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Heterosis and Combining Ability of Maize (*Zea mays* L.) Grain Protein, Oil and Starch Content and Yield as Affected by Water Stress

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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

Information on heterosis and combining ability of available germplasm would help maize breeder in identifying proper genotypes and breeding procedures for improving tolerant varieties to water stress. The objective of this investigation was to assess the performance, heterobeltiosis, general combining ability (GCA) and specific combining ability (SCA) for grain quality and yield traits among inbred lines of maize under water stress (WS) and well watering (WW) conditions. Six inbred lines of maize differing in drought tolerance and their diallel F_1 crosses were evaluated in 2013 and 2014 seasons, in two separate experiments; one under WW and one under WS. In most cases, heterobeltiosis under WS was higher than WW. The GCA (additive) variance was higher than SCA (non-additive) variance for grain protein content (GPC) and/or grain oil content (GOC) and grain starch content (GSC) under WS, but the opposite was true for the rest of traits. Under WS, there were significant correlations between inbred mean and GCA effects for GPC, grain yield/plant (GYPP), grain yield/ha (GYPH), protein yield/ha (PYPH) and starch yield/ha (SYPH),

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between hybrid mean and SCA effects for GYPP, GYPH, PYPH and SYPH, between hybrid mean and heterobeltiosis for GPC, GOC and GSC and between SCA effects and heterobeltiosis for GOC only. The breeding method of choice is selection for improving GPC, GOC and GSC, and heterosis for GYPP, GYPH, PYPH, OYPH and SYPH. Mean performance for yield traits of a given inbred and hybrid could be considered as an indication of its GCA and SCA effects, respectively.

Keywords: Heterobeltiosis; grain chemical composition; gene action; water stress at flowering.

1. INTRODUCTION

The development of maize (*Zea mays* L.) cultivars with high and stable yields under drought is an important priority as access to drought-adapted cultivars may be the only affordable alternative to many small-scale farmers [1]. Maize is considered more susceptible than most other cereals to water stresses at flowering, when yield losses can be severe through barrenness or reductions in kernels per ear [2,3]. Egypt produces about 5.8 million tons of maize grain per year cultivated in approximately 0.75 million hectares [4]. Maize is used primarily for animal feed, especially for poultry in Egypt and ranks second to wheat in land under cereal cultivation. Maize is a summer season crop in Egypt and depends on flood irrigation from River Nile and its branches. However, the amount of water available for irrigation is reducing, especially at the ends of canals, due to expanding maize cultivation into the deserts and competition with other crops; especially rice. In order to stabilize maize production in Egypt, there is need to develop maize hybrids with drought tolerance.

Heterosis is the genetic expression of the superiority of a hybrid in relation to its parents [5]. The term heterobeltiosis has been suggested to describe the increased performance of the hybrid over the better parent [6]. Since inbreds are more sensitive to environmental differences, some traits have been found to be more variable among inbreds than among hybrids [7]. Similarly, Betran et al. [8] reported extremely high expression of heterosis in maize under stress, especially under severe water stress because of the poor performance of inbred lines under these conditions.

Combining ability has been defined as the performance of a line in hybrid combinations [9]. Since the final evaluation of inbred lines can be best determined by hybrid performance, it plays an important role in selecting superior parents for hybrid combinations and in studying the nature of genetic variation [10-12]. In general, diallel analysis has been used primarily to estimate general combining ability (GCA) effects and specific combining ability (SCA) effects from crosses of fixed lines [10,13].

Grain quality is an important objective in maize (*Zea mays* L.) breeding [14-18]. In maize grain, a typical hybrid cultivar contains approximately 4% oil, 9% protein, 73% starch, and 14% other constituents; mostly fiber [16]. 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 [19]. The protein content in maize is a quantitative trait [20]. Additive and non-additive effects are important and dominance occurs essentially for the reduction of this trait [21]. Significant environment and genotype × environment interaction effects are in general detected for protein content [16,21]. Among the environment factors that influence protein content, availability of water is the most important [22]. The oil content in maize grains was reported as a quantitative trait [23]. The additive genetic variance seems to be the main component in the control of this trait [23]. However, non-additive gene effects including dominance and epistasis had the predominant role in the inheritance of grain oil content in maize [24-26]. Knowledge about the heterosis and combining ability of maize kernel composition in diverse environments is essential for plant breeding programs. The objectives of the present study were to: (i) assess performance, heterosis and combining ability among maize inbreeds under optimum and drought conditions for grain protein, oil and starch content and yield traits, (ii) identify suitable parents and hybrids for further breeding studies on improving maize drought tolerance and (iii) analyze interrelationships among inbred and hybrid *per se* performance, general and specific combining ability and heterosis for grain quality traits.

2. MATERIALS AND METHODS

This study was carried out at the Agricultural Experiment and Research Station of the Faculty of Agriculture, Cairo University, Giza, Egypt

(30° 02' N latitude and 31° 13' E longitude with an altitude of 22.50 meters above sea level), in 2012, 2013 and 2014 seasons.

2.1 Plant Material

Based on the results of previous experiments [27], 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 water stress, 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).

