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Interrelationships of Performance, Heterosis and Combining Ability of Corn (*Zea mays* L.) Crop under Elevated Plant Density Combined with Water Deficit

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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

The objective of the present investigation was to test the validity of predictions of GCA and SCA effects from mean performance and/or heterobeltiosis for agronomic and yield traits under elevated plant density (D) combined with water deficit. Six maize inbreds varying in high-D tolerance were intercrossed in a diallel fashion and evaluated along with their F1 crosses in six environments representing combinations of 3 plant densities and two irrigation regimes in two seasons. Both GCA and SCA variances were significant for all studied traits under all environments. The magnitude of GCA was higher than SCA variance for 45.8% of cases, but the magnitude of SCA was higher than GCA variance for the rest of cases. The best general combiners were the inbreds L53 and L20 for all studied traits and the best SCA effects for grain yield were exhibited by the crosses Sk5 × L18, L20 × L53 and L28 × Sd7 under the 6 environments. The results indicate that the highest performing inbred lines are also the highest general combiners and vice versa for 9 out of 12 traits and the highest performing crosses are also the highest specific combiners and vice versa for all 12 studied traits. Yield traits did not exhibit any correlation between heterobeltiosis and mean performance of crosses, and between SCA effects and heterobeltiosis under all six environments. For agronomic traits, the useful heterosis of a cross could be used as an indicator of its SCA effects under all environments.

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1. INTRODUCTION

Maximization of maize productivity per land unit area could be attained by using high plant density, optimum fertilization and irrigation as well as hybrids that can withstand high plant density up to 100,000 plants/ha [1]. Average maize grain yield per land unit area in the USA increased dramatically during the second half of the 20th century, due to improvement in crop management practices and greater tolerance of modern hybrids to high plant densities [2,3]. Modern maize hybrids in developed countries are characterized with high yielding ability from land unit area under high plant densities, due to their morphological and phenological adaptability traits, such as early silking, short anthesis silking interval (ASI), less barren stalks (BS) and prolificacy [4]. Radenovic et al. [5] pointed out that maize genotypes with erect leaves are very desirable for increasing the population density due to better light interception.

Egyptian maize hybrids selected under normal plant density are not tolerant of high density and therefore are subject to yield losses when grown under high plant density. Thus, grain yield ha^{-1} cannot be increased by increasing plant density using the present Egyptian cultivars [6]. Introducing previously mentioned adaptive traits to Egyptian cultivars is important to enable these cultivars to produce higher grain yield from land unit area than present cultivars.

Maize is considered more susceptible than most other cereals to drought stresses at flowering, when yield losses can be severe through barrenness or reductions in kernels per ear [7]. Recent studies have shown considerable genetic variation in the response of commercial hybrids to drought stress imposed during reproductive growth [8] and that these responses vary considerably among hybrids [9]. Tolerant genotypes of maize were characterized by having shorter anthesis-silking interval (ASI) [10], more ears/plant [11,12] and greater number of kernels/ear [12,13]. The heterosis, combining ability and type of gene action of such traits should be studied. Such information, especially in Egypt is scarce. There is good evidence suggesting that hybrids maintain their advantage over open pollinated varieties in both stress and non-stress environments [14-16]. Inbred lines with superior breeding values for yield and tolerance to abiotic stresses have been used as base materials to develop high-yielding and stress-tolerant hybrids [17,18].

Combining ability analysis is useful to assess the potentiality of inbred lines and also helps in identifying the nature of gene action involved in various quantitative characters. Such information is helpful to plant breeders for formulating hybrid breeding programs. Information on the heterotic patterns and combining ability of maize germplasm is essential in maximizing the effectiveness of hybrid development [19]. Exploitation of heterosis is a quick, cheap and easy method of attaining maximum yields. An understanding of the fundamental nature of gene action or genetic basis of heterosis and combining ability of parents are of primary interest to plant breeders. Sprague and Tatum [20] proposed the concept of combining ability to provide information on the relative importance of additive and non- additive gene effects involved in the expression of the quantitative traits. Mason and Zuber [21] reported that general (GCA) and specific (SCA) combining ability effects appeared to be equally important in the expression of leaf angle. They also found that crosses of upright-leafed parents tend to produce upright leaf progeny, and *vice versa*.

A wide array of biometrical tools is available to breeders for characterizing genetic control of economically important traits as a guide to decide the appropriate breeding methodology for hybrid breeding. Diallel analysis proposed by Griffing [22] has widely been used in crop plants for identifying the best combiner to exploit heterosis or link up fixable favorable genes that may lead to the development of superior genotypes. Besides, it also helps in characterization of nature and magnitude of gene action for various characters of economic importance. Prediction of general (GCA) and specific (SCA) combining ability effects from data on mean performance and/or heterosis would save time and effort spent in calculations and make the process of identification of the best parents and crosses more easier in plant breeding programs. The objectives of the present investigation were: (*i*) to assess performance, heterobeltiosis, GCA and SCA effect parameters in maize for agronomic and yield traits under six combinations of environments between three plant densities and two contrasting irrigation regimes and (*ii*) to perform correlations among these parameters in order to test the validity of predictions of GCA and SCA effects.

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 [23], six maize (*Zea mays* L.) inbred lines in the 8th selfed generation (S_8), showing clear differences in performance and general combining ability for grain yield under high plant density, 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 6 parents were also increased by selfing in the same season (2012) to obtain enough seeds of the inbreds in the 9th selfed generation (S_9 seed).

2.3 Evaluation of Parents and F1`s

Six field evaluation experiments were carried out separately at the Agricultural Experiment and Research Station of Faculty of Agriculture, Cairo University, Giza, Egypt in 2013 and 2014 seasons. Each experiment included 15 F_1 crosses, their 6 parents. Evaluation in each season was carried out under one combination of two water regimes (well watering; WW and water stress; WS at flowering stage by skipping the 4th and 5th irrigations) and three plant densities (D), (47,600, 71,400 and 95,200 plants/ha, representing low-; LD, medium-; MD and high-plant density; HD, respectively). The first experiment was under WW-LD, the 2nd under WW-MD, the 3rd under WW-HD, the 4th under WS-LD, the 5th under WS-MD and the 6th under WS-HD. A randomized complete blocks design (RCBD) with three replications was used for 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 15, 20 and 30 cm apart, thereafter (before the 1st irrigation) were thinned to one plant/hill to achieve the 3 plant densities, *i.e.* 95,200, 71,400 and 47,600 plants/ha, respectively. Sowing date each season was on May 5 and May 8 in 2013 and 2014 seasons, respectively. The soil analysis of the experimental soil at the experimental site, 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. All other agricultural practices were followed according to the recommendations of ARC, Egypt.

Table 1. Designation, origin and most important traits of 6 inbred lines used for making diallel crosses of this study

Entry designation	Origin	Institution (country)	Prolificacy	Productivity under high density	Leaf Angle
L20-Y	SC 30N11	Pion. Int.Co.	Prolific	High	Erect
L53-W	SC 30K8	Pion. Int.Co.	Prolific	High	Erect
Sk5-W	Tepalcinco # 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
Sd7-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, Pop = Population, A.E.D.= American Early Dent (Old local OPV), W = White grains and Y = Yellow grains

2.4 Data Recorded

Days to 50% anthesis (DTA) as number of days from planting to anthesis of 50% 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) (o) measured as the angle between stem and blade of the leaf just above ear leaf according to Zadoks et al. [24]. The following grain yield traits were measured at harvest. Number of ears per plant (EPP) calculated by dividing number of ears per plot on number of plants per plot. Number of rows per ear (RPE) using 10 random ears/plot at harvest. Number of kernels per row (KPR) using the same 10 random ears/plot. Number of 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 per 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 Analyses

Combined analysis of variance of RCBD for each of the six environments (WW-LD, WW-MD, WW-HD, WS-LD, WS-MD and WS-HD) across the two seasons were performed if the homogeneity test was non-significant using the MIXED procedure of SAS ® [25]. Least significant differences (LSD) were calculated according to Steel et al. [26]. Diallel crosses were analyzed to obtain general (GCA) and specific (SCA) combining ability variances and effects for studied traits according to Griffing [22] 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 (%) = $100[(\bar{F}_1 - \overline{BP})/\overline{BP}]$ Where: $\bar{F}_1$ = 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 (L.S.D) at 0.05 and 0.01 levels of probability according to Steel et al. [26] using the following formula: LSD $_{0.05}$ = $t_{0.05}$*(edf) x SE*, LSD $_{0.01}$ = $t_{0.01}$*(edf) x 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. [26]. 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 six environments (from E1 to E6); representing combinations of 3 plant densities × 2 irrigation regimes, *i.e.* E1 = well watering- low density, E2 = well watering-medium density, E3 = well watering- high density, E4 = water stress- low density, E5 = water stress- medium density and E6 = water stress-high density across two seasons is presented in Table 2. Mean squares due to genotypes, parents and crosses under all environments were significant ($P \leq 0.01$) for all studied traits, except ASI under E1, E3 and E5 and EPP under E6, indicating the significance of differences among studied parents and among F_1 diallel crosses in the majority of cases. These results are in agreement with those reported by Al-Naggar et al. [27-29]. Mean squares due to parents *vs.* F_1

crosses were significant ($P \leq 0.01$) for all studied traits under all six environments, except for ASI under E1, E3 through E6, EPP under E3, BS under E1, suggesting the presence of significant heterosis for most studied cases.

Mean squares due to the interactions parents × years (P × Y) and crosses × years (F_1 × Y) were significant ($P \leq 0.05$ and 0.01) for most studied cases (96 out of 144 cases), *i.e.* 66.7% of total cases. Mean squares due to parents *vs.* crosses × years were ($P \leq 0.05$ and 0.01) in 39 out of 72 cases (Table 2). Such interaction was expressed in > 3 environments for BS, LANG, EPP, KPR, and 100KW traits. This indicates that heterosis differ from season to season in these cases. Among genotypes components under all six environments (72 cases), the largest contributor to total variance was parents vs. F_1's (heterosis) variance for 40 cases, followed by F_1 crosses (26 cases) and parents (6 cases).

3.2 Mean Performance

Mean of studied traits across years under the six environments for all inbreds and hybrids is presented in Table 3. In general, under all environments, the F_1 hybrids were earlier than inbred lines for DTA and DTS and lower in grain protein content. The crosses were taller than for PH and EH and had wider LANG. On the other hand, F_1 hybrids showed higher means than inbreds for KPP, RPE, KPR, 100KW, GYPP, indicating that heterozygotes exhibit better (more favorable) values for most studied traits than homozygotes, which is logic and could be attributed to heterosis phenomenon.

Parental inbreds varied in most studied traits under all environments, especially for grain yield and its components. The inbred L53 showed the highest (favorable) means for EPP, RPE, KPP, 100-KW, GYPP, and the lowest (favorable) mean for BS. The inbred L20 showed the second highest for grain yield and yield components, while inbred SK5 came in the third rank. On the contrary, the inbred L18 exhibited the lowest means for PH, EPP, RPE, KPR, 100KW, and the highest means (unfavorable) for DTA and DTS. The inbred Sd7 exhibited the highest (unfavorable) mean for BS and the lowest (unfavorable) means for KPP and GYPP. The inbred L28 showed the lowest mean for DTA, DTS and EH the highest mean for LANG. Such significant differences among inbred lines in this study are prerequisite for the validity of using them as parents of diallel crosses to study the inheritance of their traits.

In general, GYPP of the three inbreds L53, L20 and Sk5 was higher than that of the three other inbreds L18, L28 and Sd7 under all the six environments. Reduction due to both stresses together was the highest in the inbred Sd7 under E5 and E6, and the lowest in inbred Sk5 under E5 and inbred L20 under E6. This means that the inbreds Sk5 and L20 could be considered tolerant to combinations of both stresses, while inbred Sd7 is sensitive. The highest GYPP of all inbreds was achieved under E1 (WW-LD) because of the optimum irrigation and the low plant density which is currently used by the Egyptian farmers. The effect of the second order interaction (G×I×D) was clearly shown by the F_1 crosses, where the rank of crosses was changed from one environment (a combination of irrigation regime and plant density) to another; especially when comparing poor with good environments. The highest GYPP of the F_1 crosses was generally obtained at the combination between WW and low-D (E1), where competition between plants is at minimum and the optimum availability of irrigation water at flowering stage. The highest GYPP in this experiment (277.36 g) was obtained from the cross L20 × L53 under well watered-low-density environment (E1) followed by the crosses L53 × Sk5 (245.53 g) and L53 × Sd7 (240.96 g) under the same environmental conditions. These crosses could therefore be considered responsive to this combination of good environment. The highest GYPP under the most severe stress in this experiment (water stress and high density stress) (E6) was obtained by the same crosses (161.05 g, 136.96 g and 132.46 g, respectively; these crosses were considered tolerant to both stresses together and responsive at good environments. It is clear that L53, Sk5 and L20 might be considered as source of tolerance and responsiveness in these crosses. Genotypic differences under drought and high density stresses were reported by several investigators [6,27-30].

