LANG, the lowest negative (favorable) and significant SCA effects were exhibited only under WS by the cross Sk5 × L18. Regarding BS, the lowest negative and significant SCA effects were shown by the crosses Sk5 ×L18, L20 x L53, L18 x Sd7 and L28 x SD7 under both environments. For PH and EH, the lowest negative (favorable) and significant SCA effects were recorded by the crosses Sk5 × L18, L18 x Sd7, L20 x L53 and L28 x Sd7 under both environments. For days to 50% anthesis, the lowest negative (favorable) and significant SCA effects were shown by the cross Sk5 × L18 under both environments, L18 × Sd7 under WS. For ASI, the lowest negative and significant SCA effects were shown only under WS by the cross Sk5 × L18.

It is worthy to note that for the studied traits, most of the best crosses in SCA effects for a given trait included at least one of the best parental inbred lines in GCA effects for the same trait. The same conclusion was confirmed previously by several investigators [3,27,32,33,35,36,46-48]. In this study, it could be concluded that the $F_1$ cross Sk5 x L18 is superior to other crosses in SCA effects for grain yield and all of its components, as well as in earliness, short plants, lower EH, BS and LANG under water stressed and non-stressed environments, i.e. all adaptive traits to drought tolerance. The crosses L20 x L53, L18 x Sd7 and L28 x Sd7 follow the cross Sk5 x L18 in superiority of SCA effects for such traits. These crosses could be offered to plant breeding programs for improving maize tolerance to drought tolerance at flowering stage.

### 3.7 Correlations between Performance, GCA, SCA and Heterobeltiosis

Rank correlation coefficients calculated between mean performance of inbred parents **($\bar{x}_p$)** and their GCA effects, between mean performance of $F_1$'s ($\bar{x}_c$) and their SCA effects and heterobeltiosis and between SCA effects and heterobeltiosis, for studied characters are presented in Table 9. Out of 12 studied traits, significant (P≤ 0.05 or 0.01) correlations between $\bar{x}_p$ and GCA effects existed for nine traits, namely PH, EH, LANG, EPP (except WS), RPE, KPR, KPP, 100KW, GYPP. Such significant correlations between **($\bar{x}_p$)** and their GCA effects in this investigation representing 75.0% of all studied cases (18 out of 24 cases) suggest the validity of this concept in the majority of studied traits, especially yield, yield components, PH, EH and LANG under both environments. These results indicate that the highest performing inbred lines are also the highest general combiners and *vice versa* for the previously mentioned traits and therefore, the mean performance of a given parent for these traits under both WW and WS environments is an indication of its GCA. This conclusion was previously reported by several investigators [34, 61] in maize and [33,35,36,62,63] in wheat.

All significant correlations between $\bar{x}_p$ and GCA effects in the present study, were positive for all traits, except for PH and EH, where the correlations were negative. The traits which did not show any correlation between $\bar{x}_p$ and GCA effects under both environments were DTA and ASI. The strongest correlation (highest in magnitude) between $\bar{x}_p$ and GCA effects was shown by GYPP, RPE, KPR, KPP, 100-KW and EPP traits under WW environment (r > 0.91).

For $F_1$ crosses, rank correlation coefficients calculated between mean performance of crosses ($\bar{x}_c$) and their SCA effects (Table 9) showed that out of 12 studied traits, significant (P≤ 0.05 or 0.01) correlations existed for ten traits under both environments, namely, PH, EH, BS, LANG, EPP, RPE, KPR, KPP, 100KW and GYPP. Moreover, significant correlations existed in some environments for three traits, namely DTA and ASI under WW. Such significant

**Table 8. Estimates of specific combining ability (SCA) effects for studied characters under six environments combined across 2013 and 2014 seasons**

