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Combining Ability for Drought Tolerance in Maize (*Zea mays* L.) Using Line x Tester Analysis

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ABSTRACT

Seven white maize inbred lines (L_2, L_5, L_{10}, L_{20}, L_{46}, L_{51} and L_{52}) derived during an inbreeding program by the Genetics and Plant Breeding Group, Genetics and Cytology Department, National Research Center (NRC) were crossed with five testers (Tri hybrid variety TWC310, T1; double cross variety Taba, T2; drought-tolerant synthetic variety Giza 2, T3; single crosses S.C. 10, T4; a local open-pollinated cultivar Nab El Gamal, T5) to estimate combining ability and type of gene action under normal and drought stress to identify the desirable lines that could be used in a hybrid breeding program for future utilization and studies. The selection index revealed that the best desirable crosses for grain yield and most agronomic characters were the crosses 'TWC310' × L_2, 'TWC310' × L_{20}, 'Taba' × L_{51} and 'Taba' × L_{46} under normal and drought environments. Significance of mean squares of genotypes, crosses, parents, parents vs. crosses, lines, tester, and the line × tester interaction for most studied traits under both conditions indicated that the crosses performed significantly better than their respective parents and therefore heterotic effects were present. Results of general combing ability (GCA) effects indicated that the lines L_2, L_{20}, L_{51}, and L_{52} under normal and drought stress conditions seem to be good general combiners for increasing yield and yield components of hybrids. On the other hand, the testers 'TWC310' and 'Taba' displayed highly significant positive GCA effects, which has interest in breeding programs for developing high grain yield/plant and one or more of the remaining traits under normal and drought environments. The best hybrids 'TWC310' × L_5, 'Taba' ×L_5, 'Nab El Gamal' × L_{52}, and 'SC10' × L_2 showed significantly high positive specific combining ability effects for yield/plant and most yield components under drought. Thus, we recommend further testing of these new inbred lines for use in a crossing program so as to combine major yield components with high yield under drought conditions.

Keywords: drought environment, heterotic effects, hybrid combination, inbred lines, plant parameters
Abbreviations: D, drought stress; **DF**, degree of freedom; **ENV**, environment; **1 faddan** = 4200 m^2; **GCA**, general combining ability; **Gen**, genotypes; **N**, normal conditions; **REP**, replicates; **SC**, single crosses **SCA**, specific combining ability; **T**, tester

INTRODUCTION

Maize (*Zea mays* L.) is one of the most important crops in Egypt. The area cultivated by maize is estimated to be about 1.99 million faddan, equivalent to 8358 km^2 (Ministry of Agriculture and Land Reclamation, Economic Affairs Sector 2010). Maize is used as a food grain for human and animals. Therefore, corn breeders make great and continuous efforts to improve the yielding ability of this crop.

Performance of inbred lines in top crosses with divergent testers of known origin can be used as a practical tool to determine the heterotic patterns among lines under drought and non-stressed conditions. Previous reports in maize under drought condition elucidate the nature of performance in yield and its components (Najeeb *et al.* 2009; Khalily *et al.* 2010). A selection index (SI) for standardized variables across environments was used to select the best lines in hybrid combinations across water regimes.

SI, illustrated by Smith (1936), gives proper weight to each of two or more characters to be considered for selecting better genotypes. When the economic importance of a plant type is considered, the entry with the highest yield may not get the highest score resulting from use of the SI (Robinson *et al.* 1951). A number of studies in maize have been conducted to elucidate the SI which identify traits like ear length, ear diameter, number of kernels/row, number of ears/plant, 100-kernel weight, and number of rows/ear as potential selection criteria in breeding programs aiming at higher yield (Tollenaar *et al.* 2004; Awadalla *et al.* 2007; Najeeb *et al.* 2009; Khalily *et al.* 2010).

The top cross (line × tester) method proved to be efficient in testing inbred lines for general combining ability (GCA) and identifying the more promising inbred lines by making fewer crosses than the possible single cross combinations among the same number of lines (Kempthorne 1957). After selecting the more promising high general combiner lines, it is necessary to identify the particular combination that will produce the highest yield through specific combining ability (SCA). GCA is the relative ability of an individual to transmit genetic superiority to its offspring when crossed with other individuals, although the GCA of a parent signifies the average performance of its progenies in various crosses, compared with progenies of other parents in the same test and the breeding value of a parent is twice its GCA, while SCA is the degree to which the average performance of a specific family (usually full sibs) departs from the average of its parental breeding values (Dictionary of Forestry 2011). The importance of a line × tester hybridization technique in maize breeding has already been emphasized (Menkir *et al.* 2003; Tassawar *et al.* 2007; Rahman *et al.* 2010). The present study was planned to identify maize inbred lines for their GCA and SCA by top crossing with five maize open pollinated varieties: T_1 Tri hybrid variety 'TWC310', T_2 double crosses variety 'Taba', T_3 drought tolerant synthetic variety 'Giza 2', T_4 single crosses 'SC10' and T_5 local open pollinated cultivar 'Nab El Gamal' under normal irrigation and drought stress.