3.3 Heterobeltiosis

In general, based on parents used, two major types of estimation of heterosis are reported in literature: (1) Mid-parent or average heterosis, which is the increased vigor of the F_1 over the mean of two parents. (2) High-parent or better parent heterosis, which is the increased vigor of the F_1 over the better parent [31,32]. The term heterobeltiosis has been suggested to describe the increased performance of the hybrid over the better parent [33]. Estimates of better parent heterosis (heterobeltiosis) across all F_1 crosses, maximum values and number of crosses showing significant favorable heterobeltiosis for all studied traits under the six environments 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 remaining studied traits under all combinations between plant densities and irrigation regimes. In general, the highest average significant and positive (favorable) heterobeltiosis was shown by grain yield per plant (313.14, 455.28, 404.32, 736.00, 680.84 and 851.69%) under E1 through E6, respectively. The lowest minimum (favorable) heterobeltiosis was shown by ASI (-29.41, -25.58, -20.69, -18.42, -14.89 and -1.85%) under E1 through E6, respectively. The traits PH, EP, BS, LANG under all environments, ASI under E4, E5 and E6, EPP and RPE under E1, E2 and E3 showed on average unfavorable heterobeltiosis. However, some crosses showed significant favorable heterobeltiosis in these cases.

In general, E2 environment (WW-MD), where irrigation was optimum and plant density was medium, showed the largest number of crosses showing significant favorable heterobeltiosis for studied traits. For GYPP, the severest stressed environment (WS-HD) showed the highest maximum heterobeltiosis. The reason for getting the highest average heterobeltiosis estimates under E6 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 stresses of both high plant density and water deficit stresses existed in this environment. These results are in agreement with those of Weidong and Tollenaar [33], who reported that increasing plant density from 4 to 12 plants m^{-2} resulted in increased heterosis for grain yield of maize. 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 [16]. 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.

On the contrary, the E1 environment (the non-stressed environment; WW-LD) showed the lowest average favorable heterobeltiosis for all yield traits, *viz.*KPR (25.57%), KPP (28.44%), GYPP (151.79%), (Table 4). The largest significant favorable heterobeltiosis for GYPP in this study was shown by the cross (L18 × Sd7) under E6 environment (WS-HD) (Table 5). This cross showed also the highest significant and favorable heterobeltiosis under E6 for the yield components RPE (18.06%), KPR (88.74%) and KPP (175.63%).

Under environments E1 through E5, the highest estimates of GYPP heterobeltiosis were generally obtained by the cross (L28 × Sd7) (313.14, 418.62, 404.32, 736.00 and 680.84%), respectively, followed by the cross L18 × Sd7 and the cross L18 × L28 (in the same 5 environments). Under the severest environment (E6), the cross (L28 × Sd7) showed the second highest per se grain yield/fed (Table 3) followed by the cross L53 x Sd7 and could therefore be recommended for commercial application under high plant density and water stress conditions and as good genetic material for maize breeding programs. The cross L28 x Sd7 showed the highest heterobeltiosis for RPE, KPR and KPP under all environments, EPP under E5 and E6. The second highest heterobeltiosis was also shown by the cross L18 xSd7 for 100-KW, KPR and KPP and the cross L20 x L53for EPP under all environments.

For days to anthesis, six crosses (L18 x Sd7, L53 x Sd7, L53 x Sk5, Sk5 x L18, Sk5 x Sd7 and L20 x L53) showed favorable, but slight and significant heterobeltiosis estimates under all the six environments. Three crosses exhibited significant favorable BS heterobeltiosis estimates, namely L20 x L53 under E6 (-49.84%), L53 x L28 and L53 x Sd7 under E1 environment (-51.63 and -54.44%, respectively) (Table 5).

Regarding anthesis-silking interval (ASI), significant and negative (favorable) heterobeltiosis estimates were shown by some crosses such as L53 x Sk5 under E1, E2 and E3 (-25.00, 25.58 and 20.69%, respectively) and L53 x L18 (-25.00%), L53 x L28 (-25.00%), L53 x Sd7 (-29.41%) and L18 x Sd7 (-25.00%) under E1 environment. In this respect, Bolanos and Edmeades [7] reported that short anthesis-silking interval (ASI) in hybrids and subsequently better pollination should not be discarded as an explanation of heterosis in grain number. Days required to tasseling along with other maturity traits are commonly used by plant breeders as basis of determining maturity of maize. Anthesis-silking interval revealed the time span or heat units required between anthesis to pollination. It is a trait used mostly in screening genotypes for tolerance to stresses especially for drought, and high plant density resistance [34].

Table 2. Combined analysis of variance of RCBD across two years for studied traits of 6 parents (P) and 15 F_1 crosses (F) and their interactions with years (Y) under six environments

SOV	df	% Sum of squares											
		E1	E2	E3	E4	E5	E6	E1	E2	E3	E4	E5	E6
		Days to 50% anthesis						Anthesis-silking interval					
P	5	7.84**	8.17**	14.57**	9.71**	13.04**	20.65**	2.50	8.85*	2.44	2.94	6.02	3.00
F_1	14	3.95*	4.87*	7.17**	37.40**	39.71**	5.66**	14.83	29.08**	9.51	18.45**	9.69	13.33*
P vs F_1	1	29.35**	28.77**	19.95**	5.49**	5.72**	23.97**	2.42	2.53*	2.21	1.11	0.00	0.12
P × Y	5	7.58**	2.74*	2.79*	2.72**	1.37*	9.56**	1.61	5.64*	7.97	8.56*	6.67	1.69
F_1 × Y	14	1.97	3.78	4.95**	34.99**	31.88**	3.28*	15.00*	14.67**	13.19	18.73**	18.19**	18.44**
P vs F_1 × Y	1	0.27	0.22	0.09	0.65	0.04	0.91**	2.18	0.01	0.11	5.45**	5.99**	0.01
		Plant height						Ear height					
P	5	13.22**	6.42**	20.39**	13.53**	9.23**	0.92	15.48**	15.94**	33.49**	14.10**	13.57**	9.82**
F_1	14	21.97**	9.90**	15.79**	10.03**	5.56**	9.96**	25.23**	17.57**	18.15**	24.70**	17.88**	22.75**
P vs F_1	1	58.93**	71.74**	58.03**	72.77**	72.45**	68.96**	50.17**	54.43**	34.31**	47.19**	46.32**	52.17**
P × Y	5	0.26	0.47*	0.09	0.26	0.28	2.93**	0.46	0.58	2.55**	0.69	1.34*	1.65**
F_1 × Y	14	0.41*	0.29	0.44	0.47	0.32	0.48	1.77**	1.19**	3.69**	2.60**	3.72**	3.74**
P vs F_1 × Y	1	0.07	0.23*	0.03	0.01	0.01	0.97**	0.02	0.43**	0.04	0.02	0.06	3.23**
		Barren stalks						Leaf angle					
P	5	9.11*	20.55**	14.02**	7.05**	12.61**	3.55	19.35**	24.74**	19.89**	24.31**	23.30**	25.27**
F_1	14	17.60**	19.02**	14.84**	6.42**	22.60**	17.89**	50.17**	42.71**	33.36**	19.93**	31.29**	31.66**
P vs F_1	1	0.04	9.71**	9.65**	36.81**	3.27**	9.91**	6.12**	3.52**	4.37**	7.24**	2.19**	5.56**
P × Y	5	9.11*	1.35	6.82*	3.09*	2.32	0.55	2.65**	3.93**	3.50**	5.24**	8.99**	4.06**
F_1 × Y	14	19.56**	9.84**	6.64	5.49*	9.46**	7.98	10.12**	4.89*	13.16**	14.57**	10.69**	9.25**
P vs F_1 × Y	1	0.33	0.86	2.51*	18.62**	13.64**	7.71**	0.40*	0.19	0.99*	1.58**	0.89*	6.34**
		Ears per plant						Rows per ear					
P	5	17.23**	18.95**	17.93**	3.93	1.28	4.67	28.95**	29.18**	24.81**	19.45**	17.87**	25.90**
F_1	14	27.41**	26.08**	20.44**	22.58**	12.27**	2.29	28.54**	27.01**	27.93**	17.92**	30.58**	20.86**
P vs F_1	1	3.82**	5.97**	0.66	8.61**	6.74**	9.08**	7.44**	4.13**	4.15**	10.42**	7.12**	11.59**
P × Y	5	2.07	3.36	5.57*	11.95**	7.63	3.58	3.73**	0.16	1.20	14.41*	0.87	2.70
F_1 × Y	14	7.97*	3.86*	4.04	14.78**	11.76**	10.05**	4.68*	3.98	6.26*	2.24	1.47	2.04
P vs F_1 × Y	1	2.81*	0.83*	10.38**	4.32**	2.30*	7.60**	0.09	0.34	0.01	1.55*	1.94*	0.97

SOV	df	% Sum of squares											
		E1	E2	E3	E4	E5	E6	E1	E2	E3	E4	E5	E6
		Days to 50% anthesis						Anthesis-silking interval					
		Kernels per plant						Kernels per row					
P	5	9.69**	8.35**	7.07**	4.69**	5.63*	6.66**	5.85**	12.20**	13.61**	13.92**	5.69**	14.53**
F_1	14	6.63**	18.17**	13.53**	11.27**	11.86**	2.02	10.66**	13.80**	12.49**	9.68**	13.92**	9.59**
P vs F_1	1	59.24**	46.18**	52.05**	51.92**	41.82**	48.61**	65.45**	58.66**	57.73**	59.17**	50.41**	53.79**
P × Y	5	0.74	0.37	0.98	5.34**	2.86	0.63	1.64*	1.24**	0.85	2.11*	3.96**	1.82
F_1 × Y	14	5.21**	4.14**	1.54	5.56**	4.10*	4.08	1.84**	2.29**	1.16*	1.19*	3.05*	2.03
P vs F_1 × Y	1	0.001	0.00	0.54	1.94**	3.35**	3.38**	0.90**	0.15	0.01	1.06**	3.41**	1.44**
		100-Kernel weight						Grain yield / plant					
P	5	11.75**	22.80**	18.87**	15.20**	6.26**	5.10**	5.50**	6.07**	3.53**	3.71**	1.64**	3.31**
F_1	14	16.33**	12.05**	9.73**	13.54**	16.24**	12.38**	9.66**	12.07**	10.52**	17.83**	14.69**	14.82**
P vs F_1	1	45.48**	46.16**	32.91**	16.00**	11.06**	8.68**	75.18**	71.22**	71.13**	70.56**	75.13**	67.51**
P × Y	5	4.11**	4.20**	4.54	0.65	2.92**	2.92*	0.37**	0.26**	0.20*	0.18*	0.42**	0.05
F_1 × Y	14	4.20**	5.39**	10.60**	11.18**	8.97**	12.29**	1.91**	1.88**	1.22**	1.95**	1.17*	1.42**
P vs F_1 × Y	1	2.09**	0.72**	0.16	1.82**	1.09**	4.08**	0.01	0.38**	0.55**	0.17**	0.02	0.02

and indicate significant at 0.05 and 0.01 probability level, respectively*

Table 3. Means of studied agronomic and yield traits of each inbred and hybrid under six environments across two seasons

Genotype	DTA						ASI					
	E1	E2	E3	E4	E5	E6	E1	E2	E3	E4	E5	E6
							Parents					
L20	59.67	62.67	62.58	61.67	62.75	65.17	2.33	3.42	4.67	3.25	3.25	4.00
L53	63.33	64.67	65.75	65.83	66.33	69.50	2.83	3.58	5.17	2.67	4.00	4.92
Sk5	61.00	63.17	65.67	64.83	65.83	68.67	2.67	3.83	4.83	2.67	4.33	4.42
L18	64.58	66.00	67.50	65.83	67.33	68.75	2.67	4.33	4.67	3.17	3.00	4.67
L28	60.00	60.83	63.50	61.33	62.00	63.33	2.67	3.67	4.50	2.67	3.92	4.50
Sd7	64.08	66.00	67.17	65.67	67.17	68.83	3.00	3.33	4.33	3.42	3.25	4.58
Average	62.11	63.89	65.36	64.19	65.24	67.38	2.69	3.69	4.69	2.97	3.63	4.51
							Crosses					
L20 X L53	58.00	59.17	60.67	59.50	61.00	62.33	2.00	2.83	3.83	2.67	3.33	4.42
L20 XSK5	59.00	60.83	62.00	60.83	62.33	64.17	2.33	3.17	4.33	3.00	4.00	5.00
L20 X L18	60.00	61.00	62.00	61.50	62.83	64.67	2.00	3.00	4.17	2.58	4.00	4.83