| | WW | WS | WW | WS | WW | WS | WW | WS | WW | WS | WW | WS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **DTA** | | **ASI** | | **PH** | | **EH** | | **BS** | | **LANG** | |
| L20 × L53 | -0.39 | -0.08 | -0.12 | -0.20 | -9.72** | -4.02** | -11.29** | -8.06** | -1.24 | -2.02 | -3.08** | -2.51** |
| L20 ×SK5 | 0.30 | 2.02** | 0.01 | 0.03 | 10.77** | 4.44** | 5.79** | 2.88* | 1.54* | 2.83* | 2.05** | 1.41** |
| L20 × L18 | 0.23 | -1.16** | -0.31 | 0.08 | -3.06* | -1.44 | 0.21 | 0.46 | -0.53 | -0.43 | 0.01 | 0.28 |
| L20 × L28 | -0.29 | -1.27** | -0.01 | 0.08 | -1.72 | -0.56 | 0.28 | 0.89 | -0.56 | -1.37 | -0.28 | -0.34 |
| L20 × Sd7 | 0.15 | 0.48** | 0.43 | 0.01 | 3.73** | 1.57 | 5.01** | 3.83** | 0.79 | 0.99 | 1.30* | 1.16** |
| L 53 × Sk5 | 0.21 | 0.34 | 0.09 | 0.22 | -6.10** | -0.72 | -0.45 | -2.12* | 0.31 | -0.57 | -0.16 | -0.63* |
| L53 × L18 | 0.65** | 3.23** | 0.11 | 0.26 | 19.23** | 7.90** | 11.88** | 10.96** | 0.95 | 4.33** | 3.97** | 4.08** |
| L53 × L28 | -0.37 | -2.45** | -0.10 | -0.16 | -1.43 | -1.39 | 0.41 | 0.15 | -0.57 | -0.86 | -0.49 | -0.05 |
| L53 × Sd7 | -0.10 | -1.04** | 0.01 | -0.13 | -1.98 | -1.77 | -0.56 | -0.94 | 0.55 | -0.89 | -0.24 | -0.88* |
| Sk5 × L18 | -1.16** | -1.74** | -0.01 | -0.51** | -15.93** | -8.31** | -12.21** | -8.55** | -2.27** | -5.38** | -4.41** | -4.51** |
| Sk5 × L28 | 0.07 | -1.52** | -0.05 | 0.08 | -1.10 | -1.77 | 0.13 | 0.75 | -0.61 | 0.39 | 0.14 | 0.53 |
| Sk5 × Sd7 | 0.59* | 0.90** | -0.04 | 0.18 | 12.36** | 6.36** | 6.74** | 7.04** | 1.02 | 2.73* | 2.38** | 3.20** |
| L18 × L28 | 0.75** | 2.63** | 0.38 | 0.12 | 9.07** | 5.86** | 5.25** | 2.63* | 2.97** | 3.08* | 2.26** | 1.74** |
| L18 × Sd7 | -0.48 | -2.95** | -0.18 | 0.06 | -9.31** | -4.02** | -5.13** | -5.51** | -1.12 | -1.59 | -1.83** | -1.59** |
| L28 × Sd7 | -0.16 | 2.61** | -0.22 | -0.11 | -4.81** | -2.14* | -6.07** | -4.43** | -1.23 | -1.24 | -1.62** | -1.88** |
| SE $S_{ij} - S_{ik}$ | 0.42 | 0.32 | 0.32 | 0.32 | 1.73 | 1.47 | 1.5 | 1.92 | 1.12 | 1.65 | 0.73 | 0.46 |
| SE $S_{ij} - S_{kl}$ | 0.35 | 0.26 | 0.26 | 0.26 | 1.41 | 1.20 | 1.22 | 1.57 | 0.91 | 1.35 | 0.60 | 0.37 |
| | **EPP** | | **RPE** | | **KPR** | | **KPP** | | **100-KW** | | **GYPP** | |
| L20 × L53 | 0.10 | 0.10 | 0.53** | 0.80** | 3.74** | 3.41** | 64.97** | 62.25** | 1.80** | 2.52** | 20.88** | 16.72** |
| L20 ×SK5 | -0.02 | -0.01 | -0.54** | -0.43* | -1.29** | -1.70* | -31.02* | -35.35** | -1.36** | -2.58** | -18.21** | -19.40** |
| L20 × L18 | -0.01 | -0.01 | -0.01 | -0.14 | -0.26 | -0.13 | 4.40 | -5.70 | 0.31 | 0.26 | 3.43 | 13.87** |
| L20 × L28 | -0.02 | -0.04 | 0.18 | 0.09 | -0.74 | -0.35 | -2.72 | 0.37 | 0.08 | 0.16 | 2.93 | 2.44 |
| L20 × Sd7 | -0.05 | -0.05 | -0.16 | -0.31* | -1.46** | -1.24* | -35.63** | -21.57* | -0.83* | -0.37* | -9.03* | -13.63** |
| L 53 × Sk5 | -0.02 | 0.00 | 0.14 | -0.01 | -0.16 | 0.05 | -2.68 | 8.82 | 0.11 | 0.68** | 0.34 | 2.68 |
| L53 × L18 | -0.11 | -0.09 | -0.72** | -0.86** | -3.11** | -3.50** | -76.70** | -81.49** | -2.07** | -3.45** | -23.56** | -26.55** |
| L53 × L28 | 0.02 | -0.02 | -0.02 | 0.03 | -0.36 | -0.16 | 6.73 | 0.91 | 0.14 | 0.09 | 2.40 | -0.04 |
| L53 × Sd7 | 0.01 | -0.01 | 0.08 | 0.05 | -0.11 | 0.20 | 7.67 | 9.51 | 0.02 | 0.17 | -0.06 | 7.18 |
| Sk5 × L18 | 0.09 | 0.09 | 1.05** | 1.16** | 3.08** | 4.04** | 79.19** | 90.96** | 2.45** | 4.00** | 30.40** | 26.39** |
| Sk5 × L28 | 0.00 | -0.01 | 0.16 | -0.08 | 0.29 | -0.08 | 5.01 | -8.26 | 0.16 | 0.18 | 4.67 | 10.05* |
| Sk5 × Sd7 | -0.04 | -0.07 | -0.80** | -0.64** | -1.92** | -2.31** | -50.51** | -56.16** | -1.36** | -2.28** | -17.21** | -19.72** |
| L18 × L28 | -0.03 | -0.03 | -0.76** | -0.54** | -1.19* | -1.59* | -47.19** | -32.50** | -1.62** | -1.85** | -23.29** | -26.17** |
| L18 × Sd7 | 0.06 | 0.03 | 0.44** | 0.39* | 1.48** | 1.18* | 40.30** | 28.73* | 0.93* | 1.05** | 13.02** | 12.46* |