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Table 1 The origin of seven elite maize inbred lines tested in the line x testers mating design.

Lines code	Pedigree	Origin
L_2	Single crosses S.C. 10 (ARC, Giza)	Egypt
L_5	Local open pollinated cultivar Nab El Gamal	Egypt
L_{10}	Single crosses S.C. 10 (ARC, Giza)	Egypt
L_{20}	Local open pollinated cultivar Sabieny	Egypt
L_{46}	Double crosses variety Taba	Egypt
L_{51}	Single crosses S.C. 10 (ARC, Giza)	Egypt
L_{52}	Drought tolerant synthetic variety Giza 2 (ARC, Giza)	Egypt

ARC: Agricultural Research Center

MATERIALS AND METHODS

Seven white corn inbred lines (L_2, L_5, L_{10}, L_{20}, L_{46}, L_{51} and L_{52}) were used as female parents (**Table 1**). These lines were derived from five different corn cultivars during an inbreeding program by the Genetics and Plant Breeding Group, Genetics and Cytology Department, NRC (Khattab 2003). Five testers (T_1-T_5; Tri hybrid variety TWC 310 (T_1), double crosses variety Taba (T_2), drought tolerant synthetic variety Giza 2 (T_3), single cross S.C. 10 (T_4) and the local open pollinated cultivar Nab El Gamal (T_5) were used in line × tester analysis study as common males.

During the June-October 2007 summer crop season, the 7 elite lines were crossed with the above 5 testers in a line × tester fashion at The Shalakan Agriculture Research Station (NRC).

During the June-October 2008 summer crop season, the 35 white top crosses (7 × 5) and their parents were evaluated at Bahada village, Kalubia Governorate, Egypt under normal irrigation (irrigation every 15 days, Experiment 1) and drought stress conditions (irrigation at 30 days intervals, Experiment 2) in a replicated trial using a randomized complete block design (RCBD), with three replications. Each row was 4 m in length and 75 cm wide and plants was spaced at 25 cm with one plant/well. Ten plants were selected at random from each row for studying the following characters: plant height (cm), ear height (cm), number of leaves, leaf area (cm^2), grain yield (g), ear length (cm), ear diameter (cm), number of rows/ear, ear weight (g) and 100-kernel weight (g).

Data for each trait was separately analyzed in each experiment and combined analysis was performed across environments according to Steel and Torrie (1980). SI was performed as illustrated by Smith (1936). The estimates of combining ability effects (GCA and SCA) under normal conditions and drought stress were detected based on the method described by Singh and Chaudhary (1985).

RESULTS AND DISCUSSION

Mean performance

SI, illustrated in plants by Smith (1936), gives proper weight to each of two or more characters to be considered for selecting better genotypes.

The mean performance of the best 10 desirable genotypes based on 10 traits is ranked in **Table 2** under a normal environment. Results revealed that the crosses between 'Taba' with each line (L_{51}, L_{10}, L_{46} and L_5) and the crosses between 'SC10' with each line (L_{51}, L_5, L_{10} and L_2) are considered to be superior hybrids of the 35 top crosses and did not differ statistically from the tester varieties 'SC10' and 'TWC310' under a normal environment.

Mean performance of all studied traits for the best 10 desirable genotypes of all tested entries under a drought environment is shown in **Table 3** and illustrates that the crosses between 'TWC310' with each line (L_{51}, L_2, L_{52}, and L_{20}) were better crosses as were the crosses between 'Nab El Gamal' with each line (L_{20}, L_2, L_{46}, and L_{10}). In addition, the crosses between 'Taba' with each line (L_{51} and L_{46}) showed desirable hybrids for mean performance which performed similarly to tester varieties 'TWC310' and 'Taba' under a drought environment.

The best desirable crosses for grain yield and most agronomic characters were the crosses 'TWC310' × L_2, 'TWC310' × L_{20}, 'Taba' × L_{51}, and 'Taba' × L_{46}, which per-

Table 2 Ranking the 10 desirable genotypes from mean performance of ten characters based on selection index for tester, line and hybrids under normal environment.