Genotype	DTA						ASI					
	E1	E2	E3	E4	E5	E6	E1	E2	E3	E4	E5	E6
L20 X L28	59.00	60.00	61.50	61.00	62.50	63.50	2.50	3.50	4.00	2.73	3.92	5.25
L20 X Sd7	59.17	60.58	62.00	61.00	62.50	63.67	2.83	2.92	3.58	2.85	4.00	5.83
L 53 X Sk5	59.00	60.00	61.00	60.00	61.67	63.00	2.00	2.67	3.83	3.00	3.83	4.58
L53 X L18	60.50	61.50	62.67	62.00	68.25	70.00	2.00	3.42	4.33	2.93	3.83	5.00
L53 X L28	59.00	60.00	61.50	60.83	62.33	63.50	2.00	3.00	4.00	2.50	3.33	5.00
L53 X Sd7	59.00	60.00	61.25	60.08	62.00	63.50	2.00	3.00	4.00	2.92	3.50	4.67
Sk5 X L18	59.00	60.00	61.50	61.00	62.50	63.50	2.08	3.08	4.00	2.55	3.50	5.00
Sk5 X L28	59.75	60.92	62.00	61.50	62.50	64.25	2.25	2.92	4.00	2.50	4.00	5.25
Sk5 X Sd7	60.00	61.33	62.50	61.50	63.17	65.17	2.17	3.17	4.17	3.00	4.25	5.25
L18 X L28	61.50	63.17	64.67	63.08	70.33	72.33	2.67	2.83	3.83	3.08	4.00	4.83
L18 X Sd7	60.00	61.17	62.17	61.50	63.00	65.00	2.00	3.00	4.33	3.00	4.08	4.67
L28 X Sd7	59.83	61.00	62.17	61.50	68.33	69.92	2.17	2.50	3.83	3.00	3.83	4.42
Average	59.52	60.71	61.97	61.12	63.68	65.23	2.20	3.00	4.02	2.82	3.83	4.93
	PH						EH					
							Parents					
L20	194.17	201.17	212.67	174.50	182.00	197.67	72.30	75.84	91.54	65.67	70.67	79.47
L53	233.67	206.83	250.33	192.17	209.00	222.33	99.25	92.60	127.95	88.17	98.57	102.13
Sk5	174.67	194.17	201.67	168.67	183.50	198.50	72.25	94.83	87.86	74.98	83.93	97.83
L18	178.33	177.25	186.67	158.17	167.83	181.00	66.33	69.74	86.65	67.08	71.33	78.31
L28	182.83	186.17	166.50	175.83	179.17	198.17	56.70	58.45	64.83	52.78	62.57	72.00
Sd7	202.33	215.17	204.67	184.67	199.33	212.00	87.76	92.72	95.66	72.14	87.94	95.17
Average	194.33	196.79	203.75	175.67	186.81	201.61	75.77	80.70	92.42	70.13	79.17	87.49
							Crosses					
L20 X L53	216.00	227.17	227.00	222.50	231.33	239.17	78.17	89.98	91.17	83.05	86.35	92.05
L20 XSK5	243.33	247.33	255.17	236.33	244.67	256.00	105.12	109.58	112.37	100.21	103.20	110.24
L20 X L18	247.17	251.67	258.50	240.17	246.83	254.33	110.65	113.11	119.12	105.92	112.40	118.11
L20 X L28	240.17	243.33	252.50	235.67	243.83	250.33	104.42	109.83	114.29	102.17	108.00	113.94
L20 X Sd7	242.17	247.67	253.50	236.83	244.50	252.17	107.28	111.39	116.45	103.89	109.50	115.50
L 53 X Sk5	224.00	235.00	238.33	229.50	237.17	243.33	93.82	101.73	106.17	92.78	94.97	101.77
L53 X L18	267.00	257.00	271.83	248.83	253.83	265.50	117.27	121.87	122.69	114.56	119.67	125.33
L53 X L28	238.00	239.33	247.83	232.00	240.67	245.83	99.50	105.65	110.33	98.49	104.02	110.76
L53 X Sd7	234.00	237.33	245.50	231.00	238.83	244.50	96.66	104.25	109.17	96.06	101.50	108.79
Sk5 X L18	238.67	241.83	250.17	233.83	242.50	249.17	103.06	107.93	112.30	100.40	106.07	112.50

Genotype	DTA						ASI					
	E1	E2	E3	E4	E5	E6	E1	E2	E3	E4	E5	E6
Sk5 X L28	245.17	250.00	255.33	238.33	245.17	253.50	109.09	112.42	118.17	104.60	110.54	116.43
Sk5 X Sd7	255.17	255.17	266.50	246.33	251.83	260.67	113.83	118.52	121.01	110.87	115.39	121.31
L18 X L28	273.00	268.00	280.67	254.67	260.83	278.67	125.33	125.98	131.63	120.36	124.03	135.30
L18 X Sd7	251.17	252.83	263.00	243.17	249.50	257.33	113.08	115.09	120.17	108.83	114.46	119.70
L28 X Sd7	247.33	248.67	257.00	240.33	247.50	257.50	105.84	112.09	116.39	105.46	110.71	116.53
Average	244.16	246.82	254.86	237.97	245.27	253.87	105.54	110.63	114.76	103.18	108.06	114.55
	BS						LANG					
Parents												
L20	9.22	11.19	26.16	7.37	12.04	19.54	23.33	23.33	23.00	25.50	27.00	26.67
L53	12.24	14.70	9.95	10.02	9.27	16.23	23.83	20.67	22.17	25.17	23.67	25.33
Sk5	9.43	10.28	10.97	15.66	15.69	17.56	19.67	18.33	20.67	24.00	24.00	21.67
L18	12.06	9.31	10.03	11.15	22.39	11.77	31.33	27.67	28.17	31.00	33.17	32.17
L28	7.46	14.81	13.88	11.87	12.50	14.04	35.00	32.33	30.33	32.67	33.83	34.67
Sd7	9.22	15.82	15.39	14.53	15.54	21.60	26.50	26.67	25.33	26.83	31.50	29.67
Average	9.94	12.69	14.40	11.77	14.57	16.79	26.61	24.83	24.94	27.53	28.86	28.36
Crosses												
L20 X L53	6.13	5.49	5.58	5.53	6.68	8.14	20.17	20.17	22.33	24.67	21.67	23.67
L20 XSK5	10.50	10.95	12.60	13.20	14.06	14.53	28.33	27.33	28.17	30.67	28.50	29.00
L20 X L18	10.36	11.96	12.73	14.29	14.31	15.45	29.83	30.17	28.50	33.67	31.67	31.67
L20 X L28	9.55	8.12	10.73	12.50	11.08	13.48	27.50	27.50	26.50	31.00	28.83	29.83
L20 X Sd7	9.78	9.97	11.45	13.19	13.03	14.06	28.33	28.67	27.17	31.83	29.67	30.17
L 53 X Sk5	8.45	6.57	8.00	8.01	9.17	10.49	24.67	22.83	24.00	26.83	25.00	25.67
L53 X L18	11.00	15.38	16.21	16.37	17.57	17.92	32.33	31.67	31.00	35.50	34.00	33.83
L53 X L28	8.71	7.11	10.03	10.64	10.10	12.53	25.83	25.50	25.83	29.00	27.67	27.83
L53 X Sd7	8.71	6.70	9.47	9.27	9.65	11.63	25.33	24.17	25.00	27.83	26.17	26.67
Sk5 X L18	9.39	7.39	10.36	11.37	10.40	13.15	27.00	26.50	26.33	30.33	28.33	28.50
Sk5 X L28	10.26	10.71	11.89	13.65	13.88	14.58	29.50	29.00	27.50	32.83	31.17	30.67
Sk5 X Sd7	10.77	14.49	14.93	15.60	15.80	16.94	31.00	30.83	30.00	34.67	33.17	32.83
L18 X L28	15.76	18.79	22.40	22.43	20.08	26.36	35.17	34.50	35.33	38.67	36.67	36.50
L18 X Sd7	10.56	13.21	13.63	14.84	15.00	16.18	30.33	30.67	29.00	34.33	32.67	32.33
L28 X Sd7	9.67	11.92	12.09	11.41	13.06	14.17	28.50	27.17	28.33	32.00	30.17	30.33

Genotype				DTA						ASI		
	E1	E2	E3	E4	E5	E6	E1	E2	E3	E4	E5	E6
Average	9.97	10.59	12.14	12.82	12.92	14.64	28.26	27.78	27.67	31.59	29.69	29.97
				KPR						KPP		
							Parents					
L20	37.38	36.29	35.79	32.02	30.08	27.15	681.12	578.35	492.03	504.14	401.81	312.36
L53	42.37	38.58	36.51	39.40	33.37	28.98	755.07	580.90	508.08	670.36	465.82	356.25
Sk5	33.72	30.57	28.49	30.70	29.15	23.29	575.11	495.58	415.10	454.19	388.26	260.44
L18	29.08	27.25	21.57	28.17	24.01	17.41	492.13	418.55	281.99	423.87	288.20	167.90
L28	28.22	28.13	24.78	26.12	23.02	21.36	458.08	447.64	354.61	390.20	274.15	228.89
Sd7	30.88	25.73	25.64	24.96	21.29	19.34	524.59	376.73	366.29	338.11	256.19	173.87
Average	33.61	31.09	28.80	30.23	26.82	22.92	581.02	482.96	403.02	463.48	345.74	249.95
							Crosses					
L20 X L53	54.03	52.34	50.48	50.88	49.28	47.17	1001.41	868.19	767.64	914.82	766.61	628.74
L20 XSK5	46.54	44.47	42.24	43.28	41.36	38.73	851.19	682.39	621.17	770.97	612.13	509.13
L20 X L18	44.57	42.47	41.01	42.04	39.78	37.27	800.63	660.83	586.49	694.53	565.84	493.17
L20 X L28	45.74	44.13	42.53	43.82	41.66	39.23	829.05	689.41	626.51	748.89	617.49	512.31
L20 X Sd7	45.49	43.76	41.93	43.12	41.11	38.70	818.54	682.08	614.78	734.12	599.97	504.12
L 53 X Sk5	48.48	46.11	44.92	45.46	44.56	42.54	903.14	764.50	677.72	846.61	689.38	553.81
L53 X L18	42.54	40.37	39.11	39.42	37.86	35.30	743.15	616.68	554.81	635.25	523.15	456.74
L53 X L28	46.94	45.14	43.17	44.76	43.29	40.68	862.10	722.66	657.61	775.94	651.12	533.00
L53 X Sd7	47.67	45.74	43.88	45.11	43.99	41.31	885.44	736.47	667.41	810.39	664.14	543.48
Sk5 X L18	46.26	44.67	42.97	44.28	42.58	39.63	844.80	707.07	638.41	762.38	638.69	520.70
Sk5 X L28	45.12	42.99	41.63	42.53	40.56	38.32	806.15	671.31	597.51	722.57	585.05	498.26
Sk5 X Sd7	43.39	41.18	40.00	40.63	38.68	36.02	773.02	640.12	567.11	659.12	541.57	471.63
L18 X L28	40.64	37.49	35.75	37.13	35.91	32.61	667.98	499.06	456.88	543.51	484.88	376.22
L18 X Sd7	43.79	41.72	40.42	41.14	39.02	36.50	777.86	647.87	575.60	674.35	550.53	479.22
L28 X Sd7	45.96	43.84	43.11	43.61	42.11	39.50	811.27	684.51	614.15	713.85	606.84	493.70
Average	45.81	43.76	42.21	43.15	41.45	38.90	825.05	684.88	614.92	733.82	606.49	504.95
				EPP						RPE		
							Parents					
L20	1.34	1.30	1.17	1.10	1.07	1.00	15.30	15.02	14.66	14.06	13.79	13.59
L53	1.39	1.27	1.16	1.25	1.15	1.03	15.97	15.40	14.79	14.97	14.14	13.86
Sk5	1.25	1.16	1.06	1.13	1.03	0.87	14.23	13.91	13.59	13.73	13.56	12.62
L18	1.15	1.03	0.98	1.16	0.98	0.70	12.92	11.82	11.38	13.04	12.29	9.59

Genotype				DTA						ASI		
	E1	E2	E3	E4	E5	E6	E1	E2	E3	E4	E5	E6
L28	1.09	1.12	1.02	1.10	0.85	0.82	12.55	12.76	12.03	12.31	11.69	11.61
Sd7	1.18	1.05	1.04	1.16	0.90	0.85	13.30	12.39	12.33	11.67	11.38	10.72
Average	1.23	1.16	1.07	1.15	1.00	0.88	14.04	13.55	13.13	13.30	12.81	12.00
						Crosses						
L20 X L53	1.47	1.26	1.20	1.48	1.32	1.18	16.58	16.31	15.83	16.10	15.64	15.14
L20 XSK5	1.29	1.11	1.07	1.25	1.11	1.02	14.83	14.27	13.75	14.04	13.66	13.00
L20 X L18	1.20	1.05	1.03	1.15	1.01	0.98	14.22	13.63	13.10	13.58	13.10	12.90
L20 X L28	1.23	1.12	1.09	1.21	1.05	1.00	14.90	14.17	13.74	14.11	13.81	13.17
L20 X Sd7	1.21	1.12	1.06	1.20	1.05	1.00	14.83	14.02	13.63	14.00	13.58	13.00
L 53 X Sk5	1.32	1.20	1.12	1.35	1.18	1.02	15.80	15.31	14.60	15.00	14.44	13.80
L53 X L18	1.13	1.04	1.00	1.09	1.00	0.94	13.80	13.14	12.90	13.00	12.73	12.10
L53 X L28	1.29	1.15	1.11	1.29	1.14	1.00	15.00	14.60	14.06	14.61	14.11	13.39
L53 X Sd7	1.30	1.17	1.11	1.31	1.15	1.00	15.36	14.90	14.39	14.80	14.30	13.70
Sk5 X L18	1.26	1.13	1.10	1.23	1.08	1.00	14.90	14.30	13.99	14.20	14.00	13.24
Sk5 X L28	1.20	1.10	1.04	1.18	1.05	1.00	14.50	13.74	13.32	13.91	13.24	12.96
Sk5 X Sd7	1.18	1.05	1.00	1.12	1.00	0.95	13.80	13.33	13.00	13.21	12.86	12.48
L18 X L28	1.08	1.00	1.00	1.04	0.93	0.89	12.44	12.08	11.66	12.23	11.93	11.59
L18 X Sd7	1.19	1.05	1.01	1.14	1.00	0.96	13.90	13.52	13.07	13.37	13.03	12.66
L28 X Sd7	1.20	1.12	1.08	1.19	1.12	0.98	14.40	14.10	13.62	14.18	13.64	13.12
Average	1.24	1.11	1.07	1.22	1.08	1.00	14.62	14.10	13.64	14.02	13.61	13.08
				100-KW						GYPP		
						Parents						
L20	34.09	31.25	28.96	30.09	28.57	27.21	106.58	92.85	71.48	57.74	36.71	41.55
L53	35.41	30.99	29.76	33.40	29.19	28.83	132.05	93.69	71.70	85.54	51.04	50.94
Sk5	31.69	28.75	26.35	28.95	27.57	24.81	77.56	64.94	52.97	46.87	37.48	26.14
L18	26.35	23.12	18.74	27.66	24.68	20.57	46.69	27.23	20.07	34.79	20.72	10.57
L28	25.55	25.76	22.95	25.46	24.12	22.61	44.37	35.38	30.45	21.20	18.92	16.94
Sd7	28.09	23.59	22.78	24.37	22.74	20.41	55.10	29.14	32.87	13.21	12.75	8.03
Average	30.20	27.24	24.92	28.32	26.14	24.07	77.06	57.20	46.59	43.23	29.60	25.70
						Crosses						
L20 X L53	40.60	36.94	35.20	37.02	35.95	34.03	277.36	238.19	191.55	242.72	196.60	161.05
L20 XSK5	35.75	32.76	31.05	31.67	28.60	26.94	221.68	182.28	153.06	166.82	145.85	115.84
L20 X L18	35.43	33.58	31.05	31.87	29.00	26.72	219.17	193.75	178.07	182.09	153.92	129.66