| | WW | WS | WW | WS | WW | WS | WW | WS | WW | WS | WW | WS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L28 × Sd7 | 0.03 | 0.09 | 0.44** | 0.51** | 2.00** | 2.17** | 38.18** | 39.48** | 1.24** | 1.43** | 13.28** | 13.72** |
| SE $S_{ij} - S_{ik}$ | 0.87 | 1.22 | 0.21 | 0.21 | 0.61 | 0.83 | 16.70 | 15.49 | 0.53 | 0.24 | 5.34 | 6.24 |
| SE $S_{ij} - S_{kl}$ | 0.71 | 1.00 | 0.17 | 0.17 | 0.50 | 0.68 | 13.64 | 12.65 | 0.44 | 0.20 | 4.36 | 5.10 |

*WW = Well watering, WS = Water stress, DTA = Days to 50% anthesis, ASI = Anthesis silking interval, RH = Plant height, EH = Ear height, BS = Barren stalks, LANG = Leaf angle, EPP = Ears per plant, RPE = Rows per ear, KPR = Kernels per row, KPP = Kernels per plant, 100-KW = 100 Kernel weight, GYPP = Grain yield per plant, * and ** significant at 0.05 and 0.01 probability levels, respectively*

**Table 9. Rank correlation coefficients among mean performance of inbreds ($\bar{x}_p$) and their GCA effects and between mean performance of $F_1$'s ($\bar{x}_c$) and their SCA effects and between heterosis (H) and each of $\bar{x}_c$ and SCA effects under six environments combined across two seasons**

| Correlation | WW | WS | WW | WS | WW | WS | WW | WS |
|---|---|---|---|---|---|---|---|---|
| | DTA | | ASI | | PH | | EH | |
| $\bar{x}_p$ *vs.* GCA | 0.43 | 0.03 | -0.49 | 0.51 | -0.61* | -0.69* | -0.67* | -0.62* |
| $\bar{x}_c$ *vs.* SCA | 0.60** | 0.36 | 0.74** | 0.49 | 0.65** | 0.64** | 0.60** | 0.59* |
| $\bar{x}_c$ *vs.* H | 0.35 | 0.50* | 0.92** | 0.74** | 0.73** | 0.73** | 0.79** | 0.83** |
| SCA *vs.*H | 0.37 | 0.21 | 0.56* | 0.28 | 0.22 | 0.23 | 0.28 | 0.29 |
| | **BS** | | **LANG** | | **EPP** | | **RPE** | |
| $\bar{x}_p$ *vs.* GCA | -0.16 | 0.29 | 0.66* | 0.76* | 0.94** | 0.49 | 0.94** | 0.72* |
| $\bar{x}_c$ *vs.* SCA | 0.66** | 0.61** | 0.62** | 0.57* | 0.59* | 0.51* | 0.55* | 0.60** |
| $\bar{x}_c$ *vs.* H. | 0.87** | 0.73** | 0.36 | 0.56* | 0.52* | 0.86** | 0.26 | 0.55* |
| SCA *vs.*H | 0.49 | 0.52* | 0.63** | 0.68** | 0.89** | 0.54* | 0.72** | 0.76** |
| | **KPR** | | **KPP** | | **100-KW** | | **GYPP** | |
| $\bar{x}_p$ *vs.* GCA | 0.93** | 0.80* | 0.93** | 0.79* | 0.92** | 0.67* | 0.91* | 0.76* |
| $\bar{x}_c$ *vs.* SCA | 0.61** | 0.65** | 0.57* | 0.55* | 0.64** | 0.67** | 0.67** | 0.66** |
| $\bar{x}_c$ *vs.* H | -0.13 | -0.01 | -0.07 | 0.03 | -0.05 | 0.39 | -0.36 | -0.04 |
| SCA *vs.*H | 0.55* | 0.50* | 0.59* | 0.53* | 0.52* | 0.66** | 0.27 | 0.36 |

