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Evaluation of Inbred Lines of Maize in a Diallel Cross under Normal Condition and Drought Stress

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Abstract: In this study, we examined eight white inbred lines of maize and their F_1 crosses under normal and drought stress conditions to estimate their combining ability for grain yield and associated traits. The results showed significant correlation (mean squares) of irrigation treatment with the studied traits. The effects of parents, crosses, and genotypes were all determined to be highly significant under both irrigation levels. Grain yield and other traits showed significant differences (mean squares) associated with both General combining ability (GCA) and Specific combining ability (SCA) under both irrigation regimes, demonstrating the importance of both additive and non-additive genetic effects in the expression of performance traits. The parental line (P-86) had positive and highly significant GCA effects, as well as the crosses (P-17×P-96), (P-8×P-96), (P-8×P-171), (P-24×P-86), (P-86×P-96), (P-86×P-171), and (P-96×P-171) which then gave the highest specific combinations under both irrigation regimes for grain yield and some of the associated traits. The highest level of heterosis (heterobeltiosis) for grain yield was obtained in the crosses (P-8×P-96), (P-8×P-137), (P-8×P-171), (P-96×P-137), and (P-96×P-171) under both irrigation regimes.

1 Introduction

Maize (*Zea mays* L.), which is an essential source of human food, animal feed, and industrial materials, has been identified as the most important cereal crop in a number of countries. In Egypt, maize is grown on a total of 1.97 million feddans, yielding an average of 25.4 ardeb per feddan; this is equivalent to approximately 7.05 million tons, which is less than the total domestic consumption of approximately 18.5 million tons (USDA-FAS 2021). Thus, to face the gap between production and demand, maize production must be enhanced. This has prompted concerted efforts to increase the self-sufficiency ratio of the crop by developing new maize hybrids with high productivity under both regular irrigation and drought stress conditions, as well as increasing the acreage under maize cultivation, particularly on newly reclaimed lands.

In most parts of the world, drought is known to be a major factor restricting maize productivity. In Egypt, a shortage of available water for irrigation in some agricultural areas has become the norm rather than the exception in the last several decades (Mohie-El-Din and Moussa 2016). The water deficit in Egypt is expected to worsen due to the altered flow of the Nile as a result of filling the reservoir of the Ethiopian Renaissance Dam. This reduction in water flow has been anticipated to be a 31 BCM yr^{-1} overall annual water budget deficit, which would surpass one-third of Egypt's current total water budget (Heggy et al 2021).

Given that further irrigation water shortages are expected in the future, maize breeders must focus their efforts on developing drought tolerant maize hybrids that can provide high grain yield under both regular irrigation and drought conditions. Thus, the development of hybrids that are more drought tolerant is one of the most effective and practical ways to lessen the detrimental impacts of drought on maize productivity (Erdal et al 2015). The genotype performance and gene action of maize have been examined under normal and drought environments (Beyene et al 2013). Previously, Betran et al (2003) had discovered that additive and non-additive gene effects are important for grain yield under ideal conditions, as well as the additive gene effect under water stress. These findings give direction to current breeding programs; researchers need to determine the GCA of parents to be used as inbred lines in cross combinations and to obtain information on specific combining ability (SCA) and heterotic patterns. In this respect, the general and specific combining abilities of maize have been estimated under drought stress conditions in several studies (Murtadha et al 2018, Ertiro et al 2017, Saif-ul-Malook et al 2016, Al-Naggar et al 2016b, Aminu et al 2014).

Taking into account these previous findings, this present study aims to evaluate the mean performance of 8 maize parents and their 28 F_1 crosses, assessing several different agronomic traits under drought stress conditions. We have also aimed to identify desirable parents and cross combinations and to gather information on the genetic behavior (under drought stress conditions) of earliness, grain yield, and the contributing characters in eight inbred lines of a half-diallel cross of maize.

2 Materials and Methods

2.1 Materials and experimental layout

The experimental field work was carried out at the experimental farm of the Faculty of Agriculture, Ain Shams University, Shoubra El-Kheima, Kalubia Governorate, and at the farm of the Higher Institute for Agricultural Cooperation, Cairo-Alex, Desert Road 76 km (latitude 31.40°N, longitude 30.40°E), during the summer growing seasons of 2020 and 2021, respectively. Eight white inbred lines of maize were used as the parents, namely, P-17 (In-17), P-8 (In-8), P-24 (In-24), P-53 (In-53), P-86 (In-86), P-96 (In-96), P-137 (In-137), and P-171(In-171). The parent plants were obtained from the Maize Research Section of the Agricultural Research Center, Giza, Egypt.

In a half-diallel mating, eight inbred lines were crossed to produce a total of 28 F_1 crosses during the 2020 growing summer season. In two separate experiments in the 2021 growing season, the 8 parents and their 28 F_1 hybrids, as well as the commercial check hybrid (SC-10), were evaluated under two drip irrigation treatments: the full requirements of irrigation (IR) and 70% of IR. The total amount of irrigation water was calculated using the Penman-Monteith procedure of the Food and Agriculture Organization (FAO), FAO 56 method (Allen et al 1998). The total amount of irrigation water in each treatment was measured with a water flow meter.