2.3 Evaluation of Parents and F_1's

Two field experiments were carried out in each season of 2013 and 2014 at the Agricultural Experiment and Research Station of the Faculty of Agriculture, Cairo University, and Giza. Each experiment included 21 genotypes (15 F_1 crosses and their 6 parents). The first experiment was done under well irrigation by giving all required irrigations, but the second experiment was done under water stress at flowering stage by skipping the fourth and fifth irrigations. A randomized complete blocks design with three replications was used in each experiment. Each experimental plot consisted of one ridge of 4 m long and 0.7 m width, *i.e.* the experimental plot area was 2.8 m^2. Seeds were sown in hills at 20 cm apart, thereafter (before the 1st irrigation) were thinned to one plant/hill to achieve a plant density of 76,400 plants/ha, respectively. Sowing date of the two experiments was on May 5 and May 8 in 2013 and 2014 seasons, respectively. The soil of the experimental site was clayey loam. All other agricultural practices were followed according to the recommendations of ARC, Egypt. The analysis of the experimental soil, as an average of the two growing seasons 2013 and 2014, indicated that the soil is clay loam (4.00% coarse sand, 30.90% fine sand, 31.20% silt, and 33.90% clay), the pH (paste extract) is 7.73, the EC is 1.91 dSm-1, soil bulk density is 1.2 g cm-3, calcium carbonate is 3.47%, organic matter is 2.09%, the available nutrient in mg kg-1are Nitrogen (34.20), Phosphorous (8.86), Potassium (242), hot water extractable B (0.49), DTPA - extractable Zn (0.52), DTPA - extractable Mn (0.75) and DTPA - extractable Fe (3.17). Meteorological variables in the 2013 and 2014 growing seasons of maize were obtained from Agro-meteorological Station at Giza, Egypt. For May, June, July and August, mean temperature was 27.87, 29.49, 28.47 and 30.33℃, maximum temperature was 35.7, 35.97, 34.93 and 37.07℃ and relative humidity was 47.0, 53.0, 60.33 and 60.67% respectively, in 2013 season. In 2014 season, mean temperature was 26.1, 28.5, 29.1 and 29.9℃, maximum temperature was 38.8, 35.2, 35.6 and 36.4℃ and relative humidity was 32.8, 35.2, 35.6 and 36.4%, respectively. Precipitation was nil in all months of maize growing season for both seasons. Sibbing was carried out in each entry for the purpose of determining the grain contents of protein, oil and starch.

2.4 Data Recorded

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. 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. Grain yield per hectare (GYPH) in ton, by adjusting grain yield/plot to grain yield per hectare. Protein yield per hectare (PYPH), by multiplying grain protein content by grain yield/ha in kg. Oil yield per hectare (OYPH), by multiplying grain oil content by grain yield/ha in kg. Starch yield per hectare (SYPH)**,** by multiplying **g**rain starch content by grain yield/ha in kg.

2.5 Biometrical and Genetic Analyses

Analysis of variance of the RCBD was performed on the basis of individual plot observation using GENSTAT 10th addition windows software. Combined analysis of variance across the two seasons was also performed if the homogeneity test was non-significant. Least significant differences (LSD) values were calculated to test the significance of differences between means according to Steel et al. [28]. Diallel crosses were analyzed to obtain general (GCA) and specific

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

Inbred line	Origin	Institution-country	Prolificacy	Productivity under water stress	Leaf Angle
L20-Y	SC 30N11	Pion. Int. Co.	Prolific	High	Erect
L53-W	SC 30K8	Pion. Int. Co.	Prolific	High	Erect
Sk 5-W	Teplacinco - 5	ARC-Egypt	Prolific	High	Erect
L18-Y	SC 30N11	Pion. Int. Co.	Prolific	Low	Wide
L28-Y	Pop 59	ARC-Thailand	Non-Prolific	Low	Wide
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, A.E.D. = American Early Dent, an open pollinated variety, W = White grains and Y = Yellow grains

(SCA) combining ability variances and effects for studied traits according to Griffing [29] 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. [28] 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. [28]. 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 8 traits of 21 maize genotypes (6 inbreds + 15 F_1's) under two environments (WW and WS); across two seasons is presented in Table 2. Mean squares due to parents and crosses under both environments were very significant for all studied traits, indicating the significance of differences among studied parents and among F_1 diallel crosses in all cases.

Mean squares due to parents *vs.* F_1 crosses were very significant for all studied traits under both environments, except for GSC under WS, suggesting the presence of significant average heterosis for most studied cases. Mean squares due to the interactions parents × years (P × Y) and crosses × years (F_1 × Y) were significant for all studied traits under both environments, except GYPH under WW for P × Y and F_1 × Y, GSC under WW for P × Y, PYPH under WW for P × Y and WW for F_1 × Y, OYPH under WW for P × Y and SYPH under WW for P × Y and F_1 × Y. Mean squares due to parents *vs.* crosses × years were significant in 8 out of 16 cases, indicating that heterosis differ from season to season in these cases (Table 4). It is observed from Table 2 that the largest contributor to total variance was parents vs. F_1's (average heterosis) variance for 12 cases, followed by F_1 crosses (4 cases).

3.2 Mean Performance

Means of each inbred and cross for studied grain quality and yield traits under contrasting irrigation regimes, *i.e.* well watering and water stress at flowering across two years are presented in Table 3. The highest mean grain yield per plant and per hectare, protein yield, oil yield and starch yield per hectare was recorded for the inbred line L53 followed by L20 and Sk5 under both irrigation regimes, while the lowest ones were exhibited by Sd7, L28 and L18. The first three inbreds are high yielding under both water stress and non-stress conditions. The second three inbreds are low-yielders under both irrigation regimes. The present results assure the diversity of the parental inbreds in tolerance to drought at silking stage and therefore are valid for diallel analysis. It is observed that the inbred L18 showed the highest grain protein content under both water stress and non-stress conditions. Moreover, the highest grain oil content and starch content were shown by the parental inbreds L28 and L20, respectively under water stress conditions.

Results in Table 3 indicated the existence of cross × irrigation regime interaction in most studied F_1 crosses for all studied traits. This conclusion is in agreement with that reported by Al-Naggar et al. [30]. The rank of crosses for studied traits under well watering was changed from that under water stress conditions. The highest mean grain yield per hectare under water stress was shown by the F_1 cross L20 × L53 (11.23 ton/ha) followed by L20 × L28 (7.79 ton/ha) and L53 × Sd7 (8.96 ton/ha).

