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Research Article

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Correlations Among Mean Performance, Heterosis and Combining Ability of Corn (Zea mays L.) Grain Quality and Yield Traits Under Elevated Plant Density Combined With Water Deficit

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Abstract Using data of mean performance of parents and their diallel crosses in prediction of their general combining ability (GCA) and specific combining ability (SCA) effects could save breeder's time and effort. 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 grain quality and yield traits under elevated plant density (D) combined with water deficit. Six experiments were conducted in two seasons, each represent one combination out of six, between 3 plant densities and two water regimes and included 6 inbred lines differing in tolerance to high plant density and their 15 diallel crosses. Combined analysis of data across years for each environment indicated that GCA was higher in magnitude than SCA variance for grain quality traits (grain protein content; GPC, grain oil content; GOC and grain starch content; GSC) and the opposite was true for yield traits (grain yield/plant; GYPP, grain yield/ha; GYPH, protein yield/ha; PYPH, oil yield/ha; OYPH and starch yield/ha; SYPH). The best inbreds in GCA effects were L53, L20 and Sk5 and the best crosses in SCA effects were Sk5 x L18, L20 x L53, L18 x Sd7 and L28 x Sd7 for GYPH, PYPH, OYPH, GYPH under stress and non-stress conditions. The results indicated that under all environments, especially the most stressed one, there are significant correlation coefficients between mean performance for studied yield traits of parents and their GCA effects, and between the mean performance of crosses and their SCA effects. But the mean performance for studied yield traits of crosses was not significantly correlated with their heterobeltiosis values, For studied yield and GSC traits, the heterobeltiosis crosses was not correlated with their SCA effects. These results concluded that GCA and SCA effects for yield traits could be predicted from mean performance of parents and crosses, respectively.

Keywords Prediction, Maize grain composition, Heterobeltiosis, Drought at flowering, High density stress

Introduction

Globally, corn (*Zea mays* L.) contributes 15% (representing more than 50 million ton) of the protein and 20% of the calories derived from food crops in the world's diet [1]. In many developing countries in Latin America Africa and Asia, maize is the stable food and sometimes the only source of protein in diet. Because maize is a relevant food source, the quantification of the grain constituents with a nutritional role is important for the best exploitation of the different genotypes. The feed industry would gain value from maize with increased energy content, *i.e.* maize with higher oil content, and from increased protein content and a better amino acid balance. Specifically, different industries have different requirements of maize for their particular use.

Grain quality is an important objective in maize breeding [2, 3]. Some of the most important traits of interest in the maize market are those related to the nutritional quality of the grain, especially protein and oil content [4]. Trials have shown that unfavorable abiotic stresses, might alter the seed composition and related qualities such as oil physicochemical properties [5]. It has been reported that lack of water during all stages of growth and development is the limiting factor for seed growth that can influence its composition [5, 6].

Current maize hybrids cultivated in Egypt are selected under low plant density, good irrigation and fertilization and therefore are subject to yield losses when grown under high plant density and/or water deficit. Developing new adaptive cultivars to high density and/or deficit irrigation is important to enable these cultivars to produce higher grain, protein and oil yields 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].

The heterosis, combining ability and type of gene action of grain quality traits of maize should be studied under variety of environments, such as combinations of different plant densities and irrigation regimes. Such information, 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 [10-12]. 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 [13, 14].

Heterosis and combining ability are prerequisites for developing economically viable hybrid maize varieties. 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 [15]. Exploitation of heterosis is a quick, cheap and easy method of attaining maximum yield and quality in maize. 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 [16] 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.

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 [17] 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 effects in maize for grain quality and yield traits under six combinations of environments (between three plant densities and two irrigation regimes) and (*ii*) to perform correlations among these parameters in order to test the validity of predictions of GCA and SCA effects.

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.

Plant material

Based on the results of previous experiments [18], six maize (*Zea mays* L.) inbred lines in the 8thselfed 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).

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).

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.**

Evaluation of parents and F_1\`s

Six field evaluation experiments were carried out 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 4^{th} and 5^{th} 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 2^{nd} under WW-MD, the 3^{rd} under WW-HD, the 4^{th} under WS-LD, the 5^{th} under WS-MD and the 6^{th} under WS-HD. A randomized complete blocks design (RCBD) with three replications was usedfor 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 1^{st} 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°C, maximum temperature was 35.7, 35.97, 34.93 and 37.07°C 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°C, maximum temperature was 38.8, 35.2, 35.6 and 36.4°C 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.

Data Recorded

Grain yield per plant (GYPP in g) estimated by dividing the grain yield per plot (adjusted at 15.5% grain moisture) on number of plants/plot at harvest. **Grain yield per hectare** (GYPH) in ton, by adjusting grain yield/plot to grain yield per hectare. **Grain protein content** (%) (GPC%), **Grain oil content** (%) (GOC%) and **Grain starch content** (%) (GSC%) were determined using the non-destructive grain analyzer, Model Infratec TM 1241 Grain Analyzer, ISW 5.00 valid from S/N 12414500, 1002 5017/Rev.1, manufactured by Foss Analytical AB, Hoganas, Sweden. **Protein yield per hectare** (PYPH) was estimated by multiplying grain protein content x grain yield per hectare. **Oil yield per hectare** (OYPH) was estimated by multiplying grain oil content x grain yield per hectare. **Starch yield per hectare** (SYPH) was estimated by multiplying grain starch content x grain yield per hectare.

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 ® [19]. Least significant differences (LSD) were calculated according to Steel *et al*. [20]. Diallel crosses were analyzed to obtain general (GCA) and specific (SCA) combining ability variances and effects for studied traits according to Griffing [17] 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 (L.S.D) at 0.05 and 0.01 levels of probability according to Steel *et al*. [20] 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*., [20].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.

Results and Discussion

Analysis of variance

Combined analysis of variance of a randomized complete blocks design for 8 traits of 21 maize genotypes under each of the six environments (E1 through E6); representing combinations of 3 plant densities × 2irrigation 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 plant density and E6 = water stress-high density across two seasons is presented in Table (2). Mean squares due to parents and crosses under all environments were highly significant for all studied traits, indicating the significance of differences among parents and among F_1diallel crosses in the majority of cases.

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

		% Sum of squares											
SOV	**df**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**
		Grain protein content (GPC%)						**Grain oil content (GOC%)**					
P	**5**	14.22**	32.44**	16.74**	12.88**	8.92**	16.62**	18.01**	10.26**	12.05**	8.11**	9.97**	14.26**
F_1	**14**	10.27**	6.80**	11.90**	16.08**	10.18**	10.02**	19.84**	32.27**	22.66**	30.07**	28.69**	23.41**
P vs F_1	**1**	42.39**	14.05**	53.24**	28.04**	11.72**	20.53**	7.37**	14.90**	15.84**	13.16**	6.76**	9.91**
P × Y	**5**	2.05*	13.45*	0.68*	3.30**	4.03**	0.68	3.33**	6.07**	1.97	3.81**	6.05*	4.06**
F_1 × Y	**14**	2.31*	0.99	4.36**	6.12**	8.86**	5.79**	17.06**	9.02**	13.50**	5.70*	4.93**	7.98**
P vs F_1 × Y	**1**	9.14**	0.67	2.92**	6.04**	3.33**	7.69**	6.62**	1.39**	0.50*	0.43	5.06**	0.76**
		Grain starch content (GSC%)						**Grain yield / plant (GYPP)**					
P	**5**	7.93**	30.17**	14.49**	10.32**	8.81**	18.23**	5.50**	6.07**	3.53**	3.71**	1.64**	3.31**
F_1	**14**	36.19**	19.72**	18.63**	48.73**	37.73**	26.02**	9.66**	12.07**	10.52**	17.83**	14.69**	14.82**
P vs F_1	**1**	1.54*	1.60**	1.02*	0.001	0.43	0.26	75.18**	71.22**	71.13**	70.56**	75.13**	67.51**
P × Y	**5**	2.67	14.73**	3.35	8.91**	9.40**	6.94**	0.37**	0.26**	0.20*	0.18*	0.42**	0.05
F_1 × Y	**14**	15.69**	7.30**	18.87**	9.88**	9.09**	18.17**	1.91**	1.88**	1.22**	1.95**	1.17*	1.42**
P vs F_1 × Y	**1**	0.26	0.2	5.23**	0.72**	0.43	1.39**	0.01	0.38**	0.55**	0.17**	0.02	0.02
		Grain yield/ ha (GYPH)						**Protein yield/ha(PYPH)**					
P	**5**	4.98**	7.82**	4.46**	4.39**	0.93**	5.75**	5.60**	7.73**	5.11**	4.81**	1.10**	7.52**
F_1	**14**	13.70**	13.63**	11.35**	23.44**	18.10**	22.72**	16.94**	14.89**	12.97**	25.66**	21.15**	26.05**
P vs F_1	**1**	75.76**	73.60**	80.53**	67.23**	77.09**	48.66**	71.64**	72.08**	76.20**	63.13**	69.19**	37.41**
P × Y	**5**	0.12	0.15*	0.76**	1.11**	0.60**	11.06**	0.25	0.33	1.31**	1.34**	0.75**	14.15**
F_1 × Y	**14**	0.42	0.53**	0.89**	1.43**	0.81**	0.41*	0.38	0.79*	2.10**	1.12**	1.30**	0.51
P vs F_1 × Y	**1**	0.01	0.05*	0.02	0.06*	0.47**	5.61**	0.38**	0.01	0.03	0.02	0.001	3.47**
		Oil yield /ha(OYPH)						**Starch yield/ha(SYPH)**					
P	**5**	3.86**	5.72**	2.75**	3.20**	0.98**	5.82**	5.01**	8.21**	4.68**	4.43**	0.91**	5.63**
F_1	**14**	17.45**	13.80**	14.92**	26.45**	23.04**	24.85**	12.72**	13.65**	10.71**	23.15**	17.22**	22.12**
P vs F_1	**1**	73.06**	74.08**	75.93**	64.78**	69.75**	46.10**	76.43**	72.80**	80.92**	67.28**	77.97**	49.56**
P × Y	**5**	0.1	0.1	0.48**	0.78**	0.41**	9.62**	0.11	0.22**	0.77**	1.15**	0.60**	10.87**
F_1 × Y	**14**	1.83**	0.96**	2.65**	1.39**	1.20**	0.70*	0.41	0.57**	0.84**	1.50**	0.80**	0.54**
P vs F_1 × Y	**1**	0.05	0.25**	0.03	0.09	1.13**	5.89**	0.01	0.03	0.06*	0.06*	0.42**	5.65**