Each irrigation treatment was set up as an independent experiment, using a randomized complete block design with three replicates. A wide border (5 m in width) was maintained between the two experiments to minimize underground water permeability. Each experimental plot consisted of one row (0.8 m wide, 5.0 m long) for each genotype. On one side of the ridge, hills were spaced 25 cm apart, with two kernels per hill. Seedlings were thinned to a single plant per hill. Soil analysis indicated that the soil pH 1:2.5 (soil:water) was 8.1, soil-EC1:2.5 of the experimental location was 0.27, and the soil texture of the location was sandy with very low organic matter. The other cultural practices were followed according to the recommendations for maize production in the region of the experiment. Fertilization with nitrogen was done through the irrigation system by dissolving fertilizer in the urea tank at the rate of 150 kg N $feddan^{-1}$.

2.2 Recording of data

The following data were collected for all trials; ten plants from each plot were chosen at random for parents and F_1 crosses: days to 50% anthesis, days to 50% silking, ear leaf area (cm^2), number of kernels row^{-1} ear length (cm), and grain yield (ardeb $feddan^{-1}$).

2.3 Statistical procedures

2.3.1 Analysis of variance

The data collected from each experiment were subjected to analysis of variance on the basis of the individual plant means to determine the significant differences among hybrids and parents.

2.3.2 Combining ability

Analysis of the two experiments under the two irrigation treatments (100% and 70% IR) was carried out whenever homogeneity of the error variance was detected for the examined traits, following the method of Gomez and Gomez (1984). The least significant difference was calculated to test the significance of differences between means, as detailed by Steel et al (1997). Specific and general combining ability mean squares and effects for traits that have been examined were determined according to Griffing (1956), that is, method two and model one.

2.3.3 Estimation of heterosis

Following the method of Mather and Jinks (1982), the percentage of heterosis was calculated as the deviation of the F_1 mean from the better parent value and expressed as follows:

Heterobeltiosis % = $[(\overline{F}_1-\overline{BP})/\ \overline{BP}] \times 100$
Standard heterosis % = $[(\overline{F}_1-\ \overline{Ch.})/\ \overline{Ch.}] \times 100$
where: $\overline{F}_1$= mean of an F_1 cross, $\overline{BP}$ = mean of the better parent, and $\overline{Ch.}$ = mean of the check variety SC-10.

3 Results and Discussion

3.1 Analysis of variance

As per our results, significant differences were noted in the performance of genotypes based on irrigation treatment, as indicated by the values of the mean squares of irrigation regimes for all studied traits (**Table 1**). Our findings agree with those of Al-Naggar et al (2019) and Shin et al (2015).

The mean square values of the three sources of variation parents, crosses, and genotypes and their combined data indicate significance or high significance for all studied traits under the two irrigation environments. The results also show that these genotypes were deemed inconsistent in their response to irrigation treatments. Our findings are consistent with those of Al-Naggar et al (2019). The mean squares of parents vs. crosses as an indicator of average heterosis of hybrids were found to be highly significant for all traits under the two irrigation regimes. Significant or highly significant mean squares associated with both GCA and SCA were observed for all traits examined under the two irrigation regimes (and their combined data), revealing the importance of both additive and non-additive gene actions in the expression of these traits under both irrigation regimes. The mean squares of the ratio GCA/SCA were found to be less than unity for all studied traits under the two irrigation environments. This means that the non-additive plays an important role in the inheritance of these traits. These findings are consistent with those of several previous studies (Turkey et al 2018, Wattoo et al 2014, Khaled et al 2013).

3.2 Mean values of performance indicators

Measurements of the days to 50% anthesis are presented in **Table 2**. Among the parental lines, the least number of days to 50% anthesis was recorded in (P-171) and (P-17) under both irrigation regimes and (P-137) under stress. In the case of the hybrid plants, the least number of days to 50% anthesis was found in (P-8×P-171) and (P-24×P-171) under both irrigation treatments. However, the hybrids (P-17×P-24), (P-8×P-171), and (P-24×P-171) were significantly earlier than the check SC-10 under the two irrigation treatments. These results are in line with previous studies (Al-Naggar et al 2016a, Ge et al 2012), in which it was reported that the number of days to 50% anthesis decreased under drought conditions.

We have also found that the number of days to 50% silking was lower in the parental lines (P-171) and (P-17) under normal irrigation and in (P-171) and (P-137) under drought conditions (Table 2). The hybrids (P-8×P-171) and (P-24×P-171) were significantly earlier than the check SC-10 under the two irrigation treatments. Thus, it can be concluded that these aforementioned single crosses seemed to have optimal performance.

With respect to ear leaf area, the parental lines were noted to vary in this trait, from 365.61 (P-17) and 276.73 (P-171) cm^2 (mean 469.63) to 573.70 (P-86) and 530.62 (P-86) cm^2 (mean 381.55) under ideal irrigation and drought stress, respectively (**Table 3**). In the hybrids, ear leaf area varied from 502.09 (P-53×P-171) and 315.55 (P-53×P-171) cm^2 (mean 638.37) to 743.97 (P-86×P-96) and 677.72 (P-86×P-96) cm^2 (mean 522.74) under the ideal irrigation and drought stress conditions, respectively. This trait did not exceed the SC-10 in any of the crosses under either normal or drought conditions.

With respect to the number of kernels row^{-1}, the parental inbred lines (P-53) and (P-96) were found to be superior, under either irrigation treatment (**Table 3**). It can be noted that none of the crosses significantly exceeded the check SC-10 value for this trait under either treatment.