Genotype	Plant height	Ear height	Leaf number	Leaf area	Ear length	Ear diameter	Rows/ear	Ear weight	Grain yield	100-kernel weight
Taba X L_{51}	273.0	149.4	15.1	711.8	14.0	3.6	13.7	109.9	47.4	29.5
SC10	260.4	138.7	13.9	516.2	17.7	4.3	11.7	155.2	124.5	28.7
Taba X L_{10}	262.3	136.3	14.0	717.1	17.2	3.8	14.1	188.7	139.5	26.5
SC10 X L_{51}	264.3	149.2	15.3	689.8	15.9	3.4	12.4	111.7	93.0	25.9
SC10 X L_5	248.8	136.2	13.7	539.8	15.5	4.1	11.5	107.8	85.4	30.4
SC10 X L_{10}	242.6	146.3	13.5	659.6	14.5	4.4	13.7	119.3	89.2	29.8
TWC310 X L_2	260.6	163.3	14.2	686.9	11.0	3.3	13.0	77.5	62.3	19.1
TWC310	251.3	159.2	15.2	718.1	15.0	3.6	12.5	151.5	118.8	25.9
SC10 XL_2	253.1	140.9	12.5	553.4	15.8	4.0	12.7	115.9	89.3	25.2
Taba XL_{46}	250.2	137.1	13.3	733.3	14.8	3.5	13.3	133.7	104.7	25.1
LSD 5%	22.3	9.7	1.3	99.4	2.8	0.3	1.4	29.6	23.1	3.4
LSD 1%	29.6	13.6	1.7	131.7	3.7	0.4	2.0	39.3	30.6	4.5

Table 3 Ranking the ten desirable genotypes from mean performance of ten characters based on selection index for tester, line and hybrids under drought environment.

Genotype	Plant height	Ear height	Leaf number	Leaf area	Ear length	Ear diameter	Rows/ear	Ear weight	Grain yield	100-kernel weight
TWC310	248.8	154.1	15.3	700.9	18.5	3.8	14.0	177.5	137.2	25.4
TWC310 X L_{51}	252.6	147.6	13.5	884.9	15.2	3.8	12.8	147.4	116.6	30.5
TWC310 X L_2	245.0	136.5	13.1	782.2	17.2	3.7	14.6	142.0	100.0	25.1
TWC310 X L_{52}	215.5	123.2	11.1	746.3	16.0	3.6	12.5	123.9	94.8	30.4
Taba	252.0	122.4	15.3	819.6	13.0	3.7	12.3	100.7	78.2	27.8
TWC310 X L_{20}	256.3	150.0	14.3	690.7	15.8	3.5	11.4	126.8	73.4	30.5
Nab El Gamal X L_{20}	267.5	150.2	12.7	562.9	15.0	3.9	11.6	89.8	67.1	24.9
Nab El Gamal X L_2	270.8	151.5	13.4	606.9	13.2	3.9	12.1	88.9	69.4	24.5
SC10 X L_{46}	256.4	135.2	14.1	629.4	13.8	3.9	13.1	85.7	67.1	26.3
Taba X L_{51}	262.8	151.9	14.4	639.8	13.6	3.5	12.9	88.4	66.5	24.8
LSD 5%	21.5	9.6	1.3	95.7	2.4	0.2	1.0	26.1	18.9	4.1
LSD 1%	28.5	13.5	1.7	126.8	3.3	0.3	1.4	34.6	25.1	5.4

Table 4 Mean squares for line x tester for various plant traits of 47 corn genotypes under drought stress (D) and normal conditions (N).

Sources of variances	Degrees of freedom	Environments	Plant height	Ear height	Leaf number	Leaf area	Ear length	Ear diameter	Rows/ ear	Ear weight	Grain yield	100-Kernel weight
Rep	2	N	1632.8**	100.0	0.252	2278.0	10.3*	0.04	1.14	185.5	44.4	2.2
		D	76.5	86.5	0.334	1974.0	17.0**	0.14	0.25	11857.8**	891.4*	8.9
Gen	46	N	3820.8**	917.5**	5.47**	32584.7**	11.5**	0.27**	2.85*	2196.1**	1182.4**	36.9**
		D	1742.6**	927.9**	2.36**	22475.7**	10.5**	0.36**	3.05*	1613.2**	1066.4**	33.4**
Cross	34	N	3244.5**	794.2**	3.90**	26244.1**	10.1**	0.33**	2.88*	1684.7**	819.3**	40.7**
		D	1589.0**	950.4**	2.11**	18232.2**	9.3**	0.32**	2.17	1270.5**	866.9**	34.1**
Par	11	N	3831.2**	1057.3**	9.13**	48266.8**	14.3**	0.10*	2.94*	3763.3**	2338.9**	26.1**
		D	2143.9**	926.4**	2.21**	37482.5**	9.4**	0.42**	5.38**	2030.3**	1420.2**	26.7**
Par vs	1	N	23298.0**	3571.7**	18.56**	75661.7**	29.8**	0.29*	1.16	2343.5**	803.2*	28.1*
Cross		D	2548.8**	182.3	12.56**	1679.0	60.4**	1.02**	7.27*	8675.1**	3958.3**	86.6**
L	6	N	1261.8**	542.2**	4.63**	55485.3**	25.6**	0.95**	1.82	3886.6**	1335.7**	27.2**
		D	1552.9**	1852.8**	3.52**	22442.7**	16.0**	1.29**	0.82	1809.8**	1517.5**	22.3**
T	4	N	2419.3**	457.4**	3.46**	19586.0**	15.5**	0.12*	3.19*	2856.9**	1720.3**	46.0**
		D	879.0**	697.7**	0.65	13839.0**	1.7	0.06	1.20	349.8	689.5**	31.8**
L x T	24	N	3877.7**	935.9**	3.74**	20043.5**	5.3	0.21**	3.09*	938.8**	540.1**	43.2**
		D	1716.4**	766.9**	1.99**	17911.7**	8.9**	0.12	2.67*	1289.1**	733.9**	37.4**
Error	92	N	176.4	84.3	0.66	3486.1	2.3	0.06	1.63	259.9	136.1	6.4
		D	189.5	61.5	0.61	3759.9	2.9	0.10	1.63	343.2	203.6	4.4