Most of highest yielding crosses showed low percentages of grain protein and/or oil contents. However, it was observed that the cross L53 × Sd7 showed the highest grain oil content, under water stress as well as well watering and was one of the three highest yielding crosses. Several investigators [20,30,31] reported a negative correlation between grain yield and either grain protein content or grain oil content, but our results and Al-Naggar et al. [16-18,30] indicated that it is possible to break such linkage between high yield and low grain protein or oil content genes of maize and obtain genotypes of high grain yield and high oil or protein content simultaneously. On the contrary, the lowest grain yield/ha under WS was exhibited by the cross L18 × L28 (5.57 ton/ha) followed by Sk5 × Sd7 (6.86 ton/ha), but these two crosses showed the highest GPC (12.32%) and GOC (4.75%) under WS, respectively.

3.3 Heterobeltiosis

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 two environments (WW and WS) across 2011 and 2012 years are presented in Table 4. Favorable heterobeltiosis in the studied crosses was considered positive for all studied traits under both irrigation regimes. It is observed that the heterobeltiosis for all studied grain quality and yield traits was more pronounced under water stress than under well watering conditions. Similarly, Betran et al. [8] reported extremely high expression of heterosis in maize under stress, especially under severe water stress because of the poor performance of inbred lines under these conditions. This was also observed under high density stress in maize [32] and under low-N stress in wheat [33-36]. In general, the highest average significant and positive (favorable) heterobeltiosis was shown by oil yield per feddan (186.25 and 302.71%) under WW and WS, respectively followed by GYPP, SYPH, GYPH and SYPH traits. On the contrary, the lowest average significant heterobeltiosis was shown by grain starch content (-0.09 and -0.48%) under WW and WS, respectively. The traits GPC, GSC under both environments, showed on average unfavorable heterobeltiosis.

The traits GYPP, GYPH, PYPH, OYPH and SYPH, showed the highest maximum heterobeltiosis (736.00, 813.39, 710.95, 876.66 and 816.74%, respectively) under WS environment. The reason for getting the highest average heterobeltiosis estimates for such traits under WS environment could be attributed to the large reduction in grain yield of the parental inbreds compared to that of F_1 crosses due to negative effects of water stress at flowering stage in this environment. 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 [11]. 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 WW environment (non-stressed) showed the lowest average favorable heterobeltiosis for all yield traits, *viz.* GYPP (49.55%), GYPH (46.71%), OYPH (52.24%), PYPH (29.38%) and SYPH (47.32%) (Table 4).

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 water stress (WS) and well watering (WW) conditions

SOV	df	%Sum of squares							
		WW	WS	WW	WS	WW	WS	WW	WS
		GPC		GOC		GSC		GYPP	
P	5	14.22**	12.88**	18.01**	8.11**	7.93**	10.32**	5.50**	3.71**
F_1	14	10.27**	16.08**	19.84**	30.07**	36.19**	48.73**	9.66**	17.83**
P *vs* F_1	1	42.39**	28.04**	7.37**	13.16**	1.54*	0.00	75.18**	70.56**
P × Y	5	2.05*	3.30**	3.33**	3.81**	2.67	8.91**	0.37**	0.18*
F_1 × Y	14	2.31*	6.12**	17.06**	5.70*	15.69**	9.88**	1.91**	1.95**
P *vs* F_1 × Y	1	9.14**	6.04**	6.62**	0.43	0.26	0.72**	0.01	0.17**
		GYPH		PYPH		OYPH		SYPH	
P	5	4.98**	4.39**	5.60**	4.81**	3.86**	3.20**	5.01**	4.43**
F_1	14	13.70**	23.44**	16.94**	25.66**	17.45**	26.45**	12.72**	23.15**
P *vs* F_1	1	75.76**	67.23**	71.64**	63.13**	73.06**	64.78**	76.43**	67.28**
P × Y	5	0.12	1.11**	0.25	1.34**	0.10	0.78**	0.11	1.15**
F_1 × Y	14	0.42	1.43**	0.38	1.12**	1.83**	1.39**	0.41	1.50**
P *vs* F_1 × Y	1	0.01	0.06*	0.38**	0.02	0.05	0.09	0.01	0.06*

*WW= Well watering, WS= Water stress, GPC= Grain protein content, GOC= Grain oil content, GSC= Grain starch content, GYPP= Grain yield/plant, GYPH= Grain yield/ha, PYPH= Protein yield/ha, OYPH= Oil yield/ha, SYPH= Starch yield/ha, * and ** indicate significance at 0.05 and 0.01 probability levels, respectively*

Table 3. Means of each inbred parent (P) and cross (F_1) for studied grain quality and yield traits under well watering (WW) and water stress (WS) across two years

Genotypes	WW	WS	WW	WS	WW	WS	WW	WS
	GPC%		GOC%		GSC%		GYPP (g)	
				Inbreds				
L20	10.97	11.88	4.23	3.67	71.0	72.1	106.6	57.7
L53	11.82	11.18	4.15	4.15	70.5	71.0	132.1	85.5
Sk5	12.80	13.08	3.48	3.57	71.3	70.6	77.6	46.9
L18	13.52	13.12	4.03	3.88	70.4	71.1	46.7	34.8
L28	12.88	12.63	4.55	4.15	69.9	70.5	44.4	21.2
Sd7	12.57	12.38	4.40	4.03	70.8	71.2	55.1	13.2
Aver. (P)	12.43	12.38	4.14	3.91	70.6	71.1	77.1	43.2
				F_1 crosses				
L20 × L53	9.73	10.37	4.38	4.07	71.7	71.6	277.4	242.7
L20 ×SK5	10.55	10.67	4.80	4.25	70.1	71.5	221.7	166.8
L20 × L18	10.95	10.82	4.05	3.72	71.6	73.0	219.2	182.1
L20 × L28	10.63	11.07	4.38	4.53	71.2	70.7	232.8	171.7
L20 × Sd7	10.33	11.00	4.50	4.12	71.0	70.8	226.7	179.9
L 53 × Sk5	10.58	11.05	4.12	4.42	70.8	70.5	245.5	203.0
L53 × L18	10.57	11.60	4.27	4.40	70.8	70.7	197.5	138.9
L53 × L28	10.63	11.45	4.53	4.32	70.8	70.9	237.5	171.6
L53 × Sd7	10.50	11.32	4.57	4.47	70.9	70.9	241.0	197.3
Sk5 × L18	11.35	11.58	4.10	3.85	71.1	72.0	234.8	183.7
Sk5 × L28	11.42	11.23	4.40	4.17	70.4	71.2	223.2	177.2
Sk5 × Sd7	10.83	11.03	4.68	4.75	70.0	69.8	207.2	147.7
L18 × L28	11.57	12.32	4.45	4.17	70.7	70.7	171.1	124.0
L18 × Sd7	10.85	11.53	4.42	4.25	71.1	70.7	213.3	154.2
L28 × Sd7	10.67	10.85	4.32	4.28	70.8	71.3	227.6	177.2
Aver. (F_1)	10.74	11.19	4.40	4.25	70.9	71.1	225.1	174.5
LSD05	0.32	0.33	0.15	0.12	0.3	0.4	13.5	10.8
	GYPH (kg)		PYPH (kg)		OYPH (kg)		SYPH (kg)	
				Inbreds				
L20	4.95	2.39	542	285	210	88	3513	1728