Table 1. Mean squares for all studied traits under normal irrigation, drought stress, and their combined data in the 2021 season

Source of variations	d.f.		Days to 50% anthesis (days)			Days to 50% silking (days)		
	Single	Comb.	Normal	Drought	Comb.	Normal	Drought	Comb.
Irrigation (I)		1			242.78**			33.45**
Replications (R)	2	4	13.176	5.06	9.12	15.06	2.08	8.57
Genotypes (G)	35	35	15.304**	24.17**	37.89**	15.40**	29.76**	42.73**
Parents (P)	7	7	3.905**	13.12**	14.08**	2.86*	7.40**	8.18**
Crosses (C)	27	27	7.299**	9.21**	15.66**	5.51**	9.96**	13.93**
P vs. C	1	1	311.241**	505.21**	804.76**	370.04**	720.86**	1061.93**
G x I		35			1.58*			2.43**
P x I		7			2.94**			2.08*
C x I		27			0.86			1.54
P vs. C x I		1			11.69**			28.97**
Error	70	140	3.928	3.64	3.79	3.13	3.26	3.20
GCA	7	7	12.036**	24.04**	34.87**	5.30**	17.16**	20.31**
SCA	28	28	16.122**	24.20**	38.64**	17.92**	32.91**	48.33**
GCA x I		7			1.20			2.16*
SCA x I		28			1.68*			2.50**
Error	70	140	1.31	1.22	0.63	1.04	1.09	0.53
σ^2GCA/σ^2SCA			0.072	0.099	0.090	0.025	0.051	0.041
			Ear leaf area (cm^2)			**Number of kernels row^{-1}**		
Irrigation (I)		1			647591.58**			5598.80**
Replications (R)	2	4	608.85	1035.67	822.26	19.24	9.44	14.34
Genotypes (G)	35	35	26351.97**	32058.04**	55727.08**	52.26**	78.13**	114.72**
Parents (P)	7	7	15146.73**	25317.63**	37959.09**	25.16**	48.97**	61.35**
Crosses (C)	27	27	10548.49**	21212.80**	29195.42**	19.28**	50.45**	52.77**
P vs. C	1	1	531482.74**	372062.51**	896457.68**	1132.56**	1029.43**	2160.77**
G x I		35			2682.93**			15.67**
P x I		7			2505.27**			12.78**
C x I		27			2565.86**			16.96**
P vs. C x I		1			7087.57**			1.23
Error	70	140	323.04	316.76	319.90	17.77	20.18	18.98
GCA	7	7	21752.92**	61362.57**	76586.91**	30.47**	73.11**	97.33**
SCA	28	28	27501.73**	24731.91**	50512.12**	57.71**	79.38**	119.06**
GCA x I		7			6528.59**			6.25**
SCA x I		28			1721.52**			18.03**
Error	70	140	107.68	105.59	53.32	5.92	6.73	3.16
σ^2GCA/σ^2SCA			0.079	0.249	0.152	0.047	0.091	0.081
			Ear length (cm)			**Grain yield (ardeb feddan^{-1})**		
Irrigation (I)		1			141.26**			4835.26**
Replications (R)	2	4	1.11	0.34	0.72	15.88	0.59	8.23
Genotypes (G)	35	35	19.93**	22.58**	41.39**	221.81**	202.13**	403.45**
Parents (P)	7	7	8.19**	10.14**	17.05**	43.42**	57.26**	90.43**
Crosses (C)	27	27	9.28**	12.85**	21.02**	99.16**	132.09**	210.67**
P vs. C	1	1	389.69**	372.36**	761.95**	4782.20**	3107.33**	7799.62**
G x I		35			1.12			20.49**
P x I		7			1.28			10.26**
C x I		27			1.11			20.57**
P vs. C x I		1			0.10			89.91**
Error	70	140	3.72	2.19	2.95	11.97	5.44	8.70
GCA	7	7	9.91**	20.11**	28.58**	114.03**	254.40**	317.30**
SCA	28	28	22.44**	23.20**	44.60**	248.76**	189.06**	424.99**
GCA x I		7			1.44			51.12**
SCA x I		28			1.04			12.83**
Error	70	140	1.24	0.73	0.49	3.99	1.81	1.45
σ^2GCA/σ^2SCA			0.041	0.086	0.064	0.045	0.135	0.075

* & ** denote significant at 0.05 and 0.01 levels of probability, respectively.

Table 2. Mean performance of maize genotypes for days to 50% anthesis and days to 50% silking under the two irrigation treatments and their combined data in the 2021 season