*WW = Well watering, WS = Water stress, DTA = Days to 50% anthesis, ASI = Anthesis silking interval, RH = Plant height, EH = Ear height, BS = Barren stalks, LANG = Leaf angle, EPP = Ears per plant, RPE = Rows per ear, KPR = Kernels per row, KPP = Kernels per plant, 100-KW = 100 Kernel weight, GYPP = Grain yield per plant, and * and ** significant at 0.05 and 0.01 probability levels, respectively* correlations between ($\bar{x}_c$) and SCA effects in this investigation representing 91.17% of all studied cases (22 out of 24 cases) suggest the validity of this concept in the majority of studied traits and environments. All correlations between ($\bar{x}_c$) and SCA effects in the present study, were positive. These results indicate that the highest performing crosses are also the highest specific combiners and *vice versa* for all studied traits and therefore, the mean performance of a given cross for these traits under the respective environments is an indication of its SCA. This conclusion was previously reported by several investigators [33-36,62,63].

Significant correlations between mean performance of crosses ( $\bar{x}_c$) and heterobeltiosis (Table 9) were exhibited only in 13 out of 24 cases (54.16%), namely ASI, PH, EH, BS and EPP under all environments, DTA and LANG under WS and RPE under WW. For these traits, the mean performance of a cross could be used as an indicator of its useful heterosis under the corresponding environments. The traits KPR, KPP, 100-KW and GYPP; *i.e.* yield traits did not exhibit any correlation between $\bar{x}_c$ and heterobeltiosis under WW and WS environments and therefore, SCA effects of crosses could not be expected from their *per se* performance in such cases.

Significant correlations between SCA effects of crosses and heterobeltiosis (Table 9) were exhibited only in 14 out of 24 cases (58.3%), namely LANG, EPP, RPE, KPR, KPP and 100KW under both environments, BS under WS, and ASI under WW. For these traits, the useful heterosis of a cross could be used as an indicator of its SCA effects under the corresponding environments. The traits PH, EH, GYPP, plant and ear heights did not exhibit any correlation between SCA effects and heterobeltiosis under both environments and therefore, SCA effects of crosses could not be expected from their heterobeltiosis values in such cases.

Summarizing the above mentioned results, it cloud be concluded that GYPP in this investigation under water stressed and non-stressed environments, the mean performance of a given parent could be considered an indication of its GCA and the mean performance of a given cross could be considered an indication of its SCA. But the mean performance of a given cross could not be considered an indication of its heterobeltiosis, and the heterobeltiosis of a given cross could not be used as indication of its SCA effects.

## 4. CONCLUSIONS

This study identified three inbreds (L53, L2 and Sk5) and three $F_1$ crosses (L20 × L53, L53 x Sk5 and L53 × Sd7) of good performance under WS conditions at flowering stage; they could be offered to future plant breeding programs aiming at improving maize drought tolerance. Results concluded that under WS, the traits LANG, ears/plant, rows/ear, 100-kernels weight, kernels/plant and BS were controlled mainly by additive and additive x additive genes and therefore selection would be effective in improving such traits, but the traits EH, kernels/row, GYPP and DTA were controlled mainly by non-additive genes and therefore heterosis breeding is the best choice for improving such traits. Correlation analysis concluded that for GYPP in this investigation under WS and non-stressed environments, the mean performance of a given parent could be considered an indication of its GCA and the mean performance of a given cross could be considered an indication of its SCA. But the mean performance of a given cross could not be considered an indication of its heterobeltiosis, and the heterobeltiosis of a given cross could not be used as indication of its SCA effects.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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