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 GSC under E4, E5 and E6, 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 ≤ 0.05 or 0.01) for all studied traits under all environments, except GYPP under E 6 for P x Y, GYPH under E1 for P x Y and F1 x Y, GPC under E6 for P x Y and E2 for F1 x Y, GOC under E3 for P x Y, GSC under E1 and E3 for P x Y, PYPH under E1 and E2 for P x Y and E1 and E6 for F_1 x Y, OYPH under E1 and E2 for P x Y and GYPH under E1 for P x Y and F_1 x Y.

Mean squares due to parents *vs.* crosses × years were significant (P ≤ 0.05 or 0.01) in 29 out of 48 cases (Table 2). Such interaction was expressed in most environments for GYPH, GPC, GOC and GYPH traits. This indicates that heterosis differ from season to season in these cases. The environment E6 (the most stressed environment) showed such interaction for all studied traits, except ASI, RPE and GYPP. It is observed from Table (2) that under all six environments (48 cases), among genotypes, the largest contributor to total variance was parents vs. F_1's (heterosis) variance for 36 cases, followed by F_1 crosses (11 cases) and parents (1 case).

Mean performance

In general, the F_1 hybrids were lower in grain protein content than inbred lines under the six environments (Table 3). This result is in agreement with that reported by Al-Naggar *et al*. [21, 22]. On the other hand, F_1 hybrids showed higher means than inbreds for GYPP, GOC, GSC, GYPH, PYPH, OYPH and SYPH under all environments, indicating that heterozygotes exhibit better (more favorable) values for most studied traits than homozygotes, which is logic and could be attributed to heterosis phenomenon. For grain protein content (GPC), the three inbreds (L18, L28 and Sk5) in descending order, exhibited the highest percentage under all environments, while the lowest GPC was recorded by the inbred Sd7, under WW-MD environment. For the F_1 crosses, variability in GPC was much less than in inbreds. The cross L18 x L28 recorded the highest GPC, while the cross L20 x L53 recorded the lowest percentage under all environments. In general, there is a tendency of increase of grain protein percentage due to elevated plant density and water stress in most studied genotypes.

For grain oil content, there is a tendency of decrease of grain protein percentage due to elevated plant density and water stress in most studied genotypes. The highest inbred for GOC was L28, but the lowest one was Sk5 under all environments. For crosses, the highest one in GOC was L18 x L28 followed by L53 x L28, while the lowest one was Sk5 x L18 under most studied environments. The range of variability in grain oil content in the present study is similar to that found in the literature for normal maize, which was between 3.5 and 4.5% [23-25]. In another study on the genetic variation for oil content in maize with normal endosperm, Mittelmann [4] found values between 3.77 and 5.10%. The F_1 crosses were generally higher than their parental inbreds in grain oil content under all environments, suggesting the superiority of heterozygotes to homozygotes in maize grain oil content. Similar conclusion was reported by previous investigators [26-30]. Heterosis for grain oil content of maize was also reported by several investigators [27-33].

For grain starch content, there is a tendency of increase due to elevated plant density and water stress in most studied genotypes. The highest percentage of GSC was recorded by the inbred L20 and the hybrid L20 x L53, while the lowest percentage was recorded by the inbred L28 and the hybrid Sk5 x Sd7 under all environments.

In general, GYPP of three inbreds, *viz.* L53, L20 and Sk5 was higher than that of the three other inbreds (L18, L28 and Sd7) under all the six environments (Table 3). The highest GYPP of all inbreds was achieved under E1 (WW-LD) because of the optimum irrigation and the low competition between plants due to low plant density. The rank of crosses was changed from one environment to another; especially when comparing poor with good environments. The highest GYPP of the F_1 crosses was also obtained at E1 environment, where competition between plants is at minimum and the optimum availability of irrigation water at flowering stage. The highest GYPP in this experiment (277.4 g) was obtained from the cross L20 × L53 under well watering-low density environment (E1) followed by the crosses L53 × Sk5 (245.5 g) and L53 × Sd7 (241.0 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 stresses in this experiment (water stress and high density together) (E6) was obtained by the same crosses (161.1 g, 137.0 g and 132.5 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.

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

	GPC						GOC					
Genotype	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**
	Parents											
L20	10.97	10.63	11.65	11.88	11.65	10.90	4.23	3.90	3.82	3.67	3.90	3.83
L53	11.82	10.97	11.47	11.18	12.07	11.53	4.15	4.20	4.13	4.15	4.37	4.25
Sk5	12.80	12.82	12.80	13.08	13.47	13.22	3.48	3.52	3.68	3.57	3.52	3.53
L18	13.52	14.38	13.43	13.12	13.53	13.70	4.03	4.15	4.05	3.88	3.93	3.68
L28	12.88	13.35	12.85	12.63	11.62	12.98	4.55	4.28	4.48	4.15	4.23	4.28