* = Significant at $P \leq 0.05$; ** = Significant at $P \leq 0.01$

Table 5 Estimates of general combining ability effects (GCA) for lines and testers under normal (N) and drought (D) environments.

Genotypes	Environments	Plant height	Ear height	Leaf number	Leaf area	Ear length	Ear diameter	Rows/ ear	Ear weight	Grain yield	100-Kernel weight
L_2	N	4.5	17.27**	-0.07	-22.15	-0.87	-0.23**	0.15	-7.14	-7.25	0.63
	D	2.15	1.64	-0.42*	61.44**	1.88**	-0.07	0.18	31.25**	14.15**	1.82**
L_5	N	5.80	1.41	-0.23	48.81**	0.04	-0.21**	-0.10	11.51*	8.79*	1.05
	D	-8.57	0.64	-0.48*	111.0**	-0.4	-0.15*	0.07	9.65*	10.99**	0.98
L_{10}	N	-2.11	-6.26**	0.84**	50.57**	-1.21**	-0.19*	-0.33	-5.25	-2.59	0.67
	D	-6.59	-6.80**	0.80**	-27.89	-0.01	-0.21**	-0.30	-4.13	-3.63	-0.44
L_{20}	N	-4.07	-13.9**	-0.09	-54.6**	1.8**	0.50**	0.20	19.76**	17.80**	-0.34
	D	-10.6**	-7.74**	0.25	-28.87	-1.99**	-0.27**	-0.22	-18.67**	-11.5**	-1.29*
L_{46}	N	1.66	1.87	-0.18	-22.43	-0.42	0.33**	-0.24	-4.75	-1.34	1.19*
	D	9.95**	3.65	0.64**	-39.8**	-1.3**	0.02	0.30	-7.66	-8.07*	0.53
L_{51}	N	13.3**	9.96**	0.78**	-5.57	-0.02	-0.10	0.03	-7.04	-3.64	-1.19*
	D	0.48	1.04	-0.20	-34.85*	0.67	0.32**	0.47	-3.46	-0.06	-2.06**
L_{52}	N	-19.1**	-10.5**	-0.70**	5.38	0.86	-0.11	0.29	-7.09	-11.8**	-2.01**
	D	13.14**	7.56**	-0.60**	-41.0**	0.77	0.36**	-0.50	-6.98	-1.93	0.47
TWC310	N	-3.03	-3.3	-0.06	-14.15	-0.16	-0.02	0.02	0.55	4.27	-2.18**
	D	12.95**	3.09	0.22	52.25**	0.86	0.03	0.31	11.72**	11.07**	1.44**
Taba	N	5.29	7.06**	-0.16	-16.15	0.43	-0.03	-0.15	-0.19	-3.39	0.8
	D	-10.5**	-6.84**	-0.63	-19.23	0.71	0.03	-0.48	8.50*	3.84	1.28*
Giza2	N	-9.5**	-7.85**	0.30	-1.82	-0.34	0.08	0.23	1.84	3.94	0.42
	D	-7.5*	-2.78	0.18	-24.26	-0.13	0.08	0.42	2.47	3.08	-0.23
SC10	N	6.29*	3.09	-0.03	-12.71	-0.01	0.02	0.22	-6.60	-8.51*	0.63
	D	10.06**	2.33	-0.17	-2.85	-0.14	-0.03	-0.31	-5.38	-5.91*	-0.26
Nab El	N	0.93	0.99	-0.06	44.83**	0.07	-0.06	-0.32	4.40	3.69	0.33
Gamal	D	-4.93	4.19*	0.40	-5.9	-1.3**	-0.11	0.07	-17.31**	-12.01**	-2.23**
SE(gi) L	N	3.55	2.02	0.20	15.83	0.44	0.08	0.33	4.72	3.68	0.54
	D	3.43	2.37	0.21	15.25	0.40	0.06	0.33	4.16	3.01	0.65
SE(gi-gj) L	N	5.03	2.86	0.28	22.39	0.62	0.11	0.47	6.68	5.21	0.76
	D	4.58	3.35	0.29	21.56	0.55	0.09	0.47	5.89	4.26	0.92
SE(gi) T	N	3.00	1.71	0.17	13.38	0.37	0.07	0.28	3.44	3.11	0.46
	D	2.9	2.00	0.18	12.88	0.33	0.05	0.28	3.52	2.55	0.55
SE(gi-gj) T	N	4.25	2.42	0.24	18.92	0.53	0.10	0.39	5.64	4.40	0.65
	D	4.10	2.83	0.25	18.22	0.47	0.08	0.39	4.98	3.60	0.78