Genotypes	Days to 50% anthesis (days)			Days to 50% silking (days)		
	Normal	Drought	Combined	Normal	Drought	Combined
In-17	61.33	60.33	60.83	64.33	66.00	65.17
In-8	63.33	63.00	63.17	66.00	66.67	66.33
In-24	63.33	62.00	62.67	66.00	66.00	66.00
In-53	63.33	63.33	63.33	66.67	67.33	67.00
In-86	64.00	63.67	63.83	65.67	68.00	66.83
In-96	62.33	62.00	62.17	65.33	66.00	65.67
In-137	63.00	59.00	61.00	65.00	63.33	64.17
In-171	60.67	58.00	59.33	63.67	64.00	63.83
Parental mean	62.67	61.42	62.04	65.33	65.92	65.63
In-17 × In-8	59.67	57.33	58.50	62.33	62.00	62.17
× In-24	56.33	53.33	54.83	59.33	57.00	58.17
× In-53	60.33	58.00	59.17	62.67	61.67	62.17
× In-86	59.33	56.33	57.83	61.33	59.00	60.17
× In-96	59.00	56.00	57.50	61.00	59.33	60.17
× In-137	58.33	55.67	57.00	61.00	58.33	59.67
× In-171	57.33	54.33	55.83	59.67	58.67	59.17
In-8 × In-24	58.00	55.00	56.50	60.33	58.33	59.33
× In-53	60.67	57.67	59.17	62.67	61.67	62.17
× In-86	60.00	56.67	58.33	62.00	60.33	61.17
× In-96	60.67	57.67	59.17	62.33	61.67	62.00
× In-137	58.00	56.33	57.17	60.00	60.00	60.00
× In-171	54.67	52.00	53.33	57.00	55.33	56.17
In-24 × In-53	57.67	55.67	56.67	59.67	59.00	59.33
× In-86	60.33	58.33	59.33	62.00	63.33	62.67
× In -96	58.33	56.33	57.33	60.33	59.33	59.83
× In-137	58.33	55.67	57.00	60.67	58.67	59.67
× In-171	55.00	53.00	54.00	58.67	56.67	57.67
In-53 × In-86	59.33	57.67	58.50	61.00	60.67	60.83
× In-96	58.00	55.33	56.67	60.67	58.33	59.50
× In-137	58.00	56.00	57.00	60.00	59.33	59.67
× In-171	57.33	54.33	55.83	60.00	58.33	59.17
In-86 × In-96	60.33	59.00	59.67	62.00	62.00	62.00
× In-137	58.33	57.67	58.00	60.33	61.00	60.67
× In-171	60.33	59.00	59.67	62.33	61.33	61.83
In-96 × In-137	58.00	56.67	57.33	60.67	60.00	60.33
× In-171	59.33	55.33	57.33	62.33	59.33	60.83
In-137 × In-171	59.33	57.67	58.50	62.33	61.00	61.67
Check SC.10	60.00	58.67	59.33	62.00	62.00	62.00
Crosses mean	58.58	56.21	57.40	60.88	59.70	60.29
genotypes mean	59.49	57.37	58.43	61.87	61.08	61.48
L.S.D. 0.05 (G)	3.228	3.109	2.221	2.882	2.942	2.041
0.05 (I)			0.524			0.481
0.05 (G×I)			3.141			2.887

Table 3. Mean performance of maize genotypes for ear leaf area and number of kernels per row under the two irrigation treatments and their combined data in the 2021 season

Genotypes	Ear leaf area (cm^2)			Number of kernels row^{-1}		
	Normal	Drought	Combined	Normal	Drought	Combined
In-17	365.61	284.46	325.04	32.07	21.67	26.87
In-8	394.18	296.74	345.46	33.40	22.13	27.77
In-24	482.24	363.69	422.96	33.33	23.73	28.53
In-53	513.30	429.56	471.43	37.53	28.60	33.07
In-86	573.70	530.62	552.16	32.67	25.53	29.10
In-96	538.02	455.80	496.91	39.20	32.67	35.93
In-137	449.63	414.83	432.23	31.60	22.27	26.93
In-171	440.37	276.73	358.55	37.20	21.20	29.20
Parental mean	469.63	381.55	425.59	34.63	24.73	29.68
In-17 × In-8	586.73	480.68	533.70	36.40	25.53	30.97
× In-24	640.40	402.90	521.65	39.40	26.13	32.77
× In-53	606.75	491.36	549.06	44.27	33.40	38.83
× In-86	573.23	456.88	515.06	44.07	33.53	38.80
× In-96	588.89	511.69	550.29	44.87	38.47	41.67
× In-137	682.20	572.15	627.17	43.40	28.00	35.70
× In-171	541.38	360.84	451.11	37.07	26.60	31.83
In-8 × In-24	638.69	520.52	579.60	44.00	38.60	41.30
× In-53	641.56	577.70	609.63	43.53	38.87	41.20
× In-86	722.87	600.95	661.91	44.47	29.53	37.00
× In-96	669.96	612.43	641.19	41.33	34.60	37.97
× In-137	734.02	606.20	670.11	43.33	28.60	35.97
× In-171	654.32	536.16	595.24	41.13	31.47	36.30
In-24 × In-53	699.61	574.92	637.26	43.60	31.00	37.30
× In-86	606.03	535.30	570.67	43.87	31.67	37.77
× In -96	619.13	515.81	567.47	41.33	28.53	34.93
× In-137	640.47	530.63	585.55	44.87	38.60	41.73
× In-171	582.31	382.69	482.50	37.33	26.67	32.00
In-53 × In-86	722.21	623.79	673.00	41.00	32.33	36.67
× In-96	626.04	519.36	572.70	45.00	35.07	40.03
× In-137	571.67	462.95	517.31	43.73	32.93	38.33
× In-171	502.09	315.55	408.82	42.33	28.67	35.50
In-86 × In-96	743.97	677.72	710.84	44.27	30.27	37.27
× In-137	609.68	500.30	554.99	43.13	29.60	36.37
× In-171	679.61	595.42	637.51	38.40	35.97	37.18
In-96 × In-137	692.70	606.36	649.53	43.07	34.60	38.83
× In-171	636.06	528.50	582.28	44.93	37.67	41.30
In-137 × In-171	661.76	536.81	599.29	43.47	33.33	38.40
Check SC.10	745.89	686.43	716.16	44.13	39.80	41.97
Crosses mean	638.37	522.74	580.55	42.41	32.15	37.28
genotypes mean	600.87	491.36	546.12	40.68	30.50	35.59
L.S.D. 0.05 (G)	29.268	28.983	20.416	6.865	7.316	4.973
0.05 (I)			4.812			1.172
0.05 (G×I)			28.872			7.032