Sd7	12.57	9.30	11.38	12.38	12.50	12.78	4.40	4.28	4.28	4.03	3.80	4.15
Average	12.43	11.91	12.26	12.38	12.47	12.52	4.14	4.05	4.07	3.91	3.96	3.96
	Crosses											
L20 X L53	9.73	9.50	9.57	10.37	10.72	10.25	4.38	4.32	4.22	4.07	3.90	4.00
L20 XSK5	10.55	10.33	10.28	10.67	11.58	11.65	4.80	4.68	4.40	4.25	4.48	4.32
L20 X L18	10.95	10.47	10.55	10.82	12.02	11.17	4.05	4.17	4.25	3.72	4.08	4.12
L20 X L28	10.63	10.70	10.50	11.07	10.98	10.82	4.38	4.40	4.65	4.53	4.28	4.38
L20 X Sd7	10.33	11.40	10.63	11.00	11.13	11.32	4.50	4.27	4.37	4.12	4.23	4.50
L 53 X Sk5	10.58	10.30	10.30	11.05	10.63	10.82	4.12	4.20	4.10	4.42	3.97	3.90
L53 X L18	10.57	10.47	10.70	11.60	11.42	11.38	4.27	4.30	4.35	4.40	4.08	4.08
L53 X L28	10.63	10.37	10.58	11.45	11.22	11.20	4.53	4.87	4.53	4.32	4.45	4.65
L53 X Sd7	10.50	10.28	10.80	11.32	11.78	11.65	4.57	4.77	4.67	4.47	4.28	4.30
Sk5 X L18	11.35	10.87	11.03	11.58	11.62	11.73	4.10	4.05	4.03	3.85	3.80	3.87
Sk5 X L28	11.42	10.68	10.58	11.23	11.35	10.63	4.40	4.17	4.50	4.17	4.43	4.12
Sk5 X Sd7	10.83	11.00	10.63	11.03	11.20	11.23	4.68	4.58	4.78	4.75	4.60	4.42
L18 X L28	11.57	11.58	11.65	12.32	11.82	11.62	4.45	4.87	4.60	4.17	4.28	4.27
L18 X Sd7	10.85	10.05	10.52	11.53	12.55	11.52	4.42	4.42	4.58	4.25	4.25	4.35
L28 X Sd7	10.67	10.20	10.48	10.85	11.12	11.48	4.32	4.58	4.57	4.28	4.32	4.33
Average	10.74	10.55	10.59	11.19	11.41	11.23	4.40	4.44	4.44	4.25	4.23	4.24
	GSC						**GYPP**					
L20	71.00	72.17	72.23	72.13	71.72	72.67	106.6	92.9	71.5	57.7	36.7	41.6
L53	70.48	71.17	70.87	70.95	70.20	70.55	132.1	93.7	71.7	85.5	51.0	50.9
Sk5	71.25	70.97	70.70	70.55	70.62	70.92	77.6	64.9	53.0	46.9	37.5	26.1
L18	70.35	69.48	71.02	71.07	70.73	70.90	46.7	27.2	20.1	34.8	20.7	10.6
L28	69.93	68.87	69.92	70.50	71.42	70.37	44.4	35.4	30.5	21.2	18.9	16.9
Sd7	70.75	70.85	71.28	71.23	71.33	71.18	55.1	29.1	32.9	13.2	12.7	8.0
Average	70.63	70.58	71.00	71.07	71.00	71.10	77.1	57.2	46.6	43.2	29.6	25.7
L20 X L53	71.67	71.48	71.52	71.63	72.07	71.60	277.4	238.2	191.6	242.7	196.6	161.1
L20 XSK5	70.12	70.33	70.87	71.53	70.40	70.70	221.7	182.3	153.1	166.8	145.9	115.8
L20 X L18	71.63	71.53	71.37	73.00	71.03	71.97	219.2	193.8	178.1	182.1	153.9	129.7
L20 X L28	71.15	70.85	70.52	70.67	71.43	71.25	232.8	186.5	156.3	171.7	154.2	113.8
L20 X Sd7	70.97	70.68	70.63	70.78	71.40	70.78	226.7	182.4	159.9	179.9	144.1	121.5
L 53 X Sk5	70.80	71.13	71.63	70.48	71.55	72.08	245.5	224.5	184.7	203.0	172.2	137.0
L53 X L18	70.75	70.92	70.53	70.70	71.23	71.42	197.5	147.7	138.3	138.9	117.8	95.3
L53 X L28	70.77	70.55	71.02	70.85	70.90	70.58	237.5	168.9	165.7	171.6	156.1	106.9
L53 X Sd7	70.87	70.55	70.40	70.88	71.52	70.95	241.0	219.1	182.0	197.3	169.2	132.5
Sk5 X L18	71.13	71.75	71.35	71.98	72.10	71.72	234.8	197.0	165.1	183.7	156.1	123.2
Sk5 X L28	70.40	71.08	70.58	71.17	70.80	71.63	223.2	201.3	167.1	177.2	151.5	124.0
Sk5 X Sd7	70.00	70.20	70.17	69.78	70.58	71.10	207.2	157.6	145.2	147.7	127.7	99.7
L18 X L28	70.72	69.82	70.55	70.68	71.15	71.18	171.1	124.4	122.9	124.0	90.1	73.6
L18 X Sd7	71.07	71.12	70.48	70.67	70.03	70.50	213.3	161.8	148.6	154.2	134.7	101.7
L28 X Sd7	70.77	71.22	70.17	71.27	70.90	70.57	227.6	183.5	165.8	177.2	147.7	118.0
Average	70.85	70.88	70.79	71.07	71.14	71.20	225.1	184.6	161.6	174.5	147.9	116.9
	GYPH						**PYPH**					
	Parents											
L20	4.95	6.41	6.64	2.39	2.76	3.86	542	681	772	285	321	420
L53	6.13	6.47	6.66	3.52	3.87	4.73	735	706	766	391	469	550
Sk5	3.60	4.48	4.92	2.17	2.47	2.64	462	578	634	283	331	347
L18	2.16	1.85	1.86	1.49	1.47	0.98	295	265	251	195	199	133
L28	2.06	2.44	2.83	0.87	1.28	1.64	265	325	363	108	155	214
Sd7	2.01	2.50	3.05	0.63	0.72	1.04	257	225	350	78	90	133
Average	3.49	4.03	4.33	1.85	2.09	2.48	426	463	523	224	261	299
	Crosses											
L20 X L53	12.88	16.45	17.05	11.23	14.24	14.95	1254	1562	1633	1166	1538	1534
L20 XSK5	10.22	12.59	14.21	7.75	10.22	10.76	1082	1295	1467	832	1189	1271
L20 X L18	10.15	13.38	16.04	8.33	10.76	12.04	1111	1405	1693	902	1293	1345
L20 X L28	10.81	12.88	14.51	7.97	10.77	10.57	1149	1373	1523	882	1185	1142
L20 X Sd7	10.53	12.60	14.85	8.31	10.07	11.28	1088	1436	1578	913	1119	1273
L 53 X Sk5	11.40	15.50	16.47	9.31	12.16	12.72	1206	1597	1695	1029	1297	1377
L53 X L18	8.99	10.20	12.85	6.45	8.23	8.85	950	1068	1374	748	940	1007
L53 X L28	11.03	11.66	14.99	7.95	10.90	9.93	1173	1209	1584	911	1228	1113

L53 X Sd7	11.19	15.13	16.30	8.96	11.82	12.30	1175	1556	1760	1013	1395	1433
Sk5 X L18	10.90	13.60	15.18	8.43	10.90	11.44	1237	1479	1676	977	1274	1345
Sk5 X L28	10.34	13.90	15.45	8.17	10.59	11.52	1180	1485	1634	919	1197	1226
Sk5 X Sd7	9.58	10.88	13.48	6.86	8.92	9.26	1038	1197	1431	758	1001	1042
L18 X L28	7.91	8.59	11.42	5.76	6.30	6.84	915	995	1330	709	745	795
L18 X Sd7	9.88	11.17	13.80	7.16	9.41	9.44	1072	1123	1452	827	1182	1088
L28 X Sd7	10.49	12.67	14.67	7.97	10.60	10.95	1116	1292	1541	874	1209	1273
Average	10.42	12.75	14.75	8.04	10.39	10.86	1116	1338	1558	897	1186	1218
	OYPH						**SYPH**					
	Parents											
L20	210	250	253	88	107	148	3513	4627	4801	1728	1981	2804
L53	252	272	276	146	169	200	4319	4610	4718	2501	2716	3340
Sk5	126	157	180	77	87	94	2566	3181	3481	1534	1742	1878
L18	87	77	75	58	58	36	1523	1285	1322	1057	1037	700
L28	93	105	127	36	55	70	1440	1681	1976	618	909	1153
Sd7	87	105	129	26	27	43	1423	1770	2179	452	512	739
Average	142	161	173	72	84	99	2464	2859	3080	1315	1483	1769
	Crosses											
L20 X L53	564	710	719	456	554	598	9230	11756	12195	8043	10256	10708
L20 XSK5	492	599	627	333	475	473	7149	8829	10061	5533	7156	7569
L20 X L18	412	558	682	310	439	495	7273	9565	11450	6076	7639	8665
L20 X L28	474	570	675	362	461	464	7689	9121	10233	5633	7696	7527
L20 X Sd7	473	538	648	342	427	508	7470	8903	10487	5882	7193	7987
L 53 X Sk5	469	651	675	411	483	496	8072	11027	11802	6561	8703	9167
L53 X L18	384	438	558	284	336	362	6363	7233	9065	4559	5864	6320
L53 X L28	500	568	680	343	483	462	7804	8227	10647	5635	7726	7007
L53 X Sd7	511	721	759	400	506	529	7928	10674	11482	6351	8456	8727
Sk5 X L18	447	551	612	324	414	442	7755	9761	10829	6068	7859	8207
Sk5 X L28	455	579	695	341	471	474	7281	9880	10909	5815	7498	8250
Sk5 X Sd7	448	499	644	325	410	409	6705	7638	9467	4787	6300	6583
L18 X L28	352	418	525	240	270	291	5592	5996	8053	4068	4481	4866
L18 X Sd7	436	494	632	304	401	410	7022	7945	9726	5059	6592	6657
L28 X Sd7	463	600	683	348	470	478	7405	8999	10278	5667	7493	7732
Average	459	566	654	342	440	459	7382	9037	10445	5716	7394	7731

The rank of inbred parents for GYPH, PYPH, OYPH and SYPH was approximately similar in all six environments, indicating less effect of interaction between inbreds, irrigation and plant density on these traits. The best GYPH, PYPH, OYPH and SYPH was obtained from E3 (WW-HD) for the inbreds L20, Sk5 and L53 followed by E2 (WW-MD) and E1 (WW-LD). Regarding the F_1 crosses, the rank varied from one environment to another, especially when comparing environments that combine two stresses with those having only one stress or no stress, indicating that the GYPH, PYPH, OYPH and SYPH of a cross differs from one combination to another. The best GYPH, PYPH, OYPH and SYPH in this experiment was obtained under E3 (well irrigation- high density) and the best crosses in all environments were L20× L53 followed by L53 × Sk5, L53 × Sd7 , L20× L18 and Sk5 × L28. It is worthy to note that the three crosses (L20× L53), (L53 × Sk5) and (L53 × Sd7) were considered the highest responsive and the most tolerant ones to both stresses (water stress combined with high density).