Genotypes	WW	WS	WW	WS	WW	WS	WW	WS
L53	6.13	3.52	735	391	252	146	4319	2501
Sk5	3.60	2.17	462	283	126	77	2566	1534
L18	2.16	1.49	295	195	87	58	1523	1057
L28	2.06	0.87	265	108	93	36	1440	618
Sd7	2.01	0.63	257	78	87	26	1423	452
Aver. (P)	3.49	1.85	426	223	143	72	2464	1315
					F_1 crosses			
L20 × L53	12.88	11.23	1254	1166	564	456	9230	8043
L20 ×SK5	10.22	7.75	1082	832	492	333	7149	5533
L20 × L18	10.15	8.33	1111	902	412	310	7273	6076
L20 × L28	10.81	7.97	1149	882	474	362	7689	5633
L20 × Sd7	10.53	8.31	1088	913	473	342	7470	5882
L 53 × Sk5	11.40	9.31	1206	1029	469	411	8072	6561
L53 × L18	8.99	6.45	950	749	384	284	6363	4559
L53 × L28	11.03	7.95	1173	911	500	343	7804	5635
L53 × Sd7	11.19	8.96	1175	1013	511	401	7928	6351
Sk5 × L18	10.90	8.43	1237	977	447	324	7755	6068
Sk5 × L28	10.34	8.17	1180	919	455	341	7281	5815
Sk5 × Sd7	9.58	6.86	1038	758	448	325	6705	4787
L18 × L28	7.91	5.76	915	709	352	240	5592	4068
L18 × Sd7	9.88	7.16	1072	827	436	304	7022	5059
L28 × Sd7	10.49	7.97	1116	874	463	348	7405	5667
Aver. (F_1)	10.42	8.04	1116	897	459	342	7383	5716
LSD05	0.47	0.43	48	45	19	12	258	207

WW= Well watering, WS= Water stress, GPC= Grain protein content, GOC= Grain oil content, GSC= Grain starch content, GYPP= Grain yield/plant, GYPH= Grain yield/ha, PYPH= Protein yield/ha, OYPH= Oil yield/ha, SYPH= Starch yield/ha

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

Parameter	WW	WS	WW	WS	WW	WS	WW	WS
	GPC		**GOC**		**GSC**		**GYPP**	
Aver	-17.11	-12.75	0.97	4.75	-0.09	-0.48	151.79	236.58
Max	-11.38	-6.1	13.39	17.77	0.94	1.29	313.14	736.00
Min	-21.82	-18.47	-5.13	-4.29	-1.75	-2.04	49.55	62.37
No.	0	0	1	2	0	3	15	15
	GYPH		**PYPH**		**OYPH**		**SYPH**	
Aver	162.31	264.08	129.7	234.38	186.25	302.71	162.95	263.41
Max	409.27	813.39	321	710.95	402.92	876.66	414.13	816.74
Min	46.71	82.98	29.38	91.32	52.24	94.28	47.32	82.31
No.	15	15	15	15	15	15	15	15

WW= Well watering, WS= Water stress, GPC= Grain protein content, GOC= Grain oil content, GSC= Grain starch content, GYPP= Grain yield/plant, GYPH= Grain yield/ha, PYPH= Protein yield/ha, OYPH= Oil yield/ha, SYPH= Starch yield/ha

The largest significant favorable heterobeltiosis for GYPP in this study (736.00%) was shown by the cross (L28 × Sd7) under WS environment (Table 5). This cross showed also the highest significant and favorable heterobeltiosis under WS for GYPH (813.39%), PYPH (710.95%), OYPH (876.66%) and SYPH (816.74%). Under the environments WW and WS, the highest estimates of GYPP heterobeltiosis were generally obtained by the cross (L28 × Sd7) (313.14, and 736.00 %), respectively, followed by the crosses L18 × Sd7 and L18 × L28 in the same environments.

The highest heterobeltiosis for PYPH, OYPH and SYPH, GYPH and GYPP under WS as well as WW environments was shown by L28 × Sd7 followed by L18 × Sd7, L18 × L28, Sk5 × L18 and Sk5 × L28. The two crosses L20 × Sk5 and Sk5 × Sd7 showed significant heterobeltiosis for grain oil content under water stress conditions (15.91 and 17.77%, respectively). These crosses could therefore be recommended for plant breeding programs aiming at improving such traits under water stress conditions.

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 the two environments (WW and WS) are presented in Table 6. Mean squares due to GCA and SCA were significant (P≤ 0.01 or 0.05) for GYPP, GYPH, PYPH, OYPH and SYPH under both environments, GPC under WW and GOC under WS, suggesting that both additive and non-additive gene effects play important roles in controlling the inheritance of such traits under respective environments. Moreover, SCA variance (non-additive variance) was significant for GPC and GSC under WS conditions. A similar conclusion was reported by Al-Naggar et al. [16-18,36].