Genotype	DTA						ASI					
	E1	E2	E3	E4	E5	E6	E1	E2	E3	E4	E5	E6
L20 X L28	36.31	34.55	32.31	33.21	31.02	27.97	232.77	186.52	156.26	171.71	154.22	113.79
L20 X Sd7	35.92	34.35	32.09	32.72	30.51	27.52	226.70	182.42	159.88	179.94	144.12	121.52
L 53 X Sk5	38.08	36.12	33.75	34.95	32.85	30.54	245.53	224.51	184.72	202.98	172.24	136.96
L53 X L18	33.91	31.71	29.72	29.89	26.28	25.17	197.48	147.69	138.34	138.90	117.81	95.30
L53 X L28	37.23	35.07	32.98	33.77	31.94	28.91	237.53	168.89	165.70	171.64	156.06	106.91
L53 X Sd7	37.63	35.42	33.50	34.27	32.04	29.86	240.96	219.13	181.95	197.33	169.25	132.46
Sk5 X L18	36.74	34.75	32.66	33.42	31.48	28.37	234.83	197.02	165.10	183.68	156.13	123.23
Sk5 X L28	35.57	34.01	31.66	32.39	29.78	27.12	223.20	201.32	167.12	177.24	151.52	124.03
Sk5 X Sd7	34.56	32.53	30.35	30.57	27.34	25.64	207.22	157.58	145.21	147.71	127.73	99.73
L18 X L28	31.78	29.89	27.73	27.30	25.30	22.99	171.09	124.38	122.94	123.96	90.11	73.61
L18 X Sd7	34.84	32.94	30.66	31.21	28.22	26.11	213.29	161.79	148.59	154.19	134.71	101.67
L28 X Sd7	36.28	34.51	32.55	33.45	30.72	28.94	227.64	183.46	165.78	177.24	147.70	117.96
Average	36.04	33.94	31.82	32.51	30.07	27.79	225.10	184.60	161.62	174.54	147.87	116.91

Table 4. Estimates of average (Aver), minimum (Min) and maximum (Max) heterobeltiosis and number (No.) of crosses showing significant favorable heterobeltiosis for studied traits under six environments across two seasons

Para-meter	E1 WW-LD	E2 WW-MD	E3 WW-HD	E4 WS-LD	E5 WS-MD	E6 WS-HD	E1 WW-LD	E2 WW-MD	E3 WW-HD	E4 WS-LD	E5 WS-MD	E6 WS-HD
	Days to 50% anthesis (DTA)						Anthesis-silking interval (ASI)					
Aver	-2.07	-3.02	-3.37	-2.89	-0.21	-0.98	-13.63	-13.73	-11.09	2.31	17.06	14.37
Max	2.5	3.84	1.84	2.85	13.44	14.21	21.43	2.44	0	15.62	36.11	45.83
Min	-6.84	-7.32	-7.44	-8.5	-6.53	-8.25	-29.41	-25.58	-20.69	-18.42	-14.89	-1.85
No.	9	13	11	10	9	9	5	1	1	0	0	0
	Plant height (PH)						Ear height (EH)					
Aver	34.75	31.67	37.55	41.82	38.3	31.79	61.92	59.02	45.73	66.54	54.4	45.1
Max	53.08	51.2	68.57	61.01	55.41	53.96	121.05	115.53	103.02	128.03	98.24	87.92
Min	11.24	12.92	6.74	25.09	19.82	15.33	8.11	9.86	-0.41	23.74	13.16	4.02
No.	0	0	0	0	0	0	0	0	0	0	0	0
	Barren stalks (BS)						Leaf angle (LANG)					
Aver	15.23	1.15	12.19	32.89	10.02	5.6	23.51	29.82	22.47	24.17	14.48	19.17
Max	111.3	101.77	123.39	101.13	89.57	123.91	57.63	68.18	45.16	44.44	43.66	51.54
Min	-33.48	-54.44	-43.91	-24.97	-33.7	-49.84	-13.57	-2.42	0.75	-1.99	-8.45	-6.58

Para-meter	E1 WW-LD	E2 WW-MD	E3 WW-HD	E4 WS-LD	E5 WS-MD	E6 WS-HD	E1 WW-LD	E2 WW-MD	E3 WW-HD	E4 WS-LD	E5 WS-MD	E6 WS-HD
No.	0	2	0	0	0	1	1	0	0	0	1	1
	Number of ears per plant (EPP)						Number of row per ear (RPE)					
Aver	-5.07	-8.84	-4.18	2.63	1.46	4.96	-1.59	-2.17	-2.32	0	0.79	0.81
Max	6.25	0.66	4.08	17.86	23.75	16.04	8.27	10.49	10.45	15.17	16.73	18.06
Min	-18.35	-18.71	-13.64	-12.68	-12.83	-9.4	-13.57	-14.65	-12.77	-13.14	-9.98	-12.71
No.	1	0	0	5	2	7	4	3	3	2	3	3
	Number of kernel per row (KPR)						Number of kernels per plant (KPP)					
Aver	25.57	29.38	32.18	31.38	40.94	53.14	28.44	28.95	36.01	41.42	55.91	75.78
Max	48.82	55.88	68.15	66.96	82.94	88.74	54.65	54.79	67.67	82.95	121.36	175.63
Min	0.39	4.62	7.11	0.04	13.47	21.82	-1.58	6.16	9.2	-5.24	12.31	28.21
No.	14	15	15	14	15	15	14	15	15	14	15	15
	100-kernel weight (100-KW)						Grain yield per plant (GYPP)					
Aver	10.73	15.96	16.56	7.66	8.49	6.66	151.79	176.63	191.31	236.58	315.98	287.9
Max	29.15	39.66	41.87	31.41	27.37	27.99	313.14	455.28	404.32	736	680.84	861.59
Min	-4.24	2.33	-0.14	-10.5	-9.99	-12.68	49.55	57.64	92.96	62.37	130.82	87.08
No.	11	14	14	11	10	6	15	15	15	15	15	15

WW = well watering, WS = water stress, HD = high density, MD = medium density, LD = low density

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

Cross	E1 WW-LD	E2 WW-MD	E3 WW-HD	E4 WS-LD	E5 WS-MD	E6 WS-HD	E1 WW-LD	E2 WW-MD	E3 WW-HD	E4 WS-LD	E5 WS-MD	E6 WS-HD
	Days to 50 % anthesis						Anthesis-silking interval					
L20 X L53	-2.79**	-5.59**	-3.06**	-3.51**	-2.79**	-4.35**	-14.29	-17.07	-17.86	0.00	2.56	10.42
L20 XSK5	-1.12	-2.93**	-0.93	-1.35**	-0.66	-1.53	0.00	-7.32	-7.14	12.50	23.08*	25.00**
L20 X L18	0.56	-2.66**	-0.93	-0.27	0.13	-0.77	-14.29	-12.20	-10.71	-18.42	33.33**	20.83*
L20 X L28	-1.12	-1.37**	-1.73*	-0.54	0.81	0.26	7.14	2.44	-11.11	2.50	20.51	31.25**
L20 X Sd7	-0.84	-3.32**	-0.93	-1.08*	-0.40	-2.30*	21.43	-12.50	-17.31	-12.31	23.08*	45.83**
L 53 X Sk5	-3.28**	-5.01**	-7.11**	-7.46**	-6.33**	-8.25**	-25.00*	-25.58*	-20.69*	12.50	-4.17	3.77
L53 X L18	-4.47**	-4.90**	-4.69**	-5.82**	2.89**	1.82	-25.00*	-4.65	-7.14	10.00	27.78*	7.14
L53 X L28	-1.67*	-1.37**	-3.15**	-0.82	0.54	0.26	-25.00*	-16.28	-11.11	-6.25	-14.89	11.11
L53 X Sd7	-6.84**	-7.22**	-6.84**	-8.50**	-6.53**	-7.75**	-29.41*	-10.00	-7.69	9.37	7.69	1.82
Sk5 X L18	-3.28**	-5.01**	-6.35**	-5.91**	-5.06***	-7.52**	-21.88	-19.57	-14.29	-4.38	16.67	13.21

Cross	E1	E2	E3	E4	E5	E6	E1	E2	E3	E4	E5	E6
	WW-LD	WW-MD	WW-HD	WS-LD	WS-MD	WS-HD	WW-LD	WW-MD	WW-HD	WS-LD	WS-MD	WS-HD
Sk5 X L28	-0.42	0.14	-2.36*	0.27	0.81	1.45	-15.63	-20.45	-11.11	-6.25	2.13	18.87*
Sk5 X Sd7	-1.64*	-2.90**	-4.82**	-5.14**	-4.05**	-5.10**	-18.75	-5.00	-3.85	12.50	30.77**	18.87*
L18 X L28	2.50**	3.84**	1.84	2.85**	13.44**	14.21**	0.00	-22.73	-14.81	15.62	33.33**	7.41
L18 X Sd7	-6.37**	-7.32**	-7.44**	-6.35**	-6.20**	-5.45**	-25.00*	-10.00	0.00	-5.26	36.11**	1.82
L28 X Sd7	-0.28	0.27	-2.10*	0.27	10.22**	10.39**	-18.75	-25.00	-11.54	12.50	17.95	-1.85
	Barren stalks						**Number of ears per plant**					
L20 X L53	-33.48	-50.90	-43.91	-24.97	-27.94	-49.84*	6.25**	-2.75	2.72	17.86**	14.73**	14.49**
L20 XSK5	13.91	6.49	14.86	79.10*	16.79	-17.25	-4.26*	-14.43**	-8.72**	11.04**	3.27	2.21
L20 X L18	12.40	28.36	26.92	93.85**	18.87	31.26	-10.69**	-18.71**	-12.03**	-1.43	-5.47	-1.76
L20 X L28	28.02	-27.45	-22.68	69.62*	-7.95	-4.03	-8.83**	-13.58**	-6.47**	9.73**	-1.88	0.00
L20 X Sd7	6.15	-10.87	-25.63	79.04*	8.20	-28.01	-10.00**	-14.05**	-8.94**	3.13	-1.88	0.00
L 53 X Sk5	-10.37	-36.08	-19.64	-20.02	-1.10	-35.36	-5.18*	-5.49**	-3.03	7.86*	2.94	-1.24
L53 X L18	-8.76	65.17	62.90	63.44**	89.57*	52.19	-18.35**	-18.36**	-13.64**	-12.68**	-12.83**	-9.40**
L53 X L28	16.84	-51.63*	0.72	6.23	8.99	-10.79	-6.92**	-9.98**	-4.52*	2.67	-1.06	-3.20
L53 X Sd7	-5.56	-54.44*	-4.90	-7.50	4.16	-28.33	-6.42**	-7.66**	-3.80	4.64**	0.50	-3.20
Sk5 X L18	-0.48	-20.63	3.30	1.89	-33.70	11.71	0.55	-2.66	4.08	6.04	4.86	14.74**
Sk5 X L28	37.64	4.13	8.39	15.00	11.05	3.83	-4.00	-5.08**	-1.97	4.63	1.61	14.74**
Sk5 X Sd7	16.79	40.93	36.17	7.33	1.67	-3.55	-5.21*	-9.77**	-5.46*	-3.28	-3.23	9.18**
L18 X L28	111.30**	101.77*	123.39**	101.13**	60.68	123.91**	-6.05*	-10.38**	-2.03	-10.42**	-5.09	8.32*
L18 X Sd7	14.42	41.87	35.91	33.00	-3.52	37.40	1.37	-0.30	-2.71	-2.47	1.69	13.55**
L28 X Sd7	29.64	-19.51	-12.92	-3.86	4.51	0.88	1.65	0.66	3.87	2.07	23.75**	16.04**
	Number of rows per ear						**Number of kernels per row**					
L20 X L53	3.83*	5.92**	7.06**	7.57**	10.60**	9.26**	27.51**	35.67**	38.27**	29.13**	47.70**	62.79**
L20 XSK5	-3.05	-5.03**	-6.19**	-0.08	-0.97	-4.32	24.50**	22.52**	18.00**	35.19**	37.50**	42.68**
L20 X L18	-7.04**	-9.25**	-10.61**	-3.40	-5.00*	-5.05	19.25**	17.02**	14.57**	31.32**	32.24**	37.28**
L20 X L28	-2.61	-5.70**	-6.22**	0.39	0.16	-3.04	22.37**	21.60**	18.81**	36.86**	38.50**	44.50**
L20 X Sd7	-3.07	-6.66**	-6.97**	-0.40	-1.53	-4.32	21.72**	20.57**	17.13**	34.67**	36.67**	42.56**
L 53 X Sk5	-1.04	-0.58	-1.28	0.22	2.06	-0.44	14.42**	19.51**	23.04**	15.37**	33.53**	46.82**
L53 X L18	-13.57**	-14.65**	-12.77**	-13.14**	-9.98**	-12.71**	0.39	4.62**	7.11*	0.04	13.47**	21.82**
L53 X L28	-6.05**	-5.19**	-4.96**	-2.37	-0.24	-3.41	10.79**	16.99**	18.24**	13.61**	29.75**	40.38**
L53 X Sd7	-3.83*	-3.25	-2.70	-1.11	1.10	-1.16	12.50**	18.55**	20.19**	14.48**	31.85**	42.56**
Sk5 X L18	4.68**	2.80	2.93	3.40	3.26	4.89	37.19**	46.12**	50.82**	44.23**	46.06**	70.16**
Sk5 X L28	1.87	-1.20	-1.96	1.29	-2.31	2.68	33.81**	40.65**	46.12**	38.53**	39.15**	64.55**