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 [34,35]. The term heterobeltiosis has been suggested to describe the increased performance of the hybrid over the better parent [36]. Average heterobeltiosis across all F_1 crosses, minimum and maximum values and number of crosses showing significant favorable heterobeltiosis for all studied traits under the six environments across 2013 and 2014 years are presented in Table (4). Favorable heterobeltiosis in the studied crosses was considered positive for all studied traits under all environments.

In general, the highest average significant and positive (favorable) heterobeltiosis was shown by oil yield per feddan (186.25, 201.71, 219.02, 302.71, 339.20 and 299.66%) under E1 through E6, respectively, followed by GYPP, GYPH, GYPH and GYPH traits (Table 4). However, the lowest average significant (favorable) heterobeltiosis was shown by grain starch content (-0.09, -0.59, -0.93, -0.48, -0.30 and-0.47%) under E1 through E6, respectively. The traits GPC and GSC under all environments showed on average unfavorable heterobeltiosis. However, some crosses showed significant favorable heterobeltiosis in these cases.

In general, E2 environment (WW and MD), where irrigation was optimum and plant density was medium, showed the largest number of crosses showing significant favorable heterobeltiosis for studied traits. For yield traits, *i.e.* GYPP, GYPH, PYPH, OYPH and GYPH, the E6 environment (the severest stressed environment; WS-HD) showed generally the highest maximum heterobeltiosis (861.59, 809.62, 716.71, 848.98 and 800.93%, respectively).

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.

Parameter	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
	Grain protein content (GPC)						**Grain oil content (GOC)**					
Aver	-17.11	-18.64	-17.01	-12.75	-12.01	-14.6	0.97	5.29	4.37	4.75	2.38	2.37
Max	-11.38	7.21	-5.81	-6.1	-5.72	-8.87	13.39	20.09	15.28	17.77	21.05	12.61
Min	-21.82	-30.09	-21.71	-18.47	-21.04	-19.55	-5.13	-2.72	-0.81	-4.29	-10.69	-8.24
No.	0	0	0	0	0	0	1	6	4	2	4	5
	Grain starch content (GSC)						**Grain yield per plant (GYPP)**					
Aver	-0.09	-0.59	-0.93	-0.48	-0.3	-0.47	151.79	176.63	191.31	236.58	315.98	287.9
Max	0.94	1.1	1.08	1.29	1.93	1.65	313.14	455.28	404.32	736	680.84	861.59
Min	-1.75	-2.54	-2.38	-2.04	-1.84	-2.71	49.55	57.64	92.96	62.37	130.82	87.08
No.	0	1	0	3	2	3	15	15	15	15	15	15
	Grain yield per hectare (GYPH)						**Protein yield per hectare (PYPH)**					
Aver	162.31	168.74	186.52	264.08	308.71	274.19	129.7	143.15	154.27	234.38	275.92	246.57
Max	409.27	407.55	380.66	813.39	728.46	809.62	321	323.94	323.92	710.95	679.95	716.71
Min	46.71	57.64	92.96	82.98	112.72	87.08	29.38	51.33	79.53	91.32	100.7	83.14
No.	15	15	15	15	15	15	15	15	15	15	15	15
	Oil yield per hectare (OYPH)						**Starch yield per hectare (SYPH)**					
Aver	186.25	201.71	219.02	302.71	339.2	299.66	162.95	167.92	184.47	263.41	309.6	273.9
Max	402.92	472.56	428.88	876.66	759.15	848.98	414.13	408.44	371.75	816.74	724.43	800.93
Min	52.24	61.43	102.24	94.28	99.21	80.54	47.32	56.92	92.11	82.31	115.89	89.21
No.	15	15	15	15	15	15	15	15	15	15	15	15

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

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 [37], 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 [12]. 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.* GYPP (151.79%), GYPH (162.31%), OYPH (168.25%), PYPH (129.70%), GYPH (162.95%) and for GOC (0.97%) (Table 4). The largest significant favorable heterobeltiosis for GYPP in this study (861.59%) 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 GYPH (809.62%), PYPH (716.71%), OYPH (848.98%) and GYPH (800.93%).

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). The highest GYPH heterobeltiosis (809.62%) under high density-water stressed environment (E6) was shown by L18 × Sd7 followed by L28 × Sd7 (567.95%), Sk5 x L28 (335.82%) and Sk5 x L18 (333.01%).

Under the severest environment (E6), the cross (L28 × Sd7) showed the second highest *per se* grain yield/ha (Table 3) followed by the cross L53 x Sd7 which showed the highest GYPH *per se* and 160.04% heterobeltiosis (Table 5) and could therefore be recommended for commercial application under high plant density-water stress conditions and as good genetic material for maize breeding programs.

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

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
	Grain oil content						**Grain yield per plant**					
L20 X L53	3.54	2.78	2.02	-2.01	-10.69**	-5.88*	110.04**	154.23**	167.17**	183.73**	285.18**	216.17**
L20 XSK5	13.39**	20.09**	15.28**	15.91**	14.96**	12.61**	107.99**	96.33**	114.13**	188.90**	289.14**	178.78**
L20 X L18	-4.33	0.4	4.94	-4.29	3.81	7.39**	105.63**	108.68**	149.12**	215.33**	319.33**	212.03**
L20 X L28	-3.66	2.72	3.72	9.24*	1.18	2.33	118.39**	100.89**	118.60**	197.36**	320.15**	173.84**
L20 X Sd7	2.27	-0.19	1.95	2.07	8.55*	8.43**	112.69**	96.48**	123.68**	211.62**	292.64**	192.44**
L 53 X Sk5	-0.8	0	-0.81	6.43	-9.16*	-8.24**	85.93**	139.64**	157.64**	137.29**	237.46**	168.87**
L53 X L18	2.81	2.38	5.24	6.02	-6.49	-3.92	49.55**	57.64**	92.96**	62.37**	130.82**	87.08**
L53 X L28	-0.37	13.62**	1.12	4.02	1.91	8.56**	79.87**	80.27**	131.11**	100.64**	205.75**	109.88**
L53 X Sd7	3.79	11.50**	8.95**	7.63	-1.91	1.18	82.47**	133.89**	153.78**	130.68**	231.59**	160.04**
Sk5 X L18	1.65	-2.41	-0.41	-0.86	-3.39	4.98	202.76**	203.37**	211.68**	291.88**	316.56**	371.36**
Sk5 X L28	-3.3	-2.72	0.37	0.4	4.72	-3.89	187.76**	209.98**	215.49**	278.14**	304.27**	374.42**
Sk5 X Sd7	6.44	7.21*	11.67**	17.77**	21.05**	6.43*	167.16**	142.63**	174.13**	215.14**	240.79**	281.46**
L18 X L28	-2.2	13.62**	2.6	0.4	1.18	-0.39	266.42**	251.59**	303.74**	256.34**	334.94**	334.42**
L18 X Sd7	0.38	3.31	7.00*	5.37	8.05*	4.82	287.11**	455.28**	352.04**	343.24**	550.21**	861.59**
L28 X Sd7	-5.13	7.00*	1.86	3.21	1.97	1.17	313.14**	418.62**	404.32**	736.00**	680.84**	596.14**
	Grain yield per hectare						**Protein yield per hectare**					
L20 X L53	110.04**	154.23**	156.13**	218.57**	267.95**	216.17**	70.64**	121.34**	111.60**	197.93**	228.27**	178.95**
L20 XSK5	106.46**	96.33**	114.13**	223.44**	270.04**	178.78**	99.66**	90.21**	90.15**	191.54**	258.97**	202.34**
L20 X L18	105.16**	108.68**	141.68**	247.67**	289.45**	212.03**	105.10**	106.36**	119.40**	216.06**	302.61**	219.90**
L20 X L28	118.39**	100.89**	118.60**	232.91**	290.12**	173.84**	112.08**	101.75**	97.35**	209.22**	269.09**	171.64**
L20 X Sd7	112.69**	96.48**	123.68**	246.99**	264.75**	192.44**	100.78**	110.98**	104.54**	220.11**	248.36**	202.91**
L 53 X Sk5	85.93**	139.64**	147.39**	164.14**	214.33**	168.87**	64.21**	126.28**	121.45**	162.92**	176.86**	150.36**
L53 X L18	46.71**	57.64**	92.96**	82.98**	112.72**	87.08**	29.38**	51.33**	79.53**	91.32**	100.70**	83.14**
L53 X L28	79.87**	80.27**	125.11**	125.69**	181.59**	109.88**	59.63**	71.32**	106.91**	132.80**	162.18**	102.46**
L53 X Sd7	82.47**	133.89**	144.90**	154.21**	205.56**	160.04**	59.91**	120.50**	129.87**	158.95**	197.77**	160.65**
Sk5 X L18	202.76**	203.37**	208.55**	289.17**	341.92**	333.01**	167.99**	156.08**	164.47**	244.70**	284.65**	287.70**
Sk5 X L28	187.19**	209.98**	214.11**	277.19**	329.54**	335.82**	155.57**	157.11**	157.95**	224.26**	261.45**	253.34**
Sk5 X Sd7	165.98**	142.63**	174.13**	216.59**	261.85**	250.43**	124.72**	107.20**	125.94**	167.66**	202.12**	200.28**
L18 X L28	265.32**	251.93**	303.74**	286.98**	329.78**	316.82**	210.84**	205.68**	266.09**	263.54**	273.39**	272.24**
L18 X Sd7	356.40**	347.60**	352.04**	381.35**	542.55**	809.62**	263.99**	323.94**	314.92**	323.74**	492.49**	716.71**
L28 X Sd7	409.27**	407.55**	380.66**	813.39**	728.46**	567.95**	321.00**	297.10**	323.92**	710.95**	679.95**	496.00**
	Oil yield per hectare						**Starch yield per hectare**					
L20 X L53	123.35**	161.57**	160.46**	211.94**	228.44**	198.59**	113.71**	154.04**	154.00**	221.62**	277.59**	220.59**
L20 XSK5	134.74**	139.69**	147.73**	279.46**	342.89**	219.14**	103.51**	90.79**	109.56**	220.19**	261.22**	169.94**
L20 X L18	96.42**	123.51**	169.30**	252.42**	309.43**	233.98**	107.04**	106.70**	138.48**	251.61**	285.60**	209.03**
L20 X L28	126.22**	128.07**	166.58**	311.43**	329.63**	212.51**	118.91**	97.11**	113.13**	226.00**	288.49**	168.47**
L20 X Sd7	126.00**	115.23**	156.11**	289.27**	297.75**	242.36**	112.67**	92.40**	118.42**	240.37**	263.07**	184.86**
L 53 X Sk5	86.02**	139.80**	144.52**	181.28**	186.01**	147.81**	86.88**	139.23**	150.12**	162.37**	220.43**	174.45**
L53 X L18	52.24**	61.43**	102.24**	94.28**	99.21**	80.54**	47.32**	56.92**	92.11**	82.31**	115.89**	89.21**
L53 X L28	98.24**	109.07**	146.51**	134.56**	186.52**	130.49**	80.68**	78.48**	125.64**	125.32**	184.45**	109.78**
L53 X Sd7	102.44**	165.59**	175.23**	174.00**	200.02**	164.09**	83.56**	131.57**	143.35**	153.96**	211.34**	161.27**
Sk5 X L18	255.40**	251.41**	239.76**	323.69**	374.99**	371.56**	202.27**	206.88**	211.10**	295.72**	351.23**	337.07**
Sk5 X L28	261.65**	269.26**	285.69**	344.88**	439.75**	405.78**	183.79**	210.62**	213.40**	279.19**	330.49**	339.37**
Sk5 X Sd7	256.38**	218.03**	257.34**	324.60**	370.69**	336.33**	161.35**	140.14**	171.97**	212.17**	261.69**	250.61**
L18 X L28	276.44**	299.04**	315.23**	315.34**	367.93**	317.36**	267.23**	256.62**	307.53**	284.90**	332.25**	322.19**
L18 X Sd7	402.92**	371.38**	389.72**	426.85**	595.63**	848.98**	361.15**	348.87**	346.43**	378.66**	535.90**	800.93**
L28 X Sd7	395.26**	472.56**	428.88**	876.66**	759.15**	585.40**	414.13**	408.44**	371.75**	816.74**	724.43**	570.79**