In the present study, the magnitude of GCA mean squares was higher than SCA mean squares (the ratio of GCA/SCA mean squares was higher than unity) for two traits (GPC and GOC) under both environments and GSC under WS, suggesting the existence of a greater portion of additive and additive x additive than non-additive variance in controlling the inheritance of these traits under respective environments. These results are in agreement with those reported by Al-Naggar et al. [16-18].

On the contrary, the magnitude of SCA mean squares was higher than GCA mean squares (the GCA/SCA ratio was less than unity) for the rest of cases, i.e. the five traits GYPP, GYPH, PYPH, OYPH and SYPH under both environments (WW and WS). A similar conclusion was reported by several investigators [16-18,37-38].

Table 5. Estimates of heterobeltiosis (%) for selected quality and yield traits of diallel F_1 crosses under WW and WS conditions during 2013 and 2014 seasons

Cross	WW	WS	WW	WS	WW	WS
	GOC		GYPP		GYPH	
L20 × L53	3.54	-2.01	110.04**	183.73**	110.04**	218.57**
L20 ×SK5	13.39**	15.91**	107.99**	188.90**	106.46**	223.44**
L20 × L18	-4.33	-4.29	105.63**	215.33**	105.16**	247.67**
L20 × L28	-3.66	9.24*	118.39**	197.36**	118.39**	232.91**
L20 × Sd7	2.27	2.07	112.69**	211.62**	112.69**	246.99**
L 53 × Sk5	-0.8	6.43	85.93**	137.29**	85.93**	164.14**
L53 × L18	2.81	6.02	49.55**	62.37**	46.71**	82.98**
L53 × L28	-0.37	4.02	79.87**	100.64**	79.87**	125.69**
L53 × Sd7	3.79	7.63	82.47**	130.68**	82.47**	154.21**
Sk5 × L18	1.65	-0.86	202.76**	291.88**	202.76**	289.17**
Sk5 × L28	-3.3	0.4	187.76**	278.14**	187.19**	277.19**
Sk5 × Sd7	6.44	17.77**	167.16**	215.14**	165.98**	216.59**
L18 × L28	-2.2	0.4	266.42**	256.34**	265.32**	286.98**
L18 × Sd7	0.38	5.37	287.11**	343.24**	356.40**	381.35**
L28 × Sd7	-5.13	3.21	313.14**	736.00**	409.27**	813.39**
	PYPH		OYPH		SYPH	
L20 × L53	70.64**	197.93**	123.35**	211.94**	113.71**	221.62**
L20 ×SK5	99.66**	191.54**	134.74**	279.46**	103.51**	220.19**
L20 × L18	105.10**	216.06**	96.42**	252.42**	107.04**	251.61**
L20 × L28	112.08**	209.22**	126.22**	311.43**	118.91**	226.00**
L20 × Sd7	100.78**	220.11**	126.00**	289.27**	112.67**	240.37**
L 53 × Sk5	64.21**	162.92**	86.02**	181.28**	86.88**	162.37**
L53 × L18	29.38**	91.32**	52.24**	94.28**	47.32**	82.31**
L53 × L28	59.63**	132.80**	98.24**	134.56**	80.68**	125.32**
L53 × Sd7	59.91**	158.95**	102.44**	174.00**	83.56**	153.96**
Sk5 × L18	167.99**	244.70**	255.40**	323.69**	202.27**	295.72**
Sk5 × L28	155.57**	224.26**	261.65**	344.88**	183.79**	279.19**
Sk5 × Sd7	124.72**	167.66**	256.38**	324.60**	161.35**	212.17**
L18 × L28	210.84**	263.54**	276.44**	315.34**	267.23**	284.90**
L18 × Sd7	263.99**	323.74**	402.92**	426.85**	361.15**	378.66**
L28 × Sd7	321.00**	710.95**	395.26**	876.66**	414.13**	816.74**

*WW= Well watering, WS= Water stress, GOC= Grain oil content, GYPP= Grain yield/plant, GYPH= Grain yield/ha, PYPH= Protein yield/ha, OYPH= Oil yield/ha, SYPH= Starch yield/ha, * and ** indicate significance at 0.05 and 0.01 probability levels, respectively*

Table 6. Mean squares due to general (GCA) and specific (SCA) combining ability and their interactions with years (Y) for studied characters under water stress (WS) and well watering (WW) during 2013 and 2014 seasons

Parameter	WW	WS	WW	WS	WW	WS	WW	WS
	GPC		GOC		GSC		GYPP	
GCA	7.48*	4.56	0.64	0.64*	1.24	4.71	12189**	9558**
SCA	5.14**	3.26**	0.42	0.49*	1.33	2.30*	39215**	32244**
GCA/SCA	1.45	1.40	1.52	1.30	0.93	2.05	0.30	0.30
GCA×Y	0.94	1.28	0.28	0.09	1.68*	1.59*	1067**	632**
SCA×Y	1.23*	1.05	0.38	0.20	1.33*	0.98	797.8**	1206**
GCA×Y/SCA×Y	0.76	1.22	0.74	0.43	1.26	1.62	1.30	0.52
	GYPH		PYPH		OYPH		SYPH	
GCA	247.12**	167.1*	37811.00	29653*	9470*	6167*	2476627**	1683194*
SCA	777.60**	639.4**	153673**	146260**	31507**	23372**	7696247**	6364526**
GCA/SCA	0.32	0.26	0.25	0.20	0.30	0.26	0.30	0.26
GCA×Y	21.91**	16.3**	8262**	5519**	1428**	917**	185787**	158568**
SCA×Y	16.85**	21.5**	5116**	6738**	1757**	1342**	138944**	203145**
GCA×Y/SCA×Y	1.30	0.76	1.62	0.82	0.80	0.68	1.30	0.78