Cross	E1	E2	E3	E4	E5	E6	E1	E2	E3	E4	E5	E6
	WW-LD	WW-MD	WW-HD	WS-LD	WS-MD	WS-HD	WW-LD	WW-MD	WW-HD	WS-LD	WS-MD	WS-HD
Sk5 X Sd7	-3.04	-4.15*	-4.33*	-3.80**	-5.18*	-1.14	28.69**	34.70**	40.41**	32.34**	32.69**	54.68**
L18 X L28	-3.68	-5.31**	-3.14	-6.18**	-2.89	-0.21	39.75**	33.28**	44.25**	31.83**	49.54**	52.68**
L18 X Sd7	4.51*	9.15**	5.95**	2.51	6.06*	18.06**	41.79**	53.09**	57.66**	46.07**	62.49**	88.74**
L28 X Sd7	8.27**	10.49**	10.45**	15.17**	16.73**	13.03**	48.82**	55.88**	68.15**	66.96**	82.94**	84.96**
			100-kernel weight						**Grain yield per plant**			
L20 X L53	14.66**	18.22**	18.30**	10.83**	23.15**	18.05**	110.04**	154.23**	167.17**	183.73**	285.18**	216.17**
L20 XSK5	4.88	4.84**	7.22**	5.27*	0.11	-1.01	107.99**	96.33**	114.13**	188.90**	289.14**	178.78**
L20 X L18	3.93	7.46**	7.22**	5.93*	1.48	-1.80	105.63**	108.68**	149.12**	215.33**	319.33**	212.03**
L20 X L28	6.51*	10.57**	11.56**	10.38**	8.57**	2.79	118.39**	100.89**	118.60**	197.36**	320.15**	173.84**
L20 X Sd7	5.36*	9.91**	10.83**	8.77**	6.77**	1.12	112.69**	96.48**	123.68**	211.62**	292.64**	192.44**
L 53 X Sk5	7.54**	16.57**	13.40**	4.63*	12.54**	5.95*	85.93**	139.64**	157.64**	137.29**	237.46**	168.87**
L53 X L18	-4.24	2.33	-0.14	-10.50**	-9.99**	-12.68**	49.55**	57.64**	92.96**	62.37**	130.82**	87.08**
L53 X L28	5.14*	13.16**	10.82**	1.11	9.40**	0.29	79.87**	80.27**	131.11**	100.64**	205.75**	109.88**
L53 X Sd7	6.26*	14.29**	12.57**	2.60	9.75**	3.59	82.47**	133.89**	153.78**	130.68**	231.59**	160.04**
Sk5 X L18	15.93**	20.87**	23.94**	15.46**	14.20**	14.35**	202.76**	203.37**	211.68**	291.88**	316.56**	371.36**
Sk5 X L28	12.24**	18.32**	20.16**	11.89**	8.02**	9.30**	187.76**	209.98**	215.49**	278.14**	304.27**	374.42**
Sk5 X Sd7	9.05**	13.16**	15.16**	5.61*	-0.82	3.35	167.16**	142.63**	174.13**	215.14**	240.79**	281.46**
L18 X L28	20.58**	16.03**	20.84**	-1.31	2.52	1.70	266.42**	251.59**	303.74**	256.34**	334.94**	334.42**
L18 X Sd7	24.03**	39.66**	34.58**	12.81**	14.34**	26.93**	287.11**	455.28**	352.04**	343.24**	550.21**	861.59**
L28 X Sd7	29.15**	33.97**	41.87**	31.41**	27.37**	27.99**	313.14**	418.62**	404.32**	736.00**	680.84**	596.14**

*WW = well watering, WS = water stress, HD = high density, MD = medium density, LD = low density. *and** indicate significant at 0.05 and 0.01 probability level, respectively*

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 six environments (combinations of three plant densities and two irrigation regimes) 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 all six environments, suggesting that both additive and non-additive gene effects play important roles in controlling the inheritance of these traits under all environments. A similar conclusion was reported by several investigators [6,21,35-42,].

In the present study under all environments, the magnitude of GCA mean squares was higher than that of SCA mean squares (the ratio of GCA/SCA mean squares was higher than unity) for LANG, EPP and RPE under all environments, 100KW, except E2, DTA under E1 and E5, ASI under E4 and E5, BS under E1, E4 and E5 and KPP under E1, E2 and E3, 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 (33 out of 72 cases, *i.e.* 45.8%). Selection methods would be the best choice in improving such traits under the respective environments. These results are in agreement with those reported by several investigators [6,23,40-44].

On the contrary, the magnitude of SCA mean squares was higher than that of GCA mean squares (the GCA/SCA ratio was less than unity) for the rest of cases, the most importantly are 4 traits, namely PH, EH, KPR and GYPP under all the six studied environments, suggesting the existence of a greater portion of non-additive than additive variance in controlling the inheritance of these traits under respective environments. Heterosis breeding method would be the best choice in improving such traits under the respective environments. A similar conclusion was reported by many investigators [6,36-40,45-48].

Results in Table 6. indicate that mean squares due to the SCA × year and GCA x year interactions were highly significant for 10 out of 12 traits, namely DTA, PH, EH, BS, LANG, RPE, KPR, KPP, 100KW and GYPP under all studied environments, indicating that additive and non-additive variances for these traits under the six studied environments were affected by years. This was not true for EPP under all environments and few other cases, suggesting that additive and non-additive variances for these cases were not affected by years.

The mean squares due to SCA × year was higher than those due to GCA × year for GYPP in all environments, except E1 and E5, as well as some other cases (Table 6), suggesting that SCA (non-additive variance) is more affected by years than GCA for these cases. On the contrary, mean squares due to GCA × year was higher than those due to SCA × year in all environments for PH except E2, ASI except E4, RPE, except E6 and KPR, except E4 and E6 as well as some other cases (Table 6), indicating that GCA (additive) variance is more affected by years than SCA (non-additive) variance for these traits under the respective environments.

3.5 GCA Effects

Estimates of general combining ability (GCA) effects of parental inbreds for studied traits under the six environments (combinations of 3 plant densities × 2 irrigation regimes) 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 all environments (E1 through E5) followed by L20 and Sk5. These best general combiners for grain yield (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 (Table 7) and the worst in *per se* performance for the same traits under the six 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 the 6 environments and SK5 under E4 were also the best general combiners for low DTA*, i.e.* the best in producing good hybrid combinations for earliness under the respective environments. The inbred L53 was also the best general combiner for short ASI under E1 and E4 environments.

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 across 2013 and 2014 seasons

Parameter	E1	E2	E3	E4	E5	E6	E1	E2	E3	E4	E5	E6
	Days to 50 % anthesis						**Anthesis-silking interval**					
GCA	23.90*	18.73*	19.41	16.91*	53.72	48.78	0.23	0.62	0.42	0.66	0.82	0.05
SCA	16.77**	24.38**	25.71**	23.76**	41.36	54.35	0.85	1.24**	1.08*	0.30	0.80	1.25
GCA/SCA	1.43	0.77	0.75	0.71	1.30	0.90	0.27	0.50	0.39	2.20	1.03	0.04
GCA×Y	2.72**	1.90**	6.68**	3.42**	16.49**	14.70**	0.66**	0.56	0.73*	0.42*	0.99**	0.72**
SCA×Y	1.37**	2.32**	1.57**	5.44**	34.49**	30.46**	0.37**	0.34	0.37	0.66**	0.79**	0.59**
GCA×Y/SCA×Y	1.98	0.82	4.27	0.63	0.48	0.48	1.76	1.64	1.99	0.63	1.25	1.22
	Plant height						**Ear height**					
GCA	976.55	375.2*	929.20	251.04	334.10	238.84	455.50	545.3*	621.30	337.90	446.50	412.50
SCA	6058**	5112**	6697**	7225**	6475**	5539**	2520**	2218**	1942**	2486**	2135**	1978**
GCA/SCA	0.16	0.07	0.14	0.03	0.05	0.04	0.20	0.25	0.32	0.14	0.21	0.21
GCA×Y	577.80**	61.1**	418.8**	378.34**	157.5**	337.08**	280.3**	113.59**	268.3**	114.9**	164.8**	195.5**
SCA×Y	323.73**	208.2**	251.1**	168.13**	105.1**	105.64**	126.9**	135.00**	94.9**	216.2**	182.4**	174.4**
GCA×Y/SCA×Y	1.78	0.29	1.67	2.25	1.50	3.19	2.20	0.33	2.83	0.53	0.90	1.12
	Barren stalks						**Leaf angle**					
GCA	25.05*	61.80	124.90	123.13*	212.83*	48.17**	263.1*	250.1*	157.39**	190.06**	263.93*	218.64**
SCA	21.33**	83.00	127.20	66.18*	43.02	110.99*	50.8*	58.80	41.70	62.42	35.49	37.35
GCA/SCA	1.17	0.74	0.98	1.86	4.95	0.43	5.20	4.30	3.77	3.04	7.44	5.85
GCA×Y	4.27	16.60	252.5**	26.00**	22.91	5.61	46.3**	33.8**	13.63**	9.12**	25.61**	15.09**
SCA×Y	5.32	45.1*	72.0**	22.95**	49.97*	42.82*	18.0**	33.0**	22.80**	41.15**	29.36**	26.99**
GCA×Y/SCA×Y	0.80	0.37	3.51	1.13	0.46	0.13	2.60	1.02	0.60	0.22	0.87	0.56
	Ears per plant						**Rows per ear**					
GCA	0.17**	0.12**	0.06**	0.10*	0.14**	0.12*	21.40*	23.05*	21.39**	14.86*	14.06*	21.16*
SCA	0.02	0.02	0.01	0.05	0.04**	0.03	2.35	2.53	2.28	3.60*	3.40*	4.19
GCA/SCA	9.27	7.40	6.47	2.13	3.79	3.47	9.09	9.12	9.39	4.13	4.13	5.05
GCA×Y	0.01	0.01	0.00	0.14	0.07	0.07	2.28**	2.76**	1.89**	1.50**	3.16**	2.65**
SCA×Y	0.02	0.01	0.01	0.02	0.01	0.03	1.20**	1.22**	1.06**	1.10**	1.34**	2.66**
GCA×Y/SCA×Y	0.75	1.02	0.48	5.89	7.63	2.46	1.89	2.27	1.78	1.37	2.35	1.00
	Kernels per row						**Kernels per plant**					
GCA	259.57**	257.2*	306.05**	221.6**	213.11*	235.25**	139470**	97058*	94731**	151089**	88106*	62393**
SCA	279.75**	303.9**	338.09**	321.0**	398.08**	464.09**	114543**	86904**	86824**	146868**	129622**	118495**