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 levels, respectively.

6. 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 cases (70 out of 96 cases, *i.e.* 72.9%), suggesting that both additive and non-additive gene effects play important roles in controlling the inheritance of most studied traits under respective environments. A similar conclusion was reported by several investigators [21, 38-44].

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 GPC, except E3, GOC, except E5 and GSC, except E1 and E5, 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 and that selection methods in segregating generations of maize hybrids would be the best choice for improving such grain quality traits. These results are in agreement with those reported by several investigators [43-48].

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
	Grain protein content						Grain oil content					
GCA	7.48*	14.64	5.43**	4.56	5.58	6.48*	0.64	0.81	0.88*	0.64*	0.4	0.89*
SCA	5.14**	7.15**	5.57**	3.26**	2.98	4.03	0.42	0.57	0.38	0.49*	0.47	0.31
GCA/SCA	1.45	2.05	0.97	1.4	1.88	1.61	1.52	1.42	2.32	1.30	0.86	2.84
GCA×Y	0.94	5.03**	0.27	1.28	3.29**	0.7	0.28	0.24**	0.16	0.09	0.38	0.12
SCA×Y	1.23*	1.73*	0.65	1.05	1.85*	2.08**	0.38	0.37**	0.24	0.2	0.42	0.19
GCA×Y/SCA×Y	0.76	2.9	0.42	1.22	1.78	0.34	0.74	0.64	0.66	0.43	0.9	0.6
	Grain starch content						Grain yield per plant					
GCA	1.24	5.54	3.86	4.71	0.94	3.25*	12189**	12513*	5180*	9558**	5425*	4912**
SCA	1.33	2.79	1.24	2.30*	2.21	1.8	39215**	30650**	23841**	32244**	25983**	15568**
GCA/SCA	0.93	1.98	3.11	2.05	0.42	1.8	0.3	0.41	0.22	0.3	0.21	0.32
GCA×Y	1.68*	2.33**	1.08	1.59*	2.22*	0.69	1067**	1241**	590.3**	632**	971**	335.4**
SCA×Y	1.33*	1.66**	2.02**	0.98	1.70**	2.14**	797.8**	1581.4**	689.0**	1206**	970**	578.0**
GCA×Y/SCA×Y	1.26	1.4	0.54	1.62	1.31	0.32	1.3	0.78	0.86	0.52	1.0	0.58
	Grain yield per hectare						Protein yield per hectare					
GCA	12189**	12513*	5180*	9558**	5425*	4912**	37811	88860**	54631*	29653*	50973	70519*
SCA	39215**	30650**	23841**	32244**	25983**	15568**	153673**	253511**	340543**	146260**	283694**	276776**
GCA/SCA	0.30	0.41	0.22	0.30	0.21	0.32	0.25	0.35	0.16	0.2	0.18	0.25
GCA×Y	1067**	1241**	590.3**	632**	971**	335.4**	8262**	4706**	7696**	5519**	17176**	8515**
SCA×Y	797.8**	1581.4**	689.0**	1206**	970**	578.0**	5116**	15991**	12660**	6738**	22169**	19136**
GCA×Y/SCA×Y	1.30	0.78	0.86	0.52	1.00	0.58	1.62	0.29	0.61	0.82	0.77	0.44
	Oil yield per hectare						Starch yield per hectare					
GCA	9470*	17940*	10161*	6167*	8726	12119**	2476627**	5331906*	3773304**	1683194*	2838662*	3806128**
SCA	31507**	53410**	72138**	23372**	41159**	41933**	7696247**	12817768**	17099676**	6364526**	11568861**	11792743**
GCA/SCA	0.3	0.34	0.14	0.26	0.21	0.29	0.3	0.42	0.22	0.26	0.25	0.32
GCA×Y	1428**	3425**	2133**	917**	2193**	1273**	185787**	532035**	275576**	158568**	267253**	204412**
SCA×Y	1757**	6014**	3445**	1342**	4364**	2949**	138944**	599804**	323073**	203145**	453971**	426775**
GCA×Y/SCA×Y	0.8	0.57	0.62	0.68	0.5	0.43	1.3	0.89	0.85	0.78	0.59	0.48

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.

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, i.e. for GYPP, GYPH, PYPH, OYPH and GYPH under all the six studied environments. For yield traits in the present study, the non-additive (dominance and epistasis) is more important than additive variance in controlling their inheritance, indicating that heterosis breeding is the best choice for improving these traits under studied stressed and non-stressed environments. A similar conclusion was reported by several investigators [49-52].

Results in Table (6) indicate that mean squares due to the SCA × year and GCA x year interactions were highly significant for 5 traits, namely GYPP, GYPH, PYPH, OYPH and GYPH under all six environments, indicating that additive and non-additive variances for these traits under all environments were affected by years. This was not true for GOC trait under all environments, except under E2 environment and few other cases for GPC and GSC, 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 OYPH and GOC under all environments, GYPH, PYPH and GYPH in all environments, except E1, 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 E1 for GYPP, GYPH and PYPH, E4 and E5 for GPC and E1, E2, E4 and E% for GSC (Table 6), indicating that GCA (additive) variance is more affected by years than SCA (non-additive) variance for these traits under the respective environments.

GCA effects of inbred parents

Estimates of general combining ability (GCA) effects of parental inbreds for studied traits under the six environments across two seasons are presented in Table (7). The best parental inbreds were those showing positive and significant GCA effects for all studied traits. For GYPP, GYPH, PYPH, OYPH and SYPH, the best inbred in GCA effects was L53 in all environments 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 and GYPH (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 GYPH and GYPP was associated with their superiority in GCA effects for most studied traits. In previous studies [18, 22, 43], the inbred lines L53, L20 and Sd5 were also the best general combiners for GYPP and GYPH under high and low plant densities.