*WW= Well watering, WS= Water stress, GPC= Grain protein content, GOC= Grain oil content, GSC= Grain starch content, GYPP= Grain yield/plant, GYPH= Grain yield/ha, PYPH= Protein yield/ha, OYPH= Oil yield/ha, SYPH= Starch yield/ha, * and ** indicate significance at 0.05 and 0.01 probability levels, respectively*

Results in Table 6 indicate that mean squares due to the SCA × year and GCA x year interactions were significant for the six traits GSC, GYPP, GYPH, PYPH, OYPH and SYPH under both environments, except SCA × year for GSC under WS, indicating that additive and non-additive variances for these traits under the respective environments were affected by years. This was not true for GPC and GOC traits under both environments, except SCA × year for GPC under WW, 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 GCA × year for OYPH and GOC under both environments, GYPP, GYPH, PYPH and SYPH in WS environment, and GPC in WW environment, 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 both environments for GSC, in WS for WS and in WW for GYPP, GYPH, PYPH and SYPH (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 of Parental Inbreds

Estimates of general combining ability (GCA) effects of parental inbreds for studied traits under the two environments (WW and WS) across two seasons are presented in Table 7. The best parental inbreds were those showing positive and significant GCA effects for all studied traits. For GYPP and GYPH traits, the best inbred in GCA effects was L53 in both environments (WW and WS) 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 in this study (Table 7) and the worst in *per se* performance for the same traits under the same 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 all yield-related traits, i.e. PYPH, OYPH and SYPH.

For high PYPH, the inbred L53 under both environments, inbred L20 under WW were the best general combiners. The inbreds L53 and L20 were the best general combiners for high OYPH and high SYPH under both environments. Inbred Sk5 was also the best combiner for SYPH under WW and WS environments. For the grain quality traits, *i.e.* GPC, GOC and GSC, the magnitude of GCA effects was small and not significant. However, the largest values of GCA effects were exhibited by L18 under WW and WS for GPC, Sd7 under WW and L18 under WS for GOC and L20 under WW, L53 under WS for

GSC trait. In previous studies [39], the inbred lines L53, L20 and Sd5 were also the best general combiners for GYPP and GYPH under high plant density stress.

3.6 SCA Effects of Diallel Crosses

Estimates of specific combining ability effects (SCA) of F_1 diallel crosses for studied traits under the two environments are presented in Table 8. The best crosses in SCA effects were considered those exhibiting significant positive SCA effects for the 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 water stressed and non-stressed environments. For OYPH, the highest (favorable) positive and significant SCA effects were exhibited by the cross Sk5 × L18 and L20 × L53 under both environments and L20 × L18 under WS environment. For PYPH, the highest positive and significant SCA effects were shown by the cross Sk5 × L18 under both environments followed by L20 × L18, L53 × Sd7, L20 × L53 and L28 × Sd7 under WS environment. The above-mentioned crosses may be recommended for maize breeding programs for the improvement of respective traits under water stress conditions [40-44].

Table 7. Estimates of general combining ability (GCA) effects of parents for studied characters under water stress (WS) and non-stress (WW) across 2013 and 2014 seasons

Parent	WW	WS	WW	WS	WW	WS	WW	WS
	GPC		GOC		GSC		GYPP	
L20	-0.38	-0.15	0.03	-0.04	0.32	0.16	13.05**	13.85**
L53	-0.43	-0.32	-0.03	-0.12	0.15	0.39	18.35**	18.16**
Sk5	0.25	-0.17	0.03	0.03	-0.45	-0.07	1.74	3.54
L18	0.39	0.59	-0.18	-0.16	0.26	-0.04	-22.40**	-21.66**
L28	0.3	-0.14	0.02	0.15	-0.12	-0.13	-8.31**	-9.93**
Sd7	-0.14	0.19	0.12	0.13	-0.15	-0.32	-2.42	-3.96
SE g_i-g_j	0.56	0.55	0.52	0.52	0.6	0.55	3.08	3.61
	GYPH		PYPH		OYPH		SYPH	
L20	1.86**	3.07**	10.62	41.26**	12.68**	16.44**	199.3**	311.8**
L53	2.54**	4.04**	18.47*	49.17**	14.15**	17.01**	260.8**	423.7**
Sk5	0.26	0.63*	16.91	2.89	1.94	5.55	5.2**	57.3**
L18	-3.19**	-4.78**	-31.07**	-52.17**	-27.57**	-35.69**	-305.4**	-476.3**
L28	-1.14**	-2.11**	-5.1	-38.46**	-5.23	-4.78	-119.9**	-218.0**
Sd7	-0.33	-0.85**	-9.84	-2.69	4.03	1.48	-40.1**	-98.4**
SE g_i-g_j	0.42	0.47	13.23	11.2	4.97	5.1	0.71	0.71

*WW= Well watering, WS= Water stress, GPC= Grain protein content, GOC= Grain oil content, GSC= Grain starch content, GYPP= Grain yield/plant, GYPH= Grain yield/ha, PYPH= Protein yield/ha, OYPH= Oil yield/ha, SYPH= Starch yield/ha, * and ** indicate significance at 0.05 and 0.01 probability levels, respectively*

Table 8. Estimates of specific combining ability (SCA) effects for studied characters under water stress (WS) and non-stress (WW) across 2013 and 2014 seasons