* = Significant at $P \leq 0.05$; ** = Significant at $P \leq 0.01$

formed similarly to the tester varieties 'TWC310' and 'Taba' under normal and drought environments. These results reveal that environments differed remarkably in their effect on the performance of the evaluated genotypes.

The inbred lines L_2, L_{20}, L_{51}, and L_{46} were found to be the best parents and may be exploited in a future breeding program under drought conditions since their overall performance and their possible combinations might be more useful in selecting for drought conditions. A number of studies in maize have been conducted to elucidate the performance of yield and its components which identify traits like ear length, ear diameter, kernel/row, ears/plant, 100-kernel weight and rows/ear as potential selection criteria in breeding program aiming at higher yield (Tollenaar *et al*. 2004; Najeeb *et al*. 2009; Khalily *et al*. 2010).

Analysis of variance

Analysis of variance for studied traits under normal and drought environments is presented in **Table 4**. Highly significant mean squares due to genotypes, crosses and parents were observed for all studied characters under both environments except for mean squares due to crosses for rows/ ear, which were significant under the drought environment. These results show that there was dramatic genetic variation among the investigated entries which could be exploited to select genotypes for drought-prone environments. The significance of mean squares due to parents vs. crosses for most studied traits indicated that the crosses performed significantly better than their respective parents and therefore heterotic effects were present.

Partitioning the sum of squares due to crosses into their components by using line × tester analysis showed that mean squares due to lines and tester were highly significant for all traits under both environments except for rows/ear for lines and leaves number, ear length, ear diameter, rows/ear and ear weight for testers under a normal environment which were not significant.

The significance of mean squares due to lines and testers revealed that variances due to GCA of both lines and testers played an important role in the inheritance of studied traits.

At the same time mean squares due to the line × tester interaction were significant for all studied traits except for ear length under a drought environment and ear diameter under a normal environment, indicating that the SCA variance played an important role in the inheritance of most studied traits. Similar results were reported by El-Morshidy *et al.* (2003), who indicated that genotypes, GCA and SCA mean squares were highly significant for all studied traits in maize.

General combining ability

GCA estimates of the 7 lines and 5 testers under normal and drought environments for the previously mentioned characters are given in **Table 5**. Inbred L_2 exhibited positive and highly significant GCA effects for leaf area, ear length, ear weight, grain yield and 100-kernel weight; also the inbred L_{52} showed positive and highly significant GCA effects for plant height, ear height and ear diameter under the drought environment. However, the inbred L_{20} under a normal environment exhibited positive and highly significant GCA effects for ear length, ear diameter, ear weight and grain yield, as did the inbred L_{51} for plant height, ear height and leaf number.

These results indicate that these lines may be good general combiners for increasing yield and yield components of hybrids. It is of interest that the parental lines L_{20}, L_{10} and L_{52} had significantly negative GCA effects for most studied characters under both environments indicating that crosses involving these inbred lines have favorable genes for developing improved hybrids that are short.

Abdel-Moneam *et al*. (2009) found significant positive GCA effects for all studied traits in maize and concluded that the best combiners were two inbred lines for most studied traits. These results indicate that these inbred lines could be considered as good combiners for improving these traits. Barakat and Osman (2008) indicated that tested inbred lines and testers exhibited significant GCA effects according to the studied traits. The variance magnitude due to GCA for tested and tester lines was higher than that due to SCA for all studied traits, which indicates that additive genetic variance was the major source of variation responsible for the inheritance of these traits.

On the other hand, the tester 'TWC310' displayed high significant positive GCA effects for plant height, leaf area, ear length, ear weight, grain yield and 100-kernel weight, while the tester 'Taba' had the highest positive GCA effects for ear length, ear weight and 100-kernel weight under drought conditions.

These results are of practical interest in breeding prog-

Table 6 Estimates of specific combining ability effects (SCA) for all studied characters in the crosses (Line X Tester) under normal (N) environment.