The values for ear length in the parental plants ranged from 15.13 (P-137) to 20.07 (P-53) cm (mean 17.67) and from 13.83 (P-137) to 18.90 (P-53) cm (mean 16.13) under regular irrigation and drought stress, respectively. The ear length of the crosses ranged from 18.83 (P-24×P-171) to 25.07 (P-24×P-53) cm under normal irrigation conditions. In contrast, under drought conditions, the ear length of crosses ranged from 16.50 (P-53×P-171) to 23.40 (P-24×P-53) cm.

The results for grain yield (ardeb feddan^{-1}) are presented in **Table 4**. In the parental lines, grain yield ranged from 15.90 (P-137) to 26.07 (P-86) ard/fedd (mean 19.33) and from 5.57 (P-171) to 19.55 (P-86) ard/fedd (mean 12.28) under normal and drought treatments, respectively. Grain yield in the crosses varied from 19.93 (P-53×P-96) to 42.82 (P-86×P-96) ard/fedd (mean 35.34) and from 10.91 (P-24×P-171) to 35.20 (P-86×P-96) ard/fedd (mean 25.19) under the normal and drought treatments, respectively. The overall grain yield for all genotypes was 31.78 and 22.32 ard/fedd under normal and drought treatments, respectively; thus, the drought treatment clearly had a severe, negative effect on grain yield. Our findings are consistent with previously reported results (Keimeso et al 2020, Al-Naggar et al 2019, Salgado-Aguilar et al 2019, Messina et al 2015). However, only one cross (P-86×P-96) overcame the check variety SC-10 but without significance under both irrigation regimes.

3.3 Combining ability

3.3.1 GCA effects

Negative values of GCA effects are of interest with respect to the earliness traits (**Table 5**). The most desirable GCA effects were detected for one parental line, (P-171), which exhibited negative GCA values for days to 50% anthesis under both irrigation regimes and days to 50% silking under drought condition. These findings suggest that this parent has accumulated favorable alleles for earliness and could thus be used to develop earlier hybrids under these conditions.

In terms of leaf area, the results in **Table 5** show that parental inbred lines (P-86), (P-96), and (P-137) had highly significant and positive GCA effects under normal and drought stress conditions, whereas (P-17) and (P-171) had negative and highly significant general combining ability effects under both conditions. These results indicate that the parental inbred lines (P-86), (P-96), and (P-137), under either irrigation condition, could be used as effective combiners to increase ear leaf area.

The most promising general combiner for number of kernels per row was parental line (P-96), which was known to attain positive and significant or highly significant GCA effects under either treatment (**Table 6**). On the contrary, significant negative GCA effects were detected for the line (P-17) under the drought treatment.

The most promising general combiners for ear length, as shown in **Table 6**, were the lines (P-53) and (P-86) under either irrigation treatments, as these plants were found to have positive and significant or highly significant GCA effects. On the other hand, highly significant negative GCA effects were detected for the lines (P-17) and (P-171) under both irrigation treatments.

Concerning grain yield (ardeb/feddan), as shown in **Table 6**, the parental line (P-86) showed positive and highly significant GCA effects under both irrigation treatments. In contrast, the parental lines (P-24) and (P-171) proved to be poor general combiners for grain yield, under either irrigation treatment, as indicated by the highly significant negative GCA values.

3.3.2 SCA effects

Concerning days to 50% anthesis, four of the crosses under ideal watering and eight under drought conditions exhibited significant or highly significant and negative SCA effects (**Table 7**). The highest SCA effects were reported for the hybrids (P-8×P-171) and (P-24×P-171) under normal irrigation and the hybrids (P-17×P-24), (P-8×P-171), and (P-53×P-96) under drought stress.

With respect to days to 50% silking in the 28 hybrids, 7 of the hybrids under normal irrigation and 11 under drought conditions exhibited negative and significant SCA effects. The highest SCA effects occurred in the hybrids (P-8×P-171) and (P-24×P-171) under ideal irrigation. Meanwhile, under drought conditions, the crosses (P-17×P-24), (P-17×P-86), (P-8×P-171), (P-24×P-171), and (P-53×P-96) were determined to have the highest values for SCA effects and included at least one parent as a good general combiner; therefore, they could be considered promising lines for earliness. Similar findings have been reported in previous studies (Al-Naggar et al 2016b, Sultan et al 2016, Okasha et al 2014).