Cross	WW	WS	WW	WS	WW	WS	WW	WS
	GPC		GOC		GSC		GYPP	
L20 × L53	-0.2	-0.22	-0.02	-0.17	0.35	0.38	20.88**	16.72**
L20 ×SK5	-0.07	0.49	0.34	0.26	-0.6	-0.83	-18.21**	-19.40**
L20 × L18	0.2	0.17	-0.2	0.06	0.21	-0.23	3.43	13.87**
L20 × L28	-0.03	-0.13	-0.07	-0.06	0.1	0.27	2.93	2.44
L20 × Sd7	0.1	-0.31	-0.05	-0.09	-0.05	0.42	-9.03*	-13.63**
L 53 × Sk5	0.01	-0.29	-0.28	-0.18	0.26	0.09	0.34	2.68
L53 × L18	-0.14	-0.27	0.08	0.13	-0.51	-0.26	-23.56**	-26.55**
L53 × L28	0.02	0.27	0.14	0.18	-0.12	-0.5	2.4	-0.04
L53 × Sd7	0.32	0.51	0.08	0.04	0.02	0.3	-0.06	7.18
Sk5 × L18	-0.04	-0.22	-0.15	-0.3	0.48	1.06	30.40**	26.39**
Sk5 × L28	0.12	0.25	-0.05	0.02	0.12	-0.14	4.67	10.05*
Sk5 × Sd7	-0.03	-0.23	0.14	0.2	-0.25	-0.17	-17.21**	-19.72**
L18 × L28	0.13	-0.05	0.21	0.06	-0.28	0.18	-23.29**	-26.17**

Cross	WW	WS	WW	WS	WW	WS	WW	WS
L18 × Sd7	-0.15	0.36	0.07	0.05	0.1	-0.75	13.02**	12.46*
L28 × Sd7	-0.24	-0.34	-0.23	-0.2	0.18	0.21	13.28**	13.72**
SE Sij – Sik	0.97	0.95	0.89	0.9	1.05	0.95	5.34	6.24
SE Sij – Skl	0.79	0.77	0.73	0.73	0.85	0.77	4.36	5.1
	GYPH		**PYPH**		**OYPH**		**SYPH**	
L20 × L53	2.97**	4.42**	28.52	57.37**	17.23*	14.46*	315.91**	466.46**
L20 ×SK5	-2.73**	-4.22**	-42.12*	-42.94**	-0.73	-7.18	-302.79**	-469.04**
L20 × L18	0.53	2.79**	18.25	55.71**	-4.94	18.99**	59.90**	267.41**
L20 × L28	0.44	0.18	8.15	-3.21	-1.06	-2.82	49.39**	33.19**
L20 × Sd7	-1.22*	-3.18**	-12.81	-66.94**	-10.5	-23.45**	-122.41**	-298.02**
L 53 × Sk5	0.14	0.64	2.41	-5.44	-11.60*	-4.72	23.36**	68.99
L53 × L18	-3.62**	-5.75**	-57.09**	-100.25**	-17.88**	-24.99**	-383.72**	-590.08**
L53 × L28	0.43	-0.42	10.29	7.03	8.52	5.97	35.93**	-66.28**
L53 × Sd7	0.09	1.10*	15.87	41.29**	3.73	9.28	8.52**	120.90**
Sk5 × L18	4.39**	5.67**	64.97**	86.21**	20.81**	19.28**	456.77**	614.31**
Sk5 × L28	0.65	2.08**	14.91	40.24**	1.78	12.09*	72.15**	204.34**
Sk5 × Sd7	-2.45**	-4.18**	-40.17*	-78.08**	-10.26	-19.47**	-249.48**	-418.60**
L18 × L28	-3.20**	-5.41**	-48.29**	-94.74**	-12.14*	-31.08**	-326.89**	-529.31**
L18 × Sd7	1.90**	2.69**	22.17	53.06**	14.14*	17.80*	193.95**	237.66**
L28 × Sd7	1.68**	3.57**	14.94	50.67**	2.9	15.84*	169.42**	358.06**
SE Sij – Sik	0.72	0.82	22.91	19.4	8.61	8.83	1.22	1.22
SE $S_{ij} – S_{kl}$	0.59	0.67	18.71	15.84	7.03	7.21	1	1

*WW= Well watering, WS= Water stress, GPC= Grain protein content, GOC= Grain oil content, GSC= Grain starch content, GYPP= Grain yield/plant, GYPH= Grain yield/ha, PYPH= Protein yield/ha, OYPH= Oil yield/ha, SYPH= Starch yield/ha, * and ** indicate significance at 0.05 and 0.01 probability levels, respectively*

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 L53 × Sd7 under WW and L20 × SK5 under WS for GPC, L20 × Sk5 under both environments, Sk5 × Sd7 under WS, L18 × L28 under WW for GOC and Sk5 × L18 under both environments, 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 grain yield/plant, GYPH, PYPH, OYPH, SYPH under water stressed and non-stressed environments, The crosses L20 × L53, L18 × Sd7 and L28 × 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 drought tolerance at flowering stage. 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. This conclusion was also reported by other investigators [16-18, 34,36].

3.7 Correlations between Performance, GCA, SCA 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. Out of 8 studied traits, significant (P≤ 0.05 or 0.01) correlations between $\bar{x}_p$ and GCA effects existed for 6 traits, namely GPC, GYPP, GYPH, PYPH, OYPH (except WW) and SYPH. Such significant correlations between **($\bar{x}_p$)** and their GCA effects in this investigation representing 68.75% of all studied cases (11 out of 16 cases) suggest the validity of this concept in the majority of studied traits, especially yield traits under both environments. These results indicate that the highest performing inbred lines are also the highest general combiners and *vice versa* for the previously mentioned traits and therefore, the mean performance of a given parent for these traits under the both environments is an indication of its general combining ability. This conclusion was previously reported by several investigators [33,34,36,45, 46] in wheat.

All correlations between $\bar{x}_p$ and GCA effects in the present study were positive for all traits. The traits which did not show any correlation between $\bar{x}_p$ and GCA effects under both environments were GOC and GSC. In general, the non-stressed environment showed higher correlation coefficient between $\bar{x}_{\mathbf{p}}$ and GCA effects for all studied traits. The strongest correlation (highest in magnitude) between $\bar{x}_{\mathbf{p}}$ and GCA effects was shown by GYPP, GPC and SYPH traits under WW (0.91, 0.89 and 0.89, respectively) (Table 9).