Hybrids	Plant height	Ear height	Leaf number	Leaf area	Ear length	Ear diameter	Rows/ear	Ear weight	Grain yield	100-Kernel weight
$T_1 \times L_2$	18.7*	13.1**	1.0*	48.8	-4.0**	-0.2	-0.5	-37.3**	-26.7**	-5.9**
$T_2 \times L_2$	-8.6	-1.5	0.4	41.3	1.7	0.1	0.2	17.7	2.1	8.5**
$T_3 \times L_2$	2.0	-6.5	-0.5	21.3	3.6**	0.3	0.6	37.1**	27.1**	0.2
$T_4 \times L_2$	4.1	4.4	0.2	-33.2	-0.1	-0.1	-0.2	-3.0	0.1	-2.9*
$T_5 \times L_2$	-16.1*	-9.6*	-1.1*	-78.2*	-1.2	-0.1	-0.02	-14.5	-0.6	0.1
$T_1 \times L_5$	4.4	6.8	-0.01	-62.7	2.0*	0.1	0.3	13.6	9.7	0.6
$T_2 \times L_5$	-0.4	6.4	-0.3	49.0	-2.8**	-0.2	-0.6	-46.0**	-35.4**	-2.8*
$T_3 \times L_5$	0.7	-4.8	0.7	75.3*	-0.3	0.03	0.7	-6.4	-4.4	-2.3
$T_4 \times L_5$	-19.8*	-6.0	-1.2*	-29.7	0.003	-0.2	-1.6*	-12.6	-5.0	6.0**
$T_5 \times L_5$	15.2	-2.3	0.9	-32.9	1.1	0.3	1.2	51.3**	35.0**	-1.5
$T_1 \times L_{10}$	4.8	3.5	0.2	-9.7	-0.03	-0.1	-1.0	-7.5	-9.4	3.1*
$T_2 \times L_{10}$	6.6	0.1	-0.5	48.5	-0.4	-0.003	0.5	17.7	18.7*	-3.0*
$T_3 \times L_{10}$	44.2**	27.3**	0.9	6.7	-0.5	-0.02	0.5	-8.1	-5.9	1.9
$T_4 \times L_{10}$	-11.5	-6.9	0.3	82.5*	-0.4	0.1	0.1	7.5	10.0	0.8
$T_5 \times L_{10}$	-44.1**	-24.0**	-1.0*	-122**	1.2	0.1	-0.1	-9.6	-13.4	-2.9*
$T_1 \times L_{20}$	12.2	9.1*	-0.5	-27.1	0.8	0.1	1.1	4.9	3.3	1.5
$T_2 \times L_{20}$	-37.6**	-16.4**	-0.4	-44.1	-0.8	0.1	0.2	5.3	6.4	0.1
$T_3 \times L_{20}$	4.5	18.0**	0.5	-37.3	-0.6	-0.2	-0.1	-1.5	-9.7	-0.3
$T_4 \times L_{20}$	8.4	-25.6**	0.3	12.8	0.3	-0.02	0.8	1.8	3.7	-4.0**
$T_5 \times L_{20}$	12.6	14.9**	0.8	95.6**	0.3	-0.03	-1.9**	-10.4	-3.7	2.6*
$T_1 \times L_{46}$	-18.3*	-7.1	-0.5	75.6*	1.2	0.1	-0.03	12.2	9.9	0.4
$T_2 \times L_{46}$	5.7	-4.3	-0.6	-64.4	-0.2	-0.1	-0.2	-0.6	2.0	-3.4**
$T_3 \times L_{46}$	16.2*	6.0	0.2	-92.3**	0.2	0.1	-1.8**	-10.7	-9.2	2.2
$T_4 \times L_{46}$	-5.8	5.1	0.3	38.3	-1.1	0.3	0.3	9.3	7.1	1.5
$T_5 \times L_{46}$	2.2	0.3	0.5	42.8	-0.1	-0.2	1.7*	-10.2	-9.8	-0.7
$T_1 \times L_{51}$	-2.6	-8.9	-0.3	20.2	1.5	0.1	0.3	18.9	11.5	3.8**
$T_2 \times L_{51}$	5.2	-4.1	1.3**	55.1	-0.4	-0.3	-0.8	-2.5	8.1	-0.3
$T_3 \times L_{51}$	-10.8	-7.1	-0.2	80.7*	-0.5	0.1	-0.02	-4.0	0.2	0.2
$T_4 \times L_{51}$	-1.8	16.0**	-0.2	-94.2**	0.5	0.3	0.6	-10.0	-17.7*	1.6
$T_5 \times L_{51}$	10.0	4.1	-0.6	-61.8	-1.1	-0.2	-0.1	-2.5	-2.0	-2.1
$T_1 \times L_{52}$	-19.1*	-16.6**	0.2	-45.2	-1.4	-0.04	-0.1	-4.7	1.8	-3.6**
$T_2 \times L_{52}$	29.1**	19.7**	0.1	-79.3*	2.9**	0.2	0.8	8.2	-1.9	0.9
$T_3 \times L_{52}$	-56.8**	-32.7**	-1.7**	-54.4	-2.0*	-0.1	0.1	-6.3	2.0	-1.8
$T_4 \times L_{52}$	26.5**	13.0**	0.8	22.4	0.7	-0.2	-0.1	7.0	1.7	0.2
$T_5 \times L_{52}$	20.3*	16.6**	0.5	156.5**	-0.2	0.1	-0.8	-4.2	-3.6	4.3**
SE SCA	8.0	4.5	0.5	35.4	1.0	0.2	0.7	10.6	8.2	1.2