Table 4. Mean performance of maize genotypes for ear length (cm) and grain yield (ardeb/feddan) under the two irrigation treatments and their combined data in the 2021 season

Genotypes	Ear length (cm)			Grain yield (ardeb feddan^{-1})		
	Normal	Drought	Combined	Normal	Drought	Combined
In-17	15.77	14.57	15.17	24.21	15.23	19.72
In-8	17.40	16.17	16.78	17.14	10.66	13.90
In-24	18.10	17.07	17.58	18.27	8.49	13.38
In-53	20.07	18.90	19.48	19.74	15.31	17.53
In-86	17.57	16.50	17.03	26.07	19.55	22.81
In-96	19.40	17.90	18.65	16.73	11.41	14.07
In-137	15.13	13.83	14.48	15.90	12.06	13.98
In-171	17.90	14.10	16.00	16.61	5.57	11.09
Parental mean	17.67	16.13	16.90	19.33	12.28	15.81
In-17 × In-8	19.17	18.00	18.58	31.67	22.01	26.84
× In-24	19.40	17.17	18.29	27.95	15.06	21.51
× In-53	22.83	20.67	21.75	39.21	29.37	34.29
× In-86	23.97	22.27	23.12	37.28	26.67	31.98
× In-96	23.17	20.83	22.00	40.18	31.48	35.83
× In-137	23.07	21.00	22.03	41.38	27.82	34.60
× In-171	19.73	17.13	18.43	29.78	11.56	20.67
In-8 × In-24	24.17	23.13	23.65	36.22	21.72	28.97
× In-53	24.50	22.83	23.67	41.34	26.30	33.82
× In-86	23.33	20.80	22.07	37.74	27.34	32.54
× In-96	19.17	17.70	18.43	38.59	31.26	34.93
× In-137	22.33	21.00	21.67	37.90	27.29	32.60
× In-171	22.00	18.57	20.28	38.70	26.83	32.77
In-24 × In-53	25.07	23.40	24.23	37.77	26.47	32.12
× In-86	23.00	22.03	22.52	42.47	31.77	37.12
× In -96	22.90	21.50	22.20	26.74	18.78	22.76
× In-137	23.83	22.67	23.25	34.60	25.23	29.91
× In-171	18.83	16.60	17.72	26.09	10.91	18.50
In-53 × In-86	22.17	21.23	21.70	41.62	32.67	37.14
× In-96	22.53	21.47	22.00	19.93	16.51	18.22
× In-137	22.17	20.43	21.30	35.60	31.82	33.71
× In-171	20.00	16.50	18.25	31.47	14.83	23.15
In-86 × In-96	22.50	21.73	22.12	42.82	35.20	39.01
× In-137	23.93	21.43	22.68	30.91	24.89	27.90
× In-171	21.17	21.70	21.43	39.83	32.57	36.20
In-96 × In-137	21.57	20.63	21.10	34.77	29.92	32.35
× In-171	23.83	22.90	23.37	37.47	26.90	32.18
In-137 × In-171	22.27	21.33	21.80	29.46	22.05	25.75
Check SC.10	23.17	22.57	22.87	41.59	33.39	37.49
Crosses mean	22.24	20.59	21.42	35.34	25.19	30.26
genotypes mean	21.22	19.60	20.41	31.78	22.32	27.05
L.S.D. 0.05 (G)	2.297	3.189	1.961	5.63	3.80	3.37
0.05 (I)			0.462			0.79
0.05 (G×I)			2.774			4.76

Table 5. Estimates of general combining ability effects for days to 50% anthesis, days to 50% silking, and ear leaf area for the eight maize parental lines under the two irrigation treatments in 2021 season

Parents	Days to 50% anthesis (days)		Days to 50% silking (days)		Ear leaf area (cm^2)	
	Normal	Drought	Normal	Drought	Normal	Normal
In-17	-0.24	-0.47	-0.08	-0.17	-45.70**	-57.68**
In-8	0.29	0.23	0.18	0.29	2.87	10.59**
In-24	-0.47	-0.50	-0.38	-0.54	-1.67	-23.21**
In-53	0.26	0.50	0.32	0.39	-1.13	0.25
In-86	1.06**	1.57**	0.55	1.39**	39.72**	62.94**
In-96	0.29	0.40	0.32	0.22	24.49**	46.12**
In-137	-0.11	-0.27	-0.18	-0.47	8.39**	22.3**
In-171	-1.07**	-1.47**	-0.72	-1.11**	-26.96**	-61.28**
L.S.D.						
0.05 (gi)	0.67	0.65	0.60	0.61	6.12	6.06
0.01 (gi)	0.90	0.86	0.80	0.82	8.13	8.05
0.05 (gi – gj)	1.02	0.98	0.91	0.93	9.26	9.16
0.01 (gi – gj)	1.35	1.30	1.21	1.23	12.29	12.17

* & ** denote significant at 0.05 and 0.01 levels of probability, respectively.

Table 6. Estimates of general combining ability effects for number of kernels per row, ear length, and grain yield (ardeb per feddan) for the eight maize parental lines under the two irrigation treatments in 2021 season

Parents	Number of kernels row^{-1}		Ear length (cm)		Grain yield (ardeb $feddan^{-1}$)	
	Normal	Drought	Normal	Drought	Normal	Drought
In-17	-1.25	-1.95*	-0.81*	-1.02**	0.98	-0.64
In-8	-0.51	-0.30	-0.15	-0.21	1.04	0.32
In-24	-0.51	-0.58	0.24	0.42	-1.76**	-3.40**
In-53	1.24	1.50	0.84*	0.79**	0.04	0.77
In-86	-0.16	-0.05	0.42	0.78**	3.88**	4.93**
In-96	1.70*	3.00**	0.35	0.61*	-1.21*	1.20**
In-137	0.20	-0.43	-0.15	-0.03	-0.96	1.23**
In-171	-0.71	-1.17	-0.73*	-1.35**	-2.00**	-4.41**
L.S.D.						
0.05 (gi)	1.44	1.53	0.66	0.50	1.18	0.79
0.01 (gi)	1.91	2.03	0.87	0.67	1.56	1.05
0.05 (gi – gj)	2.17	2.31	0.99	0.76	1.78	1.20
0.01 (gi – gj)	2.88	3.07	1.32	1.01	2.37	1.59

* & ** denote significant at 0.05 and 0.01 levels of probability, respectively.