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

	E1	E2	E3	E4	E5	E6	E1	E2	E3	E4	E5	E6
Inbred	**WW-LD**	**WW-MD**	**WW-HD**	**WS-LD**	**WS-MD**	**WS-HD**	**WW-LD**	**WW-MD**	**WW-HD**	**WS-LD**	**WS-MD**	**WS-HD**
	Grain protein content						**Grain oil content**					
L20	-0.38	-0.51*	-0.08	-0.15	-0.35	-0.24	0.03	-0.14	-0.1	-0.04	-0.08	0.03
L53	-0.43	-0.05	-0.46	-0.32	-0.25	-0.21	-0.03	0.1	0.06	-0.12	-0.08	-0.07
Sk5	0.25	-0.1	0.11	-0.17	-0.03	-0.02	0.03	0.05	-0.13	0.03	-0.1	-0.15
L18	0.39	0.47	0.17	0.59	0.38	0.32	-0.18	-0.22**	-0.1	-0.16	-0.1	-0.13
L28	0.3	0.24	0.2	-0.14	0.22	-0.1	0.02	0.06	0.17	0.15	0.16	0.14
Sd7	-0.14	-0.06	0.05	0.19	0.03	0.26	0.12	0.16	0.1	0.13	0.19	0.18
SE g_i-g_j	0.56	0.38	0.52	0.55	0.58	0.63	0.52	0.12	0.5	0.52	0.51	0.51
	Grain starch content						**Grain yield per plant**					
L20	0.32	0.56**	0.12	0.16	0.24	0.07	13.05**	17.64**	15.05**	13.85**	7.68**	14.32**
L53	0.15	-0.2	0.06	0.39	0.29	0.16	18.35**	20.21**	18.86**	18.16**	13.54**	12.03**
Sk5	-0.45	-0.1	0.03	-0.07	0.17	0.31	1.74	1.43	9.93**	3.54	1.78	3.81**
L18	0.26	0.42*	0.18	-0.04	0.09	0.19	-22.40**	-22.47**	-24.59**	-21.66**	-13.76**	-15.28**
L28	-0.12	-0.18	-0.22	-0.13	-0.27	-0.2	-8.31**	-12.73**	-14.60**	-9.93**	-7.57**	-12.07**
Sd7	-0.15	-0.50**	-0.16	-0.32	-0.52	-0.53	-2.42	-4.07*	-4.65	-3.96	-1.67	-2.81*
SE g_i-g_j	0.6	0.29	0.52	0.55	0.57	0.57	3.08	3	3.99	3.61	2.55	1.73
	Gain yield per hectare						**Protein yield per hectare**					
L20	1.86**	2.54**	3.12**	3.07**	2.18**	3.99**	10.62	21.91	39.95**	41.26**	10.96	50.07**
L53	2.54**	2.78**	3.91**	4.04**	2.93**	3.35**	18.47*	39.90**	31.67**	49.17**	26.81*	39.49**
Sk5	0.26	0.24	2.06**	0.63*	0.78*	1.06	16.91	2.89	37.96**	2.89	11.89	18.08**
L18	-3.19**	-3.06**	-5.09**	-4.78**	-3.36**	-4.26**	-31.07**	-34.01**	-65.23**	-52.17**	-27.87*	-53.36**
L28	-1.14**	-1.78**	-3.02**	-2.11**	-2.04**	-3.36**	-5.1	-20.1	-35.27**	-38.46**	-18.76	-56.52**
Sd7	-0.33	-0.71	-0.97	-0.85**	-0.49	-0.78	-9.84	-10.6	-9.08	-2.69	-3.03	2.24
SE g_i-g_j	0.42	0.63	0.78	0.47	0.56	17.31	13.23	21.74	13.58	11.2	19.72	7.62
	Oil yield per hectare						**Starch yield per hectare**					
L20	12.68**	9.97*	15.03**	16.44**	8.33*	25.33**	199.3**	271.7**	313.8**	311.8**	230.8**	398.9**
L53	14.15**	19.59**	27.05**	17.01**	12.59**	15.64**	260.8**	269.8**	391.9**	423.7**	311.1**	343.5**
Sk5	1.94	2.84	5.01	5.55	-2.01	-0.24	5.2**	19.5	204.8**	57.3**	88.2*	117.5**
L18	-27.57**	-25.80**	-39.02**	-35.69**	-27.49**	-31.14**	-305.4**	-288.6**	-491.9**	-476.3**	-326.0**	-414.0**
L28	-5.23	-7.87	-10.16**	-4.78	-1.4	-13.50**	-119.9**	-184.9**	-310.9**	-218.0**	-221.4**	-343.8**
Sd7	4.03	1.27	2.09	1.48	9.99**	3.9	-40.1**	-87.5*	-107.7*	-98.4**	-82.7*	-102.0**
SE g_i-g_j	4.97	7.58	5.92	5.1	5.29	45.72	0.71	64.55	81.39	0.71	53.8	48.17

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.

For the grain quality traits, *i.e.* GPC, GOC and GSC, the magnitude of GCA effects was small and not significant in most cases. However, the largest values of GCA effects were exhibited by L18 under E1, E2, E4, E5 and E6 and L28 under E3 for GPC, Sd7 under E1, E2, E5 and E6 and L18 under E3 and E4 for GOC and L20 under E1 and E2, L53 under E4 and E5, Sk5 under E6 and L18 under E3 for GSC trait.

SCA effects of F_1 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 positive SCA effects for all studied traits. For GYPP, GYPH and SYPH, 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). For OYPH, the highest (favorable) positive and significant SCA effects were exhibited by the cross Sk5 x L18 under the 6 environments, L20 × L18 under E3, E4, E5 and E6, L20 × L53 under all environments, except E5.

For PYPH, the highest positive and significant SCA effects were shown by the cross Sk5 x L18 under all environments followed by L20 x L18 and L53 x Sd7 under E3, E4, E5 and E6, L20 x L53 under E2 and E4 and L28 x Sd7 under E4 and E6. 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 [11,53,54].