* = Significant at $P \leq 0.05$; ** = Significant at $P \leq 0.01$

rams for developing high grain yield/plant and one or more of the remaining traits under normal and drought environments. Thus this stock proved to be the best potential stock for improving yield and yield components.

'Nab El Gamal' had significant negative GCA effects for ear length, ear diameter, ear weight, grain yield and 100-kernel weight under the drought environment.

High GCA effects are related to additive components for genetic variation; parents with higher positive significant GCA effects are considered to be good combiners while those with negative GCA effects are poor general combiners (Griffing 1956; Tassawar *et al*. 2007; Menkir *et al*. 2003; Rahman *et al*. 2010); such test crosses should be included in further breeding programs for developing maize germplasm. Hussain and Aziz (1998) reported, for maize, that the parents showed high GCA for a particular trait did not necessarily show high SCA for that trait, while Menkir *et al.* (2003) pointed out that only 11 of 26 maize inbred lines constantly had positive or negative GCA effects across three environments (wet season, well watered and drought stress).

Specific combining ability

Estimates of SCA effects made for all characters measured with their corresponding standard error of the 35 top crosses under normal environment are present in **Table 6**.

The greatest significant and positive SCA effects were shown in six crosses for plant height, leaf area and 100-kernel weight, eight crosses for ear height, three crosses for ear length, two crosses for each of leaf number and ear weight and one cross each for rows/ear and grain yield.

In contrast, negative and significant SCA effects were detected in 7 crosses for plant height, six crosses for ear height, 4 crosses for leaf number, 5 crosses for leaf area, 3 crosses each for ear length, rows/ear and grain yield, 8 crosses for 100-kernel weight and 2 crosses for ear weight. These results revealed that SCA effects were of considerable magnitude and importance in the inheritance of grain yield and its components. The best top cross combination 'Nab El Gamal' × L_{52} displayed a significant positive SCA for plant height, ear height, leaf area and grain yield. The most promising cross combination for yield was 'Nab El Gamal' × L_{20} followed by 'Taba' × L_2 then 'SC 10' × L_5.

Estimates of SCA for 35 hybrids under the drought environment are given in **Table 7**. Of note, 10 crosses showed significant and positive SCA for plant height and ear height, while positive and significant SCA for leaf area and leaf numbers was detected in 5/35 crosses. Similarly, positive significant SCA affects were shown in 8 crosses for ear diameter, 6 crosses for 100-kernel weight, 3 crosses each for ear weight and grain yield, 4 crosses for rows/ear, and 2 crosses for ear length.

The best hybrids ('TWC310' × L_5, 'Taba' × L_5, 'Nab El Gamal' × L_{52} and 'SC10' × L_2) showed significantly high positive SCA effects for yield/plant and most yield components under a drought environment. All other crosses showed poor SCA effects, so these are of least interest to breeders. It is suggested that hybrids involving the lines L_2, L_5, L_{20} and L_{52} in a multiple crossing program may be developed for selecting high-yielding varieties of a single cross, three-way cross, double cross or synthetic variety. These lines are recommended for use in a crossing program so as to combine major yield components with high yield.

The success to identify parents that will combine well and produce productive progenies mainly depends on the

Table 7 Estimates of specific combining ability effects (SCA) for all studied characters in the crosses (Line X Tester) under drought (D) environment.