In terms of ear leaf area, eighteen crosses under well watering and eighteen under drought stress exhibited high significant and positive SCA effects (**Table 7**). The highest SCA effects were reported for the hybrids (P-17×P-137), (P-8×P-137), (P-8×P-171), (P-24×P-53), (P-86×P-96), and (P-137×P-171) under both irrigation regimes. These findings suggest that these crosses are the most effective at increasing the ear leaf area under both irrigation conditions.

With respect to the number of kernels row^{-1}, 3 of the F_1 crosses exhibited positive and significant or highly significant SCA effects under regular watering; 7 of the crosses under drought stress showed positive and significant or highly significant SCA effects. The values for hybrids (P-17×P-86) and (P-24×P-137) were significant or highly significant and positive under both irrigation conditions.

Concerning ear length, the data showed that 13 of the crosses under regular irrigation and nine under drought stress exhibited significant or highly significant and positive SCA effects (**Table 8**). The highest effects were found in the hybrids (P-17×P-86), (P-8×P-24), and (P-96×P-171) under both irrigation regimes, then which suggests that these findings are the best combinations for increasing ear length.

Table 7. Estimates of specific combining ability effects of 28 F1 crosses of maize for days to 50% anthesis, days to 50% silking, and ear leaf area under the two irrigation treatments in the 2021 season

Crosses	Days to 50% anthesis (days)		Days to 50% silking (days)		Ear leaf area (cm^2)	
	Normal	Drought	Normal	Drought	Normal	Drought
In-17 × In-8	0.126	0.196	0.363	0.800	28.695**	36.412**
× In-24	-2.441*	-3.070**	-2.070*	-3.367**	86.903**	-7.566
× In-53	0.826	0.596	0.563	0.367	52.715**	57.429**
× In-86	-0.974	-2.137*	-1.004	-3.300**	-21.653*	-39.733**
× In-96	-0.541	-1.304	-1.104	-1.800	9.232	31.891**
× In-137	-0.807	-0.970	-0.604	-2.100*	118.636**	116.194**
× In-171	-0.841	-1.104	-1.404	-1.133	13.174	-11.555
In-8 × In-24	-1.307	-2.104*	-1.337	-2.500*	36.623**	41.782**
× In-53	0.626	-0.437	0.296	-0.100	38.951**	75.504**
× In-86	-0.841	-2.504*	-0.604	-2.433*	79.420**	36.063**
× In-96	0.593	-0.337	-0.037	0.067	41.725**	64.358**
× In-137	-1.674	-1.004	-1.870*	-0.900	121.892**	81.970**
× In-171	-4.041**	-4.137**	-4.337**	-4.933**	77.541**	95.500**
In-24 × In-53	-1.607	-1.704	-2.137*	-1.933*	101.540**	106.517**
× In-86	0.259	-0.104	-0.037	1.400	-32.882**	4.214
× In -96	-0.974	-0.937	-1.470	-1.433	-4.559	1.537
× In-137	-0.574	-0.937	-0.637	-1.400	32.879**	40.195**
× In-171	-2.941**	-2.404*	-2.104*	-2.767**	10.067	-24.175*
In-53 × In-86	-1.474	-1.770	-1.737	-2.200*	82.753**	69.246**
× In-96	-2.041	-2.937**	-1.837	-3.367**	1.806	-18.370
× In-137	-1.641	-1.604	-2.004*	-1.667	-36.457**	-50.942**
× In-171	-1.341	-2.070*	-1.470	-2.033*	-70.696**	-114.783**
In-86 × In-96	-0.507	-0.337	-0.737	-0.700	78.886**	77.301**
× In-137	-2.107*	-1.004	-1.904*	-1.000	-39.296**	-76.278
× In-171	0.859	1.530	0.630	-0.033	65.977**	102.404**
In-96 × In-137	-1.674	-0.837	-1.337	-0.833	58.945**	46.595**
× In-171	0.626	-0.970	0.863	-0.867	37.649**	52.295**
In-137 × In-171	1.026	2.030*	1.363	1.500	79.455**	84.453**
L.S.D.						
0.05 (Sij)	2.069	1.994	1.848	1.886	18.766	18.583
0.01 (Sij)	2.748	2.647	2.453	2.505	24.915	24.672
0.05 (Sij – Sik)	3.062	2.950	2.734	2.791	27.767	27.496
0.01 (Sij – Sik)	4.065	3.916	3.630	3.706	36.864	36.504
0.05 (Sij – Skl)	2.887	2.781	2.577	2.632	26.179	25.923
0.01 (Sij – Skl)	3.833	3.692	3.422	3.494	34.756	34.417

* & ** denote significance at 0.05 and 0.01 levels of probability, respectively.