Parameter	E1	E2	E3	E4	E5	E6	E1	E2	E3	E4	E5	E6
GCA/SCA	0.93	0.85	0.91	0.69	0.54	0.51	1.22	1.12	1.09	1.00	0.68	0.53
GCA×Y	23.47**	41.2**	19.43**	11.4**	37.24**	15.38**	10640**	14627**	5906**	10902**	12449**	7082**
SCA×Y	17.02**	15.4**	18.76**	18.6**	20.65**	29.83**	9869**	7218**	7938**	13394**	9476**	10123**
GCA×Y/SCA×Y	1.38	2.67	1.04	0.61	1.80	0.52	1.08	2.03	0.74	0.81	1.31	0.70
			100-kernel weight						**Grain yield per plant**			
GCA	130.19**	89.19*	121.22**	90.43**	88.17*	128.01**	12189**	12513*	5180*	9558**	5425*	4912**
SCA	71.88**	91.04**	95.11**	50.94**	52.86*	42.72	39215**	30650**	23841**	32244**	25983**	15568**
GCA/SCA	1.81	0.98	1.27	1.78	1.67	3.00	0.30	0.41	0.22	0.30	0.21	0.32
GCA×Y	9.47**	12.85**	11.53**	5.79**	16.93**	4.08**	1067**	1241**	590.3**	632**	971**	335.4**
SCA×Y	6.05**	6.39**	4.11**	12.75**	21.16**	20.37**	797.8**	1581.4**	689.0**	1206**	970**	578.0**
GCA×Y/SCA×Y	1.57	2.01	2.81	0.45	0.80	0.20	1.30	0.78	0.86	0.52	1.00	0.58

*E1= WW-LD, E2 = WW-MD, E3 = WW-HD, E4 = WS-LD, E5= WS-MD, E6 = WS-HD and * and ** indicate significance at 0.05 and 0.01 probability levels, respectively*

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

Inbred	E1	E2	E3	E4	E5	E6	E1	E2	E3	E4	E5	E6
	WW-LD	WW-MD	WW-HD	WS-LD	WS-MD	WS-HD	WW-LD	WW-MD	WW-HD	WS-LD	WS-MD	WS-HD
	Days to 50% anthesis						**Anthesis-silking interval**					
L20	-0.61**	-0.44**	-0.49**	-1.81**	-0.42**	-1.96**	0.17	-0.07	0.11	0.03	-0.04	0.17
L53	-0.52**	-0.80**	-0.72**	-0.79**	-0.70**	-0.96**	-0.25**	-0.02	-0.02	-0.33**	-0.02	-0.25
Sk5	-0.21	-0.19	-0.12	-1.56**	-0.22	-1.52**	-0.04	-0.01	0	0.11	0.06	0.1
L18	0.85**	0.87**	0.82**	2.13**	0.79**	2.33**	-0.06	0.01	0.08	0.07	0.15	-0.08
L28	0.38**	0.58**	0.38**	1.90**	0.49**	1.83**	0.15	-0.07	-0.06	-0.01	-0.1	0.02
Sd7	0.1	-0.01	0.13	0.15	0.06	0.27	0.04	0.17	-0.1	0.13	-0.04	0.04
SE g_i-g_j	0.24	0.17	0.19	0.19	0.24	0.24	0.19	0.2	0.26	0.19	0.21	0.26
			Plant height							**Ear height**		
L20	-7.99**	-4.59**	-4.24**	-3.79**	-6.90**	-4.33**	-5.52**	-5.16**	-4.81**	-5.21**	-5.10**	-5.73**
L53	-10.44**	-6.50**	-9.57**	-6.13**	-10.95**	-7.75**	-10.57**	-7.74**	-7.42**	-8.44**	-8.57**	-8.51**
Sk5	-3.61**	-1.38	-1.19	-1.25*	-2.20**	-1.67*	-0.7	-1.76**	-0.74	-2.52**	-0.95	-2.63*
L18	14.06**	7.71**	9.31**	6.79**	12.47**	8.92**	10.42**	8.55**	7.71**	9.09**	8.03**	9.55**
L28	5.72**	2.79**	3.81**	2.92**	4.76**	4.13**	4.12**	3.80**	3.21**	4.26**	4.25**	5.05**
Sd7	2.26**	1.96**	1.89**	1.46**	2.81**	0.71	2.25**	2.31**	2.05**	2.82**	2.34**	2.27*
SE g_i-g_j	1	1.07	0.95	0.85	0.83	0.99	0.87	0.72	0.73	1.11	0.81	1.73

Inbred	E1	E2	E3	E4	E5	E6	E1	E2	E3	E4	E5	E6
	WW-LD	WW-MD	WW-HD	WS-LD	WS-MD	WS-HD	WW-LD	WW-MD	WW-HD	WS-LD	WS-MD	WS-HD
			Barren stalks						**Leaf angle**			
L20	-0.89*	-1.35**	-1.61**	-1.37*	-1.90**	-1.88*	-1.78**	-1.53**	-1.26**	-2.03**	-1.42**	-1.38**
L53	-1.72**	-3.57**	-2.92**	-2.86**	-2.85**	-3.12**	-3.24**	-3.53**	-3.64**	-3.49**	-2.54**	-3.04**
Sk5	-0.12	-0.57**	-0.7	-0.33	-0.73**	-0.88	-0.2	-0.65*	-0.60**	-0.57**	-0.58*	-0.79**
L18	1.80**	3.80**	3.45**	3.19**	3.66**	3.96**	3.35**	3.64**	3.65**	3.72**	2.96**	3.25**
L28	1.02*	1.64**	0.93*	0.9	1.61**	1.98*	1.31**	1.39**	1.19**	1.51**	1.29**	1.33**
Sd7	-0.09	0.05	0.84*	0.48	0.22	-0.06	0.56*	0.68*	0.65**	0.85**	0.29	0.63**
SE g_i-g_j	0.64	0.33	0.62	0.95	0.4	0.77	0.42	0.41	0.35	0.26	0.41	0.35
			Ears per plant						**Rows per ear**			
L20	0.05	0.05	0.03	0.03	0.03	0.05*	0.57**	0.43**	0.48**	0.44**	0.46**	0.45**
L53	0.08*	0.11*	0.07**	0.10*	0.05*	0.04	0.86**	0.85**	0.95**	0.80**	0.89**	0.68**
Sk5	0.02	0.02	0.01	0.01	-0.01	0	0.19*	0.06	0.12	0.04	0.11	0.02
L18	-0.08*	-0.10*	-0.07**	-0.09*	-0.05*	-0.05*	-0.96**	-0.94**	-0.95**	-0.81**	-0.88**	-0.73**
L28	-0.05	-0.04	-0.02	-0.03	-0.01	-0.03	-0.46**	-0.27**	-0.45**	-0.32**	-0.46**	-0.30*
Sd7	-0.03	-0.03	-0.01	-0.02	-0.02	-0.02	-0.20*	-0.14	-0.15	-0.15	-0.13	-0.11
SE g_i-g_j	0.5	0.71	0.71	0.71	0.71	0.5	0.12	0.14	0.14	0.12	0.14	0.19
			Kernel per row						**Kernels per plant**			
L20	1.83**	1.85**	2.09**	1.49**	1.79**	1.65**	43.89**	48.56**	39.63**	32.39**	35.50**	30.68**
L53	2.65**	2.47**	2.72**	2.94**	2.63**	3.13**	67.50**	78.48**	71.03**	65.49**	62.65**	47.76**
Sk5	0.18	0.11	0.15	0.12	0.18	0.19	13.27*	23.14**	10.25	8.59	6.83	7.2
L18	-2.81**	-2.93**	-3.03**	-3.03**	-2.95**	-3.30**	-72.71**	-89.77**	-73.22**	-67.34**	-65.60**	-49.67**
L28	-1.16**	-0.97**	-1.30**	-0.93**	-1.22**	-1.04**	-37.17**	-41.08**	-39.36**	-21.77**	-30.49**	-27.81**
Sd7	-0.69**	-0.53**	-0.64*	-0.59	-0.43	-0.62**	-14.78*	-19.32**	-8.33	-17.35**	-8.89	-8.15
SE g_i-g_j	0.35	0.22	0.45	0.48	0.41	0.26	9.64	8.75	9.35	8.94	9.08	9.11
			100-kernel weight						**Grain yield per plant**			
L20	0.95**	0.98**	0.62**	1.19**	0.65	1.06**	13.05**	17.64**	15.05**	13.85**	7.68**	14.32**
L53	1.81**	1.83**	1.39**	2.18**	1.52**	2.39**	18.35**	20.21**	18.86**	18.16**	13.54**	12.03**
Sk5	0.12	0.11	0.12	-0.07	0.1	-0.08	1.74	1.43	9.93**	3.54	1.78	3.81**
L18	-1.88**	-2.22**	-1.71**	-2.52**	-1.82**	-2.40**	-22.40**	-22.47**	-24.59**	-21.66**	-13.76**	-15.28**
L28	-0.76**	-0.61**	-0.42**	-0.40**	-0.46	-0.75**	-8.31**	-12.73**	-14.60**	-9.93**	-7.57**	-12.07**
Sd7	-0.24	-0.09	0.01	-0.38**	0.02	-0.22	-2.42	-4.07*	-4.65	-3.96	-1.67	-2.81*
SE g_i-g_j	0.31	0.16	0.19	0.14	0.51	0.32	3.08	3	3.99	3.61	2.55	1.73

*WW = well watering, WS = water stress HD = high density, MD = medium density, LD = low density, and * and ** significant at 0.05 and 0.01 probability levels, respectively*

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

Cross	E1 WW-LD	E2 WW-MD	E3 WW-HD	E4 WS-LD	E5 WS-MD	E6 WS-HD	E1 WW-LD	E2 WW-MD	E3 WW-HD	E4 WS-LD	E5 WS-MD	E6 WS-HD
	Days to 50% anthesis						Anthesis-silking interval					
L20 × L53	-0.39	-0.38*	-0.33	-0.08	-0.19	0.02	-0.12	-0.07	-0.25	-0.20	-0.12	-0.43
L20 ×SK5	0.30	0.35	0.74**	2.02**	0.67**	2.41**	0.01	0.26	0.06	0.03	0.30	-0.20
L20 × L18	0.23	-0.05	-0.04	-1.16**	-0.33	-0.94**	-0.31	-0.18	-0.19	0.08	0.04	-0.18
L20 × L28	-0.29	-0.25	-0.60**	-1.27**	-0.54*	-1.61**	-0.01	0.05	0.46	0.08	0.13	0.13
L20 × Sd7	0.15	0.33	0.23	0.48**	0.40	0.12	0.43	-0.07	-0.08	0.01	-0.35	0.69*
L 53 × Sk5	0.21	-0.13	0.13	0.34	-0.06	0.25	0.09	0.22	-0.31	0.22	-0.22	-0.20
L53 × L18	0.65**	0.81**	0.69**	3.23**	0.60**	3.39**	0.11	0.13	0.35	0.26	0.19	0.40
L53 × L28	-0.37	-0.07	-0.37	-2.45**	-0.27	-2.61**	-0.10	-0.23	0.09	-0.16	0.11	0.30
L53 × Sd7	-0.10	-0.23	-0.12	-1.04**	-0.08	-1.05**	0.01	-0.05	0.13	-0.13	0.05	-0.06
Sk5 × L18	-1.16**	-0.80**	-1.41**	-1.74**	-1.04**	-2.55**	-0.01	-0.27	0.00	-0.51**	-0.23	0.05
Sk5 × L28	0.07	0.00	-0.06	-1.52**	-0.25	-1.30**	-0.05	-0.24	-0.02	0.08	0.03	0.19
Sk5 × Sd7	0.59*	0.58**	0.61**	0.90**	0.69**	1.18**	-0.04	0.03	0.27	0.18	0.13	0.17
L18 × L28	0.75**	0.52**	1.25**	2.63**	1.42**	2.94**	0.38	0.32	-0.19	0.12	-0.22	-0.04
L18 × Sd7	-0.48	-0.48**	-0.50**	-2.95**	-0.65**	-2.84**	-0.18	0.00	0.02	0.06	0.21	-0.23
L28 × Sd7	-0.16	-0.19	-0.22	2.61**	-0.36	2.58**	-0.22	0.09	-0.33	-0.11	-0.04	-0.58
SE $S_{ij} – S_{ik}$	0.42	0.30	0.32	0.32	0.42	0.42	0.32	0.35	0.46	0.32	0.37	0.46
SE $S_{ij} – S_{kl}$	0.35	0.24	0.26	0.26	0.35	0.35	0.26	0.28	0.37	0.26	0.30	0.37
	Plant height						Ear height					
L20 × L53	-9.72**	-4.38**	-5.85**	-4.02**	-10.01**	-2.62*	-11.29**	-7.23**	-8.43**	-8.06**	-9.93**	-8.26**
L20 ×SK5	10.77**	4.32**	5.94**	4.44**	9.41**	8.13**	5.79**	3.96**	4.51**	2.88*	3.66**	4.05*
L20 × L18	-3.06*	-0.93	-0.23	-1.44	-1.93*	-4.12**	0.21	-0.64	-0.41	0.46	1.44	-0.26
L20 × L28	-1.72	-0.51	-3.06*	-0.56	-0.22	-3.32*	0.28	0.35	0.81	0.89	0.38	0.06
L20 × Sd7	3.73**	1.49	3.19*	1.57	2.74*	1.92	5.01**	3.56**	3.53**	3.83**	4.44**	4.41*
L 53 × Sk5	-6.10**	-0.59	-1.06	-0.72	-3.38**	-1.12	-0.45	-0.91	-0.74	-2.12*	0.92	-1.64
L53 × L18	19.23**	9.66**	10.44**	7.90**	15.45**	10.47**	11.88**	10.58**	10.95**	10.96**	8.47**	9.74**
L53 × L28	-1.43	-2.26	-1.73	-1.39	-0.84	-4.41**	0.41	-0.75	-0.77	0.15	-0.11	-0.33
L53 × Sd7	-1.98	-2.42*	-1.81	-1.77	-1.22	-2.33*	-0.56	-1.69	-1.01	-0.94	0.64	0.49
Sk5 × L18	-15.93**	-10.47**	-13.10**	-8.31**	-14.97**	-11.95**	-12.21**	-9.57**	-9.67**	-8.55**	-9.54**	-8.97**
Sk5 × L28	-1.10	-1.05	0.56	-1.77	-2.09*	-2.83*	0.13	-0.62	-0.68	0.75	0.11	-0.55
Sk5 × Sd7	12.36**	7.78**	7.65**	6.36**	11.04**	7.76**	6.74**	7.14**	6.59**	7.04**	4.85**	7.11**