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

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
	Grain protein content						**Grain oil content**					
L20 × L53	-0.20	-0.27	-0.51	-0.22	-0.42	-0.53	-0.02	-0.15	-0.09	-0.17	-0.06	-0.20
L20 ×SK5	-0.07	0.08	-0.24	0.49	0.07	0.68	0.34	0.10	0.47	0.26	0.14	0.19
L20 × L18	0.20	-0.34	-0.17	0.17	-0.06	-0.14	-0.20	-0.18	-0.08	0.06	-0.02	-0.02
L20 × L28	-0.03	0.15	0.04	-0.13	0.05	-0.08	-0.07	0.37**	-0.12	-0.06	0.13	-0.02
L20 × Sd7	0.10	0.38	0.89	-0.31	0.37	0.06	-0.05	-0.15	-0.18	-0.09	-0.19	0.06
L 53 × Sk5	0.01	0.00	0.10	-0.29	-0.02	-0.18	-0.28	0.02	-0.17	-0.18	-0.16	-0.13
L53 × L18	-0.14	-0.02	0.20	-0.27	-0.02	0.05	0.08	0.26	-0.10	0.13	0.09	0.04
L53 × L28	0.02	0.06	0.07	0.27	0.03	0.28	0.14	-0.09	0.20	0.18	0.02	0.34
L53 × Sd7	0.32	0.22	0.14	0.51	0.43	0.37	0.08	-0.04	0.16	0.04	0.12	-0.05
Sk5 × L18	-0.04	0.02	0.03	-0.22	0.10	0.21	-0.15	-0.23	-0.16	-0.30	-0.22	-0.10
Sk5 × L28	0.12	-0.10	-0.18	0.25	-0.19	-0.47	-0.05	-0.19	-0.31	0.02	-0.01	-0.12
Sk5 × Sd7	-0.03	0.00	0.29	-0.23	0.04	-0.24	0.14	0.30	0.17	0.20	0.25	0.15
L18 × L28	0.13	0.41	0.66	-0.05	0.47	0.17	0.21	0.08	0.36	0.06	0.09	0.02
L18 × Sd7	-0.15	-0.07	-0.72	0.36	-0.48	-0.29	0.07	0.06	-0.03	0.05	0.05	0.07
L28 × Sd7	-0.24	-0.52	-0.60	-0.34	-0.35	0.09	-0.23	-0.17	-0.13	-0.20	-0.23	-0.22
SE $S_{ij} - S_{ik}$	0.97	0.66	0.90	0.95	1.00	1.09	0.89	0.21	0.87	0.90	0.88	0.88
SE $S_{ij} - S_{kl}$	0.79	0.54	0.73	0.77	0.82	0.89	0.73	0.17	0.71	0.73	0.72	0.72
	Grain starch content						**Grain yield per plant**					
L20 × L53	0.35	0.20	0.43	0.38	0.19	0.17	20.88**	30.32**	19.69**	16.72**	8.71*	17.79**
L20 ×SK5	-0.60	0.00	-0.69	-0.83	-0.33	-0.88	-18.21**	-26.79**	-27.29**	-19.40**	-18.02**	-19.20**
L20 × L18	0.21	0.95*	0.35	-0.23	0.25	0.50	3.43	12.38**	18.70**	13.87**	22.53**	13.70**
L20 × L28	0.10	-0.79*	0.07	0.27	-0.24	0.17	2.93	-7.74*	1.48	2.44	-5.47	-5.38*
L20 × Sd7	-0.05	-0.36	-0.16	0.42	0.13	0.04	-9.03*	-8.17*	-12.57*	-13.63**	-7.75*	-6.91**
L 53 × Sk5	0.26	-0.28	0.17	0.09	0.39	0.42	0.34	6.80*	11.12*	2.68	7.78*	4.21*
L53 × L18	-0.51	-0.59	-0.20	-0.26	-0.63	-0.14	-23.56**	-33.38**	-31.18**	-26.55**	-23.06**	-18.37**
L53 × L28	-0.12	0.16	-0.17	-0.50	0.21	-0.58	2.40	-10.39*	-19.96**	-0.04	-1.89	-9.96**
L53 × Sd7	0.02	0.51	-0.23	0.30	-0.16	0.12	-0.06	6.65*	20.32**	7.18	8.46*	6.33**
Sk5 × L18	0.48	0.60	0.66	1.06	0.31	0.02	30.40**	30.18**	27.08**	26.39**	15.47**	17.79**
Sk5 × L28	0.12	0.38	0.40	-0.14	-0.10	0.33	4.67	14.00**	21.39**	10.05*	11.30**	15.38**
Sk5 × Sd7	-0.25	-0.69	-0.55	-0.17	-0.27	0.12	-17.21**	-24.19**	-32.30**	-19.72**	-16.52**	-18.18**
L18 × L28	-0.28	-0.62	-1.02	0.18	-0.05	-0.01	-23.29**	-15.37**	-21.03**	-26.17**	-17.34**	-15.96**
L18 × Sd7	0.10	-0.33	0.21	-0.75	0.13	-0.37	13.02**	6.20	6.43	12.46*	2.40	2.84
L28 × Sd7	0.18	0.87*	0.72	0.21	0.17	0.09	13.28**	19.50**	18.12**	13.72**	13.40**	15.92**
SE $S_{ij} - S_{ik}$	1.05	0.50	0.90	0.95	0.99	0.98	5.34	5.20	6.91	6.24	4.42	3.00
SE $S_{ij} - S_{kl}$	0.85	0.41	0.73	0.77	0.81	0.80	4.36	4.24	5.64	5.10	3.61	2.45
	Gain yield per hectare						**Protein yield per hectare**					
L20 × L53	2.97**	4.26**	4.08**	4.42**	1.79*	4.96**	28.52	50.87*	22.43	57.37**	-6.35	43.27**
L20 ×SK5	-2.73**	-3.66**	-5.65**	-4.22**	-4.57**	-5.35**	-42.12*	-52.26*	-96.11**	-42.94**	-243.60	-45.73**
L20 × L18	0.53	1.38	3.87**	2.79**	5.05**	3.82**	18.25	14.02	53.25**	55.71**	73.65**	56.70**
L20 × L28	0.44	-0.96	0.31	0.18	-0.86	-1.50	8.15	-8.10	10.11	-3.21	-6.97	-25.34*
L20 × Sd7	-1.22*	-1.02	-2.60*	-3.18**	-1.41*	-1.92	-12.81	-4.54	10.31	-66.94**	0.62	-28.90**
L 53 × Sk5	0.14	0.79	2.30*	0.64	1.45*	1.18	2.41	12.36	39.07*	-5.44	18.86	9.24
L53 × L18	-3.62**	-4.49**	-6.46**	-5.75**	-5.28**	-5.12**	-57.09**	-68.40*	-79.87**	-100.25**	-76.13**	-74.56**
L53 × L28	0.43	-1.25	-4.14**	-0.42	-0.18	-2.78*	10.29	-14.15	-50.60**	7.03	2.76	-26.78*
L53 × Sd7	0.09	0.69	4.21**	1.10*	2.22**	1.76	15.87	19.32	68.98**	41.29**	60.86*	48.84**
Sk5 × L18	4.39**	3.99**	5.61**	5.67**	3.86**	4.96**	64.97**	64.41*	86.40**	86.21**	65.30*	88.80**
Sk5 × L28	0.65	1.94*	4.43**	2.08**	3.36**	4.28**	14.91	26.17	58.95**	40.24**	38.85	41.89**
Sk5 × Sd7	-2.45**	-3.07**	-6.69	-4.18**	-4.09**	-5.07**	-40.17*	-50.68*	-88.31**	-78.08**	-62.07*	-94.19**
L18 × L28	-3.20**	-2.01*	-4.36**	-5.41**	-4.61**	-4.45**	-48.29**	-24.93	-43.63*	-94.74**	-49.02*	-67.48**
L18 × Sd7	1.90**	1.13	1.33	2.69**	0.99	0.79	22.17	14.90	-16.15	53.06**	-13.80	-3.47

L28 × Sd7	1.68**	2.27**	3.75**	3.57**	2.29**	4.44**	14.94	21.00	25.17	50.67**	14.39	77.72**
SE $S_{ij} - S_{ik}$	0.72	1.09	1.35	0.82	0.96	29.99	22.91	37.66	23.53	19.40	34.16	13.19
SE $S_{ij} - S_{kl}$	0.59	0.89	1.10	0.67	0.79	24.49	18.71	30.75	19.21	15.84	27.89	10.77
	Oil yield per hectare						**Starch yield per hectare**					
L20 × L53	17.23*	18.49*	18.42*	14.46*	6.14	17.20**	315.91**	435.87**	436.06**	466.46**	192.96**	507.81**
L20 ×SK5	-0.73	-16.21	-6.44	-7.18	-17.72*	-19.20**	-302.79**	-367.99**	-605.99**	-469.04**	-480.30**	-584.76**
L20 × L18	-4.94	2.45	20.62*	18.99**	30.69**	20.94**	59.90**	168.15*	399.83**	267.41**	516.93**	407.12**
L20 × L28	-1.06	6.30	-3.45	-2.82	1.71	-10.07	49.39**	-121.46	32.52	33.19**	-98.80	-140.68*
L20 × Sd7	-10.50	-11.02	-29.16**	-23.45**	-20.82**	-8.87	-122.41**	-114.56	-262.42*	-298.02**	-130.79*	-189.49**
L 53 × Sk5	-11.60*	6.80	3.61	-4.72	-1.98	0.05	23.36**	65.78	239.20*	68.99	170.34*	141.97*
L53 × L18	-17.88**	-17.98*	-41.72**	-24.99**	-25.48**	-25.62**	-383.72**	-467.02**	-657.59**	-590.08**	-565.10**	-522.39**
L53 × L28	8.52	-11.18	-16.26*	5.97	-0.28	-1.24	35.93**	-119.00	-421.09**	-66.28**	-5.26	-303.91**
L53 × Sd7	3.73	3.89	35.95**	9.28	21.60**	9.61	8.52**	84.37	403.41**	120.90**	207.05**	176.52**
Sk5 × L18	20.81**	15.77	27.68**	19.28**	11.75*	24.07**	456.77**	417.21**	591.25**	614.31**	398.80**	496.23**
Sk5 × L28	1.78	4.65	10.57	12.09*	20.39**	19.91**	72.15**	207.03*	460.21**	204.34**	327.70**	444.16**
Sk5 × Sd7	-10.26	-11.01	-35.42**	-19.47**	-12.43*	-24.84**	-249.48**	-322.04**	-684.67**	-418.60**	-416.56**	-497.61**
L18 × L28	-12.14*	-9.07	-13.05*	-31.08**	-25.21**	-26.05**	-326.89**	-218.57*	-474.41**	-529.31**	-457.29**	-445.55**
L18 × Sd7	14.14*	8.84	6.46	17.80*	8.26	6.65	193.95**	100.23	140.92	237.66**	106.65	64.59
L28 × Sd7	2.90	9.31	22.18**	15.84*	3.40	17.44**	169.42**	252.00**	402.77**	358.06**	233.64**	445.98**
SE $S_{ij} - S_{ik}$	8.61	13.13	10.25	8.83	9.17	25.04	1.22	111.81	140.98	1.22	93.18	83.43
SE $S_{ij} - S_{kl}$	7.03	10.72	8.37	7.21	7.48	20.45	1.00	91.29	115.11	1.00	76.08	68.12

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.

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, e. g., Al-Naggar *et al.* [18, 22, 44].