For F_1 crosses, rank correlation coefficients calculated between mean performance of F_1 crosses ($\bar{x}_c$) and their SCA effects (Table 6) showed that out of 8 studied traits, significant (P≤ 0.05 or 0.01) correlations existed for 4 traits under both environments, namely GYPP, GYPH, PYPH and SYPH and 3 traits under WW, namely GOC, GSC and OYPH. Such significant correlations between ($\bar{x}_c$) and SCA effects in this investigation representing 68.75% of all studied cases (11 out of 16 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 environments is an indication of its specific combining ability. This conclusion was previously reported by Srdic et al. [47] and Al-Naggar et al. [33,34,36]. In general, the non-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. [45] and Yildirim et al. [46] under stress conditions. The strongest correlation (highest in magnitude) between $\bar{x}_c$ and SCA effects was shown by GOC and GYPH traits under WW (0.82 and 0.83, respectively) (Table 8).

Significant correlations between mean performance of crosses ($\bar{x}_{\mathbf{c}}$) and heterobeltiosis (Table 8) were exhibited only in the three quality traits GPC, GOC and GSC under both environments. For these traits, the mean performance of a cross could be used as an indicator of its useful heterosis under WW and WS environments. The traits GYPP, GYPH, PYPH, OYPH and SYPH did not exhibit any correlation between $\bar{x}_{\mathbf{c}}$ and heterobeltiosis under both environments and therefore, heterobeltiosis of crosses could not be expected from their *per se* performance in such cases. Only one significant correlation was observed between SCA effects and heterobeltiosis was exhibited in one trait, namely GOC under WW and WS environments (Table 8). For this trait, the useful heterosis of a cross could be used as an indicator of its SCA effects under both environments. The rest of studied traits did not exhibit any correlation between SCA effects and heterobeltiosis under both environments and therefore, SCA effects of crosses could not be expected from their heterobeltiosis values in such cases.

Summarizing the above mentioned results, it cloud be concluded from this investigation that under water stressed environment, the mean performance of a given parent could be considered an indication of its general combining ability for six traits (GPC, GYPP, GYPH, PYPH, OYPH and SYPH) and the mean performance of

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 water stress (WS) and non-stress (WW) across 2013 and 2014 seasons

Correlation	WW	WS	WW	WS	WW	WS	WW	WS
	GPC		GOC		GSC		GYPP	
$\bar{x}_p$ *vs.* GCA	0.89*	0.59*	0.23	0.17	-0.27	0.25	0.91*	0.76*
$\bar{x}_c$ *vs.* SCA	0.33	0.07	0.82**	0.36	0.65**	0.13	0.67**	0.66**
$\bar{x}_c$ *vs.* H.	0.52*	0.72*	0.65**	0.80**	0.85**	0.73**	-0.36	-0.04
SCA *vs* .H	0.37	-0.01	0.66**	0.54*	0.33	0.13	0.27	0.36
	GYPH		PYPH		OYPH		SYPH	
$\bar{x}_p$ *vs.* GCA	0.88*	0.76*	0.77*	0.71*	0.72*	0.51	0.89**	0.78*
$\bar{x}_c$ *vs.* SCA	0.68**	0.65**	0.83**	0.66**	0.53*	0.41	0.69**	0.68**
$\bar{x}_c$ *vs.* H.	-0.28	-0.07	-0.18	-0.08	-0.25	-0.12	-0.27	-0.05
SCA *vs.* H	0.30	0.39	0.21	0.34	0.33	0.29	0.30	0.40

*WW= Well watering, WS= Water stress, GPC= Grain protein content, GOC= Grain oil content, GSC= Grain starch content, GYPP= Grain yield/plant, GYPH= Grain yield/ha, PYPH= Protein yield/ha, OYPH= Oil yield/ha, SYPH= Starch yield/ha, * and ** indicate significance at 0.05 and 0.01 probability levels, respectively* a given cross could be considered an indication of its specific combining ability for four traits (GYPP, GYPH, PYPH and SYPH). But the mean performance of a given cross could be considered an indication of its heterobeltiosis for only three traits (GPC, GOC and GSC), and the heterobeltiosis of a given cross could be used as indication of its SCA effects for only one trait (GOC).

4. CONCLUSIONS

The highest mean grain yield, protein yield, oil yield and starch yield was recorded by inbred line L53 followed by L20 and Sk5 and crosses L20 × L53, L20 × L28 and L53 × Sd7 under WS conditions. The inbred L18 showed the highest GPC, inbreds L28 and L20 showed the highest GOC and GSC under WS conditions. It is observed that the heterobeltiosis for all studied grain quality and yield traits was more pronounced under water stress than under well watering conditions. Crosses L28 × Sd7, L18 × Sd7, L18 × L28, Sk5 × L18 and Sk5 × L28 showed significant heterobeltiosis for grain quality and yield traits. The results indicated the existence of a greater portion of additive and additive × additive variance than non-additive variance in controlling the inheritance of GPC, GOC and GSC and therefore selection methods are the best choice for improving such traits under WS. On the contrary, results indicated predominance of non-additive variance for GYPP, GYPH, PYPH, OYPH and SYPH, and therefore heterosis breeding is the best choice for such traits. The best inbreds in cross combinations for grain yield were L53, L120 and Sk5, for high PYPH, SYPH and OYPH were L53, for high GPC was L18, for high GOC were Sd7 and L18 and for high GSC were L20 and L53 under WS. These inbreds and their hybrids could be offered to maize breeding programs for improving grain quality and yield traits under WS conditions. Results also concluded that under WS conditions, the mean performance of a given inbred could be considered an indication of its general combining ability for 6 out of 8 traits (GPC, GYPP, GYPH, PYPH, OYPH and SYPH) and the mean performance of a given cross could be considered an indication of its specific combining ability for 4 traits (GYPP, GYPH, PYPH and SYPH), but the mean performance of a given cross could be considered an indication of its heterobeltiosis for only three traits (GPC, GOC and GSC), and the heterobeltiosis of a given cross could be used as indication of its SCA effects for only one trait (GOC).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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