Cross	E1	E2	E3	E4	E5	E6	E1	E2	E3	E4	E5	E6
	WW-LD	WW-MD	WW-HD	WS-LD	WS-MD	WS-HD	WW-LD	WW-MD	WW-HD	WS-LD	WS-MD	WS-HD
L18 × L28	9.07**	6.20**	8.07**	5.86**	8.58**	11.76**	5.25**	4.83**	4.43**	2.63*	4.59**	6.16**
L18 × Sd7	-9.31**	-4.47**	-5.19**	-4.02**	-7.13**	-6.16**	-5.13**	-5.20**	-5.30**	-5.51**	-4.96**	-6.67**
L28 × Sd7	-4.81**	-2.38*	-3.85**	-2.14*	-5.42**	-1.20	-6.07**	-3.82**	-3.80**	-4.43**	-4.97**	-5.34*
SE $S_{ij} - S_{ik}$	1.73	1.86	1.65	1.47	1.43	1.71	1.50	1.25	1.27	1.92	1.41	3.00
SE $S_{ij} - S_{kl}$	1.41	1.52	1.35	1.20	1.17	1.40	1.22	1.02	1.03	1.57	1.15	2.45
			Barren stalks						**Leaf angle**			
L20 × L53	-1.24	-2.38**	-0.56	-2.02	-1.80**	-1.49**	-3.08**	-1.87**	-2.71**	-2.51**	-1.38*	-1.89**
L20 ×SK5	1.54*	2.30**	2.68**	2.83*	3.09**	2.65**	2.05**	1.26*	1.42**	1.41**	2.50**	1.20*
L20 × L18	-0.53	-0.98*	-0.48	-0.43	-1.17*	-1.27**	0.01	-0.04	0.00	0.28	-0.71	-0.18
L20 × L28	-0.56	-0.61	-1.79*	-1.37	-1.11*	-1.26**	-0.28	-0.45	-0.21	-0.34	-1.04*	-0.09
L20 × Sd7	0.79	1.67**	0.15	0.99	0.99*	1.37**	1.30*	1.09*	1.50**	1.16**	0.63	0.95*
L 53 × Sk5	0.31	-0.67	-0.39	-0.57	-0.56	-0.15	-0.16	-0.57	-0.71	-0.63*	-0.54	-0.47
L53 × L18	0.95	3.33**	4.26**	4.33**	3.27**	2.44**	3.97**	3.80**	3.87**	4.08**	2.92**	3.66**
L53 × L28	-0.57	-0.24	-1.49*	-0.86	-0.87	-0.97*	-0.49	-0.45	0.17	-0.05	-0.58	-0.42
L53 × Sd7	0.55	-0.04	-1.82*	-0.89	-0.04	0.17	-0.24	-0.91*	-0.62	-0.88*	-0.42	-0.88*
Sk5 × L18	-2.27**	-4.69**	-5.94**	-5.38**	-4.71**	-4.58**	-4.41**	-4.24**	-4.33**	-4.51**	-3.71**	-3.92**
Sk5 × L28	-0.61	-0.24	-0.11	0.39	-1.13*	-1.16**	0.14	0.51	0.63	0.53	-0.88	0.16
Sk5 × Sd7	1.02	3.29**	3.77**	2.73*	3.31**	3.24**	2.38**	3.05**	3.00**	3.20**	2.62**	3.04**
L18 × L28	2.97**	4.18**	3.82**	3.08*	5.00**	5.78**	2.26**	2.05**	1.88**	1.74**	3.42**	1.95**
L18 × Sd7	-1.12	-1.84**	-1.67*	-1.59	-2.39**	-2.37**	-1.83**	-1.58**	-1.42**	-1.59**	-1.92**	-1.51**
L28 × Sd7	-1.23	-3.09**	-0.44	-1.24	-1.88**	-2.40**	-1.62**	-1.66**	-2.46**	-1.88**	-0.92*	-1.59**
SE $S_{ij} - S_{ik}$	1.12	0.57	1.07	1.65	0.69	1.33	0.73	0.70	0.60	0.46	0.71	0.60
SE $S_{ij} - S_{kl}$	0.91	0.47	0.88	1.35	0.57	1.09	0.60	0.57	0.49	0.37	0.58	0.49
			Ears per plant						**Rows per ear**			
L20 × L53	0.10	0.10	0.06	0.10	0.05	0.10	0.53**	0.80**	0.79**	0.80**	0.84**	0.93**
L20 ×SK5	-0.02	-0.03	-0.03	-0.01	-0.03	-0.03	-0.54**	-0.47*	-0.43*	-0.43*	-0.47*	-0.55*
L20 × L18	-0.01	-0.01	-0.01	-0.01	-0.02	-0.02	-0.01	0.06	0.01	-0.14	-0.13	0.10
L20 × L28	-0.02	-0.02	0.00	-0.04	0.01	-0.02	0.18	-0.08	0.04	0.09	0.10	-0.07
L20 × Sd7	-0.05	-0.04	-0.01	-0.05	-0.02	-0.03	-0.16	-0.31*	-0.40*	-0.31*	-0.34**	-0.42*
L 53 × Sk5	-0.02	0.01	0.02	0.00	0.01	-0.02	0.14	0.07	0.15	-0.01	-0.04	0.02
L53 × L18	-0.11	-0.13	-0.07	-0.09	-0.07	-0.05	-0.72**	-0.94**	-0.95**	-0.86**	-0.76**	-0.93**
L53 × L28	0.02	0.00	-0.02	-0.02	-0.01	-0.01	-0.02	0.01	0.00	0.03	-0.02	-0.08
L53 × Sd7	0.01	0.02	0.01	-0.01	0.01	-0.02	0.08	0.07	0.01	0.05	-0.02	0.05

Cross	E1	E2	E3	E4	E5	E6	E1	E2	E3	E4	E5	E6
	WW-LD	**WW-MD**	**WW-HD**	**WS-LD**	**WS-MD**	**WS-HD**	**WW-LD**	**WW-MD**	**WW-HD**	**WS-LD**	**WS-MD**	**WS-HD**
Sk5 × L18	0.09	0.11	0.08	0.09	0.09	0.05	1.05**	1.05**	1.03**	1.16**	1.11**	0.88**
Sk5 × L28	0.00	-0.01	0.00	-0.01	-0.02	0.03	0.16	0.09	-0.02	-0.08	0.02	0.16
Sk5 × Sd7	-0.04	-0.08	-0.06	-0.07	-0.05	-0.03	-0.80**	-0.74**	-0.73**	-0.64**	-0.62**	-0.51*
L18 × L28	-0.03	-0.02	-0.02	-0.03	-0.01	-0.03	-0.76**	-0.59**	-0.62**	-0.54**	-0.66**	-0.47*
L18 × Sd7	0.06	0.06	0.02	0.03	0.01	0.04	0.44**	0.42*	0.53**	0.39*	0.43*	0.42*
L28 × Sd7	0.03	0.05	0.04	0.09	0.04	0.03	0.44**	0.57**	0.60**	0.51**	0.56**	0.45*
SE $S_{ii} - S_{ik}$	0.87	1.22	1.22	1.22	1.22	0.87	0.21	0.24	0.24	0.21	0.24	0.32
SE $S_{ij} - S_{kl}$	0.71	1.00	1.00	1.00	1.00	0.71	0.17	0.20	0.20	0.17	0.20	0.26
			Kernels per row						**Kernels per plant**			
L20 × L53	3.74**	3.41**	3.77**	3.41**	3.86**	3.49**	64.97**	53.97**	72.66**	62.25**	54.58**	45.36**
L20 ×SK5	-1.29**	-1.82**	-1.54*	-1.70*	-1.93**	-2.00**	-31.02*	-34.54**	-52.37**	-35.35**	-36.08**	-33.70**
L20 × L18	-0.26	-0.02	-0.36	-0.13	-0.04	0.02	4.40	1.92	9.54	-5.70	1.68	7.21
L20 × L28	-0.74	-0.21	-0.42	-0.35	-0.25	-0.28	-2.72	7.60	4.26	0.37	6.58	4.49
L20 × Sd7	-1.46**	-1.35**	-1.45*	-1.24*	-1.64**	-1.23**	-35.63**	-28.94*	-34.10**	-21.57*	-26.75*	-23.36*
L 53 × Sk5	-0.16	-0.27	-0.52	0.05	-0.10	0.33	-2.68	11.18	-1.66	8.82	-6.68	-6.10
L53 × L18	-3.11**	-3.27**	-3.10**	-3.50**	-2.79**	-3.43**	-76.70**	-87.28**	-66.01**	-81.49**	-57.16**	-46.29**
L53 × L28	-0.36	0.12	-0.04	-0.16	-0.45	-0.30	6.73	4.73	6.11	0.91	10.53	8.11
L53 × Sd7	-0.11	0.02	-0.11	0.20	-0.53	-0.10	7.67	17.41	-11.10	9.51	-1.27	-1.08
Sk5 × L18	3.08**	3.95**	3.78**	4.04**	3.53**	3.84**	79.19**	95.19**	85.16**	90.96**	82.27**	58.23**
Sk5 × L28	0.29	0.25	0.38	-0.08	0.46	0.28	5.01	6.69	15.54	-8.26	6.24	13.93
Sk5 × Sd7	-1.92**	-2.09**	-2.09**	-2.31**	-1.96**	-2.45**	-50.51**	-78.52**	-46.68**	-56.16**	-45.75**	-32.36*
L18 × L28	-1.19*	-2.11**	-1.94**	-1.59*	-2.29**	-1.95**	-47.19**	-59.45**	-73.23**	-32.50**	-61.95**	-51.24**
L18 × Sd7	1.48**	1.46**	1.62**	1.18*	1.59**	1.52**	40.30**	49.62**	44.54**	28.73*	35.17**	32.09*
L28 × Sd7	2.00**	1.97**	2.03**	2.17**	2.54**	2.26**	38.18**	40.44**	47.33**	39.48**	38.61**	24.71**
SE $S_{ii} - S_{ik}$	0.61	0.39	0.77	0.83	0.70	0.46	16.70	15.15	16.20	15.49	15.73	15.78
SE $S_{ij} - S_{kl}$	0.50	0.32	0.63	0.68	0.57	0.37	13.64	12.37	13.23	12.65	12.85	12.88
	100-kernel weight						**Grain yield per plant**					
L20 × L53	1.80**	1.69**	1.00**	2.52**	1.22*	2.80**	20.88**	30.32**	19.69**	16.72**	8.71*	17.79**
L20 ×SK5	-1.36**	-1.93**	-1.91**	-2.58**	-1.52*	-1.83**	-18.21**	-26.79**	-27.29**	-19.40**	-18.02**	-19.20**
L20 × L18	0.31	0.60**	0.73**	0.26	0.40	0.27	3.43	12.38**	18.70**	13.87**	22.53**	13.70**
L20 × L28	0.08	0.33	0.41*	0.16	0.30	-0.12	2.93	-7.74*	1.48	2.44	-5.47	-5.38*
L20 × Sd7	-0.83*	-0.68**	-0.22	-0.37*	-0.39	-1.11**	-9.03*	-8.17*	-12.57*	-13.63**	-7.75*	-6.91**
L 53 × Sk5	0.11	0.49*	0.68**	0.68**	0.32	0.44	0.34	6.80*	11.12*	2.68	7.78*	4.21*

Cross	E1	E2	E3	E4	E5	E6	E1	E2	E3	E4	E5	E6
	WW-LD	**WW-MD**	**WW-HD**	**WS-LD**	**WS-MD**	**WS-HD**	**WW-LD**	**WW-MD**	**WW-HD**	**WS-LD**	**WS-MD**	**WS-HD**
L53 × L18	-2.07**	-2.24**	-1.91**	-3.45**	-1.80*	-2.62**	-23.56**	-33.38**	-31.18**	-26.55**	-23.06**	-18.37**
L53 × L28	0.14	0.04	0.16	0.09	0.11	-0.52	2.40	-10.39*	-19.96**	-0.04	-1.89	-9.96**
L53 × Sd7	0.02	0.01	0.08	0.17	0.15	-0.10	-0.06	6.65*	20.32**	7.18	8.46*	6.33**
Sk5 × L18	2.45**	3.02**	2.40**	4.00**	2.57**	3.06**	30.40**	30.18**	27.08**	26.39**	15.47**	17.79**
Sk5 × L28	0.16	0.38*	0.38	0.18	0.22	0.17	4.67	14.00**	21.39**	10.05*	11.30**	15.38**
Sk5 × Sd7	-1.36**	-1.97**	-1.54**	-2.28**	-1.58*	-1.84**	-17.21**	-24.19**	-32.30**	-19.72**	-16.52**	-18.18**
L18 × L28	-1.62**	-2.38**	-1.92**	-1.85**	-1.81*	-1.65**	-23.29**	-15.37**	-21.03**	-26.17**	-17.34**	-15.96**
L18 × Sd7	0.93*	1.00**	0.70**	1.05**	0.64	0.93*	13.02**	6.20	6.43	12.46*	2.40	2.84
L28 × Sd7	1.24**	1.64**	0.98**	1.43**	1.18*	2.12**	13.28**	19.50**	18.12**	13.72**	13.40**	15.92**
SE $S_{ij} - S_{ik}$	0.53	0.27	0.32	0.24	0.88	0.56	5.34	5.20	6.91	6.24	4.42	3.00
SE $S_{ij} - S_{kl}$	0.44	0.22	0.26	0.20	0.72	0.46	4.36	4.24	5.64	5.10	3.61	2.45