Hybrids	Plant height	Ear height	Leaves number	Leaf area	Ear length	Ear diameter	Rows/ear	Ear weight	Grain yield	100-Kernel weight
$T_1 \times L_2$	-4.5	-0.6	0.002	32.0	1.0	0.2*	1.5*	13.5	12.1	-2.2
$T_2 \times L_2$	-3.4	-1.8	0.8	2.6	-0.3	0.04	-0.9	1.5	-7.2	3.3*
$T_3 \times L_2$	-22.3**	-17.1**	-2.3**	56.0	0.3	0.05	0.4	1.1	2.6	0.2
$T_4 \times L_2$	9.7	13.7**	1.6**	-4.5	0.6	0.09	-1.0	15.4	2.5	4.9**
$T_5 \times L_2$	20.4**	5.8	-0.2	-86.0*	-1.5	-0.4**	-0.002	-31.5**	-10.0	-6.1**
$T_1 \times L_5$	13.8	11.5*	0.5	85.1*	0.8	0.4**	-0.2	40.5**	31.8**	4.0**
$T_2 \times L_5$	0.2	-3.0	-1.2*	18.0	1.8*	0.3**	0.3	20.2*	17.3*	4.0**
$T_3 \times L_5$	-78.0**	-22.7**	0.6	-119.2**	-0.9	-0.1	0.4	-15.2	-15.2*	-0.5
$T_4 \times L_5$	7.4	4.2	-0.4	-113.7**	-2.7**	-0.5**	-0.2	-37.9**	-26.0**	-7.3**
$T_5 \times L_5$	56.6**	10.0	0.6	129.8**	1.0	-0.1	-0.3	-7.7	-7.8	-0.2
$T_1 \times L_{10}$	22.5**	15.1**	-0.1	-109.8**	0.7	-0.1	-0.3	-5.0	-8.8	-1.2
$T_2 \times L_{10}$	23.5**	1.7	1.4**	22.4	-1.5	0.2*	-0.1	-1.2	6.4	1.3
$T_3 \times L_{10}$	42.5**	29.1**	0.08	55.3	0.2	0.1	0.2	4.6	4.4	1.4
$T_4 \times L_{10}$	-0.2	-9.9	-0.1	99.8**	1.8*	-0.1	0.5	5.7	7.9	-1.7
$T_5 \times L_{10}$	-88.3**	-36.0**	-1.2*	-67.8	-1.3	-0.2*	-0.3	-4.0	-9.81	0.3
$T_1 \times L_{20}$	-8.4	-9.1	0.2	-118.0**	-1.7*	-0.2*	-0.8	-18.9*	-14.5*	2.1
$T_2 \times L_{20}$	-0.6	13.2*	-0.2	-41.9	-0.3	0.05	-0.2	0.1	4.5	0.5
$T_3 \times L_{20}$	11.5	-11.2*	0.4	47.5	-0.4	-0.1	-1.1	1.6	3.0	-1.2
$T_4 \times L_{20}$	-19.6*	-8.7	-1.9**	-15.9	1.2	0.03	0.6	6.7	4.5	-0.7
$T_5 \times L_{20}$	17.2*	15.7**	1.6**	128.2**	1.2	0.2*	1.6*	10.5	2.5	-0.7
$T_1 \times L_{46}$	-30.0**	-7.6	-0.3	54.6	-0.5	-0.4**	-0.5	-8.3	-7.0	1.1
$T_2 \times L_{46}$	11.6	6.8	-1.0*	40.9	-0.6	-0.3**	1.5*	-9.1	-11.5	-2.3
$T_3 \times L_{46}$	27.8**	21.8**	0.4	-37.9	-0.2	0.2*	-0.7	9.7	10.2	0.6
$T_4 \times L_{46}$	-0.02	-7.8	1.2*	39.8	1.5	0.4**	-0.008	4.2	3.6	2.5
$T_5 \times L_{46}$	-9.3	-13.1*	-0.3	-97.5**	-0.3	0.1	-0.2	3.5	4.6	-2.0
$T_1 \times L_{51}$	8.6	-1.3	0.8	-24.6	-1.2	0.05	-0.2	-8.1	-6.6	2.8
$T_2 \times L_{51}$	-61.7**	-34.1**	-0.5	-28.6	0.8	-0.3**	-0.6	-14.2	-12.0	-5.9**
$T_3 \times L_{51}$	5.6	0.1	-0.7	57.1	1.4	0.03	2.5**	6.6	3.5	-3.4*
$T_4 \times L_{51}$	25.8**	15.8**	0.5	8.0	-0.8	0.1	-0.7	12.2	12.7	2.7
$T_5 \times L_{51}$	21.6**	19.5**	-0.09	-11.9	-0.2	0.1	-1.0	3.6	2.4	3.7*
$T_1 \times L_{52}$	-2.0	-8.0	-1.1*	80.8*	1.0	-0.06	0.6	-13.7	-7.1	-6.6**
$T_2 \times L_{52}$	30.5**	17.1**	0.7	-13.4	-0.007	0.08	-0.04	2.7	2.5	-1.0
$T_3 \times L_{52}$	12.8	-0.01	1.5**	-58.9	-0.4	-0.2*	-1.6*	-8.3	-8.4	2.8
$T_4 \times L_{52}$	-23.1**	-7.3	-0.8	-13.6	-1.5	-0.03	0.8	-6.2	-5.1	-0.4
$T_5 \times L_{52}$	-18.1*	-1.8	-0.3	5.1	1.0	0.2*	0.3	25.6**	18.1**	5.0**
SE SCA	7.7	5.3	0.5	34.1	0.88	0.1	0.7	9.3	6.7	1.5

* = Significant at $P \leq 0.05$; ** = Significant at $P \leq 0.01$

gene action that controls the trait under improvement (Abdel-Moneam *et al.* 2009).

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