For grain quality traits (GPC, GOC and GSC), the values of SCA effects were mostly non-significant and small in magnitude. However, the highest positive SCA effects were shown by L18 x L28 under E2, E3 and E5, L53 x Sd7 under E1, E5 and E6, L20 x Sd7 under E2 and E3 and L20 x SK5 under E4 and E6 for GPC, L20 x Sk5 under all environments except E2, L20 x L28 under E2, Sk5 x Sd7 under E2, E4 and E5, L18 x L28 under E1 and E3 and L53 x L28 under E6 for GOC and Sk5 x L18 under E1 through E5, L28 x Sd6 under E2, L20 x L18 under E2 and E6 and L53 x Sk5 under E5 and E6 for GSC trait.

In this study, it could be concluded that the F_1 cross Sk5 x L18 is superior to other crosses in SCA effects for GYPH, PYPH, OYPH, GYPH under stressed and non-stressed environments, *i.e.* all yield traits. 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.

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 ($\bar{\boldsymbol{x}}_c$) and their SCA effects and heterobeltiosis and between SCA effects and heterobeltiosis, for studied characters are presented in Table (9). Out of 8 studied traits, significant ($P \leq 0.05$ or 0.01) correlations between $\bar{\boldsymbol{x}}_p$ and GCA effects existed for 6 traits, namely GPC (except E5), GYPP, GYPH, PYPH, OYPH (except E4 and E5) and SYPH. Moreover, significant correlations existed in some environments for GOC under E3 and E6. Such significant correlations between **(** $\bar{x}_p$**)** and their GCA effects in this investigation representing 72.9% of all studied cases (35 out of 48 cases) suggest the validity of this concept in the majority of studied traits, especially yield traits and GPC under most studied environments. These results indicate that the best performing inbred lines are also the best general combiners and *vice versa* for the previously mentioned traits and therefore, the mean performance of a given parent for these traits under stressed and non-stressed environments is an indication of its general combining ability. This conclusion was previously reported by Meseka *et al* [55] and Al-Naggar *et al*. [43] in maize and Le Gouis *et al*., [56], Yildirim *et al*. [57] and Al-Naggar *et al.* [58] in wheat.

The traits which did not show any correlation between $\bar{\boldsymbol{x}}_p$ and GCA effects under all the six environments were GSC. In general, the environment E6 (the most stressed environment) showed significant correlations between $\bar{\boldsymbol{x}}_p$ and GCA effects for most studied traits (7 out 8 characters). The strongest correlation (highest in magnitude) between $\bar{\boldsymbol{x}}_p$ and GCA effects was shown by SYPH followed by GYPH and GYPP traits, yield traits.

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 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
	Grain protein content						**Grain oil content**					
$\bar{x}_p$ *vs.* GCA	0.89*	0.71*	0.70*	0.59*	0.49	0.77*	0.23	0.17	0.93**	0.17	0.15	0.70*
$\bar{x}_c$ *vs.* SCA	0.33	0.66**	0.57*	0.07	0.04	0.75**	0.82**	0.28	0.39	0.36	0.59*	0.69**
$\bar{x}_c$ *vs.* H.	0.52*	0.32	0.34	0.72*	0.35	0.31	0.65**	0.91**	0.45	0.80**	0.78**	0.62**
SCA *vs.* H	0.37	0.52*	0.61**	-0.01	0.04	0.48	0.66**	0.27	0.67**	0.54*	0.45	0.68**
	Grain starch content (GSC)						**Grain yield per plant**					
$\bar{x}_p$ *vs.* GCA	-0.27	0.18	0.55	0.25	-0.47	0.02	0.91*	0.94**	0.97**	0.76*	0.82*	0.86*
$\bar{x}_c$ *vs.* SCA	0.65**	0.57*	0.32	0.13	0.28	0.71**	0.67**	0.68**	0.71**	0.66**	0.64**	0.70**
$\bar{x}_c$ *vs.* H.	0.85**	0.35	0.56*	0.73**	0.88**	0.50*	-0.36	-0.16	-0.2	-0.04	-0.07	-0.2
SCA *vs.* H	0.33	0.27	0.24	0.13	0.24	0.34	0.27	0.42	0.32	0.36	0.37	0.34
	Grain yield per hectare						**Protein yield per hectare**					
$\bar{x}_p$ *vs.* GCA	0.88*	0.97**	0.97**	0.76*	0.81*	0.89**	0.77*	0.90**	0.93**	0.71*	0.79*	0.78*
$\bar{x}_c$ *vs.* SCA	0.68**	0.67**	0.71**	0.65**	0.63**	0.70**	0.83**	0.67**	0.82**	0.66**	0.38	0.73**
$\bar{x}_c$ *vs.* H.	-0.28	-0.13	-0.3	-0.07	-0.06	-0.18	-0.18	-0.21	-0.27	-0.08	0.06	-0.12
SCA *vs.* H	0.3	0.46	0.29	0.39	0.32	0.34	0.21	0.39	0.12	0.34	0.13	0.28
	Oil yield per hectare						**Starch yield per hectare**					
$\bar{x}_p$ *vs.* GCA	0.72*	0.87*	0.92**	0.51	0.39	0.76*	0.89**	0.98**	0.97**	0.78*	0.85*	0.91**
$\bar{x}_c$ *vs.* SCA	0.53*	0.53*	0.58*	0.41	0.54*	0.60**	0.69**	0.69**	0.70**	0.68**	0.63**	0.70**
$\bar{x}_c$ *vs.* H.	-0.25	-0.12	-0.12	-0.12	-0.07	-0.2	-0.27	-0.12	-0.32	-0.05	-0.07	-0.19
SCA *vs.* H	0.33	0.41	0.28	0.29	0.18	0.3	0.3	0.46	0.29	0.4	0.34	0.34

***and ** indicate significant at 0.05 and 0.01 probability levels, respectively.**

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 8 studied traits, significant (P≤ 0.05 or 0.01) correlations existed for 5 traits under all environments, namely GYPP, GYPH, PYPH (except E5), OYPH (except E4) and SYPH. Moreover, significant correlations existed in some environments for three traits, namely GPC under E2, E3 and E6, GOC under E1, E5 and E6 and GSC under E1, E2 and E6. Such significant correlations between ($\bar{x}_c$) and SCA effects in this investigation representing 77.1% of all studied cases (37 out of 48 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 these traits under the respective environment, especially the most stressed one, is an indication of its specific combining ability. This conclusion was previously reported by Srdic *et al*. [59] and Al-Naggar *et al*. [43]. 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*. [56] and Yildirim *et al*. [57] (2007) under stress conditions.

Significant correlations between mean performance of crosses ($\bar{x}_c$) and heterobeltiosis (Table 9) were exhibited only in 14 out of 48 cases (29.2%), namely GOC (except E3), and GSC (except E2), GPC under E1 and E4. 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 GYPP, GYPH, PYPH, OYPH and SYPH; *i.e.* yield traits 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 these cases.

Significant correlations between SCA effects and heterobeltiosis (Table 9) were exhibited only in 6 out of 48 cases (12.5%), namely, GOC under E1, E3, E4 and E6 and GPC under E2 and E3. Only for these two traits under the corresponding environments, the useful heterosis of a cross could be used as an indicator of its SCA effects. The traits GSC, GYPP, GYPH, PYPH, OYPH and SYPH; *i.e.* yield traits and grain starch content 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.

Summarizing the above mentioned results, it cloud be concluded that in this investigation under stressed and non-stressed environments, the mean performance for studied yield traits of a given parent could be considered an indication of its general combining ability and the mean performance for same traits of a given cross could be considered an indication of its specific combining ability. But the mean performance for studied yield traits of a given cross could not be considered an indication of its heterobeltiosis, and for studied yield and GSC traits, the heterobeltiosis of a given cross could not be used as indication of its SCA effects.

Conclusion

Results concluded that under stressed and non-stressed environments, selection methods in segregating generations of maize hybrids would be the best choice for improving grain quality traits; *i.e.* GPC, GOC and GSC, but heterosis breeding is the best choice for improving yield traits, *i.e.* GYPP, GYPH, PYPH, OYPH and SYPH traits. For all yield traits, the best inbred in GCA effects was L53 in all environments followed by L20 and Sk5. For grain quality traits, the largest values of GCA effects were exhibited by L18 for GPC, Sd7 and L18 for GOC and L20, L53 and Sk5 for GSC trait under some environments. The F_1 cross Sk5 x L18 is superior to other crosses in SCA effects for GYPH, PYPH, OYPH, GYPH, *i.e.* all yield traits under stressed and non-stressed environments. 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. In this investigation under stressed and non-stressed environments, the mean performance for studied yield traits of a given parent could be considered an indication of its general combining ability and the mean performance for same traits of a given cross could be considered an indication of its specific combining ability. But the mean performance for studied yield traits of a given cross could not be considered an indication of its heterobeltiosis, and for studied yield and GSC traits, the heterobeltiosis of a given cross could not be used as indication of its SCA effects.

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