*WW = well watering, WS = water stress HD = high density, MD = medium density, LD = low density, and * 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 F1's ($\bar{x}_c$) and their SCA effects and between heterosis (H) and each of $\bar{x}_c$ and SCA effects under six environments across 2013 and 2014 seasons

Correlation	E1	E2	E3	E4	E5	E6	E1	E2	E3	E4	E5	E6
	WW-LD	**WW-MD**	**WW-HD**	**WS-LD**	**WS-MD**	**WS-HD**	**WW-LD**	**WW-MD**	**WW-HD**	**WS-LD**	**WS-MD**	**WS-HD**
	Days to 50 % anthesis						**Anthesis-silking interval**					
$\bar{x}_p$ *vs.* GCA	0.43	0.01	0.42	0.03	0.05	-0.16	-0.49	-0.21	0.29	0.51	-0.25	-0.92**
$\bar{x}_c$ *vs.* SCA	0.60**	0.63**	0.66**	0.36	0.51*	0.70**	0.74**	-0.04	0.51*	0.49	0.2	0.88**
$\bar{x}_c$ *vs.* H.	0.35	0.57*	0.51*	0.50*	0.84**	0.83**	0.92**	0.89**	0.81**	0.74**	0.70**	0.86**
SCA *vs.*H	0.37	0.36	0.46	0.21	0.46	0.55*	0.56*	0.04	0.56*	0.28	0.17	0.60*
	Plant height						**Ear height**					
$\bar{x}_p$ *vs.* GCA	-0.61*	-0.63*	-0.85**	-0.69*	-0.70*	-0.78*	-0.67*	-0.54	-0.68*	-0.62*	-0.59*	-0.60*
$\bar{x}_c$ *vs.* SCA	0.65**	0.61**	0.61**	0.64**	0.61**	0.68**	0.60**	0.64**	0.57*	0.59*	0.54*	0.57*
$\bar{x}_c$ *vs.* H.	0.73**	0.78**	0.81**	0.73**	0.69**	0.78**	0.79**	0.76**	0.78**	0.83**	0.79**	0.83**
SCA *vs.*H	0.22	0.36	0.26	0.23	0.23	0.33	0.28	0.43	0.18	0.29	0.33	0.39
	Barren stalks						**Leaf angle**					
$\bar{x}_p$ *vs.* GCA	-0.16	-0.37	-0.26	0.29	0.83**	-0.64*	0.66*	0.68*	0.73*	0.76*	0.86*	0.73*
$\bar{x}_c$ *vs.* SCA	0.66**	0.63**	0.63**	0.61**	0.67**	0.65**	0.62**	0.59*	0.58*	0.57*	0.52*	0.60**
$\bar{x}_c$ *vs.* H.	0.87**	0.96**	0.94**	0.73**	0.76**	0.93**	0.36	0.50*	0.51*	0.56*	0.62**	0.51*

Correlation	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**
	WW-LD	**WW-MD**	**WW-HD**	**WS-LD**	**WS-MD**	**WS-HD**	**WW-LD**	**WW-MD**	**WW-HD**	**WS-LD**	**WS-MD**	**WS-HD**
SCA *vs.*H	0.49	0.61**	0.58*	0.52*	0.74**	0.41	0.63**	0.55*	0.58*	0.68**	0.72**	0.67**
			Ears per plant						**Rows per ear**			
$\bar{x}_p$ *vs.* GCA	0.94**	0.90**	0.92**	0.49	0.69*	0.97**	0.94**	0.94**	0.96**	0.72*	0.77*	0.94**
$\bar{x}_c$ *vs.* SCA	0.59*	0.54*	0.66**	0.51*	0.49	0.65**	0.55*	0.57*	0.58*	0.60**	0.62**	0.65**
$\bar{x}_c$ *vs.* H.	0.52*	0.39	0.49	0.86**	0.63**	0.19	0.26	0.36	0.37	0.55*	0.54*	0.29
SCA *vs.*H	0.89**	0.77**	0.80**	0.54*	0.69**	0.77**	0.72**	0.78**	0.78**	0.76**	0.77**	0.75**
			Kernels per row						**Kernels per plant**			
$\bar{x}_p$ *vs.* GCA	0.93**	0.88*	0.99**	0.80*	0.81*	0.96**	0.93**	0.84*	0.98**	0.79*	0.85*	0.91**
$\bar{x}_c$ *vs.* SCA	0.61**	0.62**	0.64**	0.65**	0.62**	0.62**	0.57*	0.58*	0.60**	0.55*	0.59**	0.60**
$\bar{x}_c$ *vs.* H.	-0.13	0.01	-0.02	-0.01	0.08	0.1	-0.07	0.48	0.27	0.03	0.06	-0.06
SCA *vs.*H	0.55*	0.63**	0.60**	0.50*	0.61**	0.69**	0.59*	0.76**	0.76**	0.53*	0.52*	0.56*
			100-kernel weight						**Grain yield per plant**			
$\bar{x}_p$ *vs.* GCA	0.92**	0.85*	0.95**	0.67*	0.67*	0.88*	0.91*	0.94**	0.97**	0.76*	0.82*	0.86*
$\bar{x}_c$ *vs.* SCA	0.64**	0.71**	0.67**	0.67**	0.70**	0.66**	0.67**	0.68**	0.71**	0.66**	0.64**	0.70**
$\bar{x}_c$ *vs.* H.	-0.05	0.15	0.07	0.39	0.71	0.37	-0.36	-0.16	-0.2	-0.04	-0.07	-0.2
SCA *vs.*H	0.52*	0.58*	0.47	0.66**	0.79**	0.79**	0.27	0.42	0.32	0.36	0.37	0.34

*WW = well watering, WS = water stress, LD = low density, MD = medium density, HD = high density and * and ** significant at 0.05 and 0.01 probability levels, respectively*

Inbreds L53 and L20 were the best general combiners under all the six environments for the eight traits PH, EH, BS, LANG, RPE, KPR, KPP and 100KW. Inbred Sk5 was also the best general combiner under E1, E4, E4 and E6 for PH, under E2, E4 and E6 for EH, under E2 and E5 for BS, under E1 for RPE and under E1 and E2 for KPP. For more ears/plant (EPP), the inbred L53 under E1 through E5 and inbred L20 under E6 were the best general combiners.

In previous studies [6, 36-39], 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 [6, 36-41,49,50].

3.6 SCA Effects of Diallel Crosses

Estimates of specific combining ability effects (SCA) of F_1 dialled crosses for studied traits under the six environments are presented in Table 8. The best crosses in SCA effects were considered those exhibiting significant negative SCA effects for DTA, PH, EH, LANG and BS and the worst ones were those showing significant 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 and L28 × Sd7 under the 6 environments and L20 × L18 under E5 (Table 8). The above crosses may be recommended for maize breeding programs for the improvement of tolerance to high plant density, as well as tolerance to drought [15,51,52].

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 all the six environments. For EPP, the highest positive, but not significant SCA effects were exhibited by the crosses Sk5 x L18 and L20 x L53 under all environments. For LANG, the lowest negative (favorable) and significant SCA effects were exhibited only under E4 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 the 6 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 all environments, except L28 x Sd7 under E5. For days to 50% anthesis, the lowest negative (favorable) and significant SCA effects were shown by the cross Sk5 × L18 under all environments, L18 × Sd7 under E2 through E6, L20 x L28, L20 x L18, L53 x L28 and L52 x Sd7 under E4 and E6. For ASI, the lowest negative and significant SCA effects was shown only under E4 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 some investigators [6,23,41].

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 ear height, barren stalks, and leaf angle under stressed and non-stressed environments, *i.e.* all adaptive traits to high density and drought stress. The crosses L20 x L53, L18 x Sd7 and L28 x Sd7 follow the cross Sk5 x L18 in superiority for such traits. These crosses could be offered to plant breeding programs for improving tolerance to high plant density and/or drought tolerance at flowering stage.

3.7 Correlations among Performance, GCA and SCA Effects and Heterosis

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. Significant ($P \leq 0.05$ or 0.01) correlations between $\bar{x}_p$ and GCA effects existed for most studied traits under all environments, (55 out of 72 cases; i.e. 76.4%), especially grain yield and its components. Such significant correlations between $\bar{x}_p$ and their GCA effects in this investigation suggest the validity of this concept in the majority of studied traits, especially yield, yield components, plant and ear heights and leaf angle under all 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 the respective environment is an indication of its general combining ability. This conclusion was previously reported by several investigators [6,53] in maize and [54-56] in wheat. All correlations between $\bar{x}_p$ and GCA effects in the present study, were positive for all traits, except for PH, EH and ASI, where the correlations were negative. In general, the environment E6 (the most stressed environment) showed significant correlations between $\bar{x}_p$ and GCA effects for most studied traits (11 out 12 characters). The strongest correlation (highest in magnitude) between $\bar{x}_p$ and GCA effects was shown by GYPP, RPE, KPR, KPP and EPP traits, *i.e.* yield and its components.

For F_1 crosses, rank correlation coefficients calculated between mean performance of crosses ($\bar{x}_c$) and their SCA effects (Table 9) showed that for all studied traits, significant (P≤ 0.05 or 0.01) correlations existed under all environments, namely DTA (except E4), ASI (except E2, E4 and E5), PH, EH, BS, LANG, EPP (except E5), RPE, KPR, KPP, 100KW, GYPP. Such significant correlations between ($\bar{x}_c$) and SCA effects in this investigation representing 93.1% of all studied cases (67 out of 72 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 for all traits. These results indicate that the highest performing crosses are also the highest specific combiners and *vice versa* for the previously mentioned traits and therefore, the mean performance of a given cross for studied traits under the respective environments is an indication of its specific combining ability. This conclusion was previously reported by Srdic et al. [57] and Al-Naggar et al. [6]. In general, the environment E6 (the most stressed environment) showed significant correlations between ($\bar{x}_c$) and SCA effects for all studied traits. This conclusion was also reported by Le Gouis et al. [54] and Yildirim et al. [55] under stress conditions.

Significant correlations between mean performance of crosses ($\bar{x}_c$) and heterobeltiosis (Table 9) were exhibited only in 40 out of 72 cases (55.6%), namely ASI, PH, EH and BS under all environments, DTA (except E1), LANG (except E1), EPP under E1, E4 and E5, RPE under E4 and E5 and 100KW under E5. For these traits, the mean performance of a cross could be used as an indicator of its useful heterosis under the corresponding environments. But, the traits KPR, KPP and GYPP; did not exhibit any correlation between $\bar{x}_c$ and heterobeltiosis under all (six) environments and therefore, SCA effects of crosses could not be expected from their *per se* performance in such cases. Significant correlations between crosses SCA effects and heterobeltiosis (Table 9) were exhibited only in 43 out of 72 cases (59.7%), namely LANG, EPP, RPE, KPR, KPP under all environments, 100KW (except E3), and BS (except E1 and E6), ASI under E1, E3 and E6, and DTA under E6. For these traits, the useful heterosis of a cross could be used as an indicator of its SCA effects under the corresponding environments. The grain yield, plant height and ear height traits did not exhibit any correlation between SCA effects and heterobeltiosis under all (six) environments and therefore, SCA effects of crosses could not be expected from their heterobeltiosis values in such cases.

4. CONCLUSIONS

The present study identified three inbreds (L53, L20 and Sk5) and three F_1 crosses (L20 x L53, L53 x Sk5 and L53 x Sd7) of good performance under stressed and non-stressed environments. These crosses are considered tolerant to both elevated density and deficit irrigation at flowering and responsive to the good environment. It is clear that L53, Sk5 and L20 might be considered as source of tolerance and responsiveness in these crosses. Results concluded that under the most stressed environment (high plant density combined with deficit irrigation), the traits leaf angle (LANG), ears/plant (EPP), kernels/row (KPP) and rows/ear (RPE),100-kernel weight (100KW) are controlled mainly by additive genes and therefore selection would be effective in improving these traits, but the opposite was true for the rest of traits including GYPP, *i.e.* they are controlled mainly by non-additive genes (dominance and epistasis) and therefore heterosis breeding is the best choice for improving such traits for tolerance to such stress conditions. For GYPP, the best inbred in GCA effects was L53 followed by L20 and Sk5 and the best cross for SCA effects was Sk5 × L18 followed by L20 × L53 and L28 × Sd7 under the six environments. Correlation analyses concluded that for studied yield traits in this investigation under stressed and non-stressed environments, the mean performance of a given parent could be considered an indication of its general combining ability and the mean performance of a given cross could be considered an indication of its specific combining ability. 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 be used as indication of its SCA effects.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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