Table 8. Estimates of specific combining ability effects of 28 sF1 crosses of maize for number of kernels per row, ear length, and grain yield (ardeb/feddan) under normal irrigation and drought stress in the 2021 season

Crosses	Number of kernels row^{-1}		Ear length (cm)		Grain yield (ardeb feddan^{-1})	
	Normal	Normal	Normal	Drought	Normal	Normal
In-17 × In-8	-2.513	-2.713	-1.090	-0.375	-2.13	0.01
× In-24	0.480	-1.833	-1.250	-1.829*	-3.05	-3.22*
× In-53	3.600	3.354	1.583	1.295	6.41**	6.92**
× In-86	4.800*	5.037*	3.136**	2.908**	0.64	0.07
× In-96	3.733	6.914**	2.410*	1.638*	8.62**	8.60**
× In-137	3.767	-0.119	2.813**	2.445**	9.58**	4.92**
× In-171	-1.653	-0.776	0.060	-0.098	-0.98	-5.71**
In-8 × In-24	4.340	8.987**	2.856**	3.315**	5.16**	2.48*
× In-53	2.127	7.174**	2.590*	2.646**	8.48**	2.89*
× In-86	4.460*	-0.609	1.843	0.626	1.04	-0.23
× In-96	-0.540	1.401	-2.250*	-2.311**	6.97**	7.43**
× In-137	2.960	-1.166	1.420	1.629*	6.04**	3.43**
× In-171	1.673	2.444	1.666	0.519	7.88**	8.60**
In-24 × In-53	2.187	-0.413	2.763**	2.585**	7.71**	6.77**
× In-86	3.853	1.804	1.116	1.232	8.57**	7.92**
× In -96	-0.547	-4.386	1.090	0.862	-2.07	-1.34
× In-137	4.487*	9.114**	2.526*	2.668**	5.55**	5.08**
× In-171	-2.133	-2.076	-1.894	-2.075**	-1.92	-3.61**
In-53 × In-86	-0.760	0.391	-0.317	0.062	5.92**	4.64**
× In-96	1.373	0.067	0.123	0.459	-10.68**	-7.78**
× In-137	1.607	1.367	0.260	0.066	4.74*	7.51**
× In-171	1.120	-2.156	-1.327	-2.544**	1.65	-3.85**
In-86 × In-96	2.040	-3.183	0.510	0.739	8.37**	6.75**
× In-137	2.407	-0.416	2.446*	1.079	-3.79*	-3.59**
× In-171	-1.413	6.694**	0.260	2.669**	6.17**	9.72**
In-96 × In-137	0.473	1.527	0.153	0.442	5.16**	5.18**
× In-171	3.253	5.337*	3.000**	4.032**	8.90**	7.79**
In-137 × In-171	3.287	4.437	1.936	3.106**	0.64	2.91*
L.S.D.						
0.05 (Sij)	4.402	4.691	2.013	1.545	3.61	2.43
0.01 (Sij)	5.844	6.228	2.672	2.051	4.80	3.23
0.05 (Sij – Sik)	6.513	6.940	2.978	2.286	5.35	3.60
0.01 (Sij – Sik)	8.647	9.214	3.954	3.034	7.10	4.78
0.05 (Sij – Skl)	6.141	6.544	2.808	2.155	5.04	3.40
0.01 (Sij – Skl)	8.152	8.687	3.728	2.861	6.69	4.51

* & ** denote significance at 0.05 and 0.01 levels of probability, respectively.

Table 9. Percentages of heterosis (%) over the better parent and over the check variety (SC-10) for grain yield (ardeb/feddan) of 28 F1 crosses under ideal irrigation and drought conditions in the 2021 season

Crosses	Grain yield (ardeb/feddan)			
	(Over the better parent)		(Over the check variety SC-10)	
	Normal	Drought	Normal	Drought
In-17 × In-8	30.85*	44.46**	-23.84**	-34.09**
× In-24	15.46	-1.13	-32.80**	-54.89**
× In-53	61.99**	91.75**	-5.72	-12.05*
× In-86	42.98**	36.45**	-10.36	-20.11**
× In-96	65.98**	106.64**	-3.39	-5.72
× In-137	70.94**	82.63**	-0.51	-16.67**
× In-171	23.04	-24.12	-28.39**	-65.38**
In-8 × In-24	98.22**	103.81**	-12.90	-34.95**
× In-53	109.44**	71.72**	-0.60	-21.24**
× In-86	44.75**	39.84**	-9.25	-18.12**
× In-96	125.10**	174.10**	-7.21	-6.37
× In-137	121.10**	126.35**	-8.86	-18.26**
× In-171	125.77**	151.74**	-6.94	-19.65**
In-24 × In-53	91.34**	72.84**	-9.19	-20.73**
× In-86	62.88**	62.53**	2.12	-4.84
× In -96	46.31**	64.63**	-35.71**	-43.76**
× In-137	89.34**	109.24**	-16.80*	-24.44**
× In-171	42.78*	28.55	-37.26**	-67.33**
In-53 × In-86	59.61**	67.11**	0.07	-2.16
× In-96	0.98	7.84	-52.07**	-50.54**
× In-137	80.37**	107.80**	-14.40	-4.69
× In-171	59.44**	-3.13	-24.33**	-55.57**
In-86 × In-96	64.23**	80.06**	2.97	5.43
× In-137	18.54	27.30**	-25.68**	-25.47**
× In-171	52.75**	66.59**	-4.23	-2.46
In-96 × In-137	107.89**	148.15**	-16.39*	-10.39
× In-171	124.02**	135.82**	-9.91	-19.44**
In-137 × In-171	85.30**	82.84**	-29.17**	-33.97**
L.S.D.				
0.05	6.03	3.92	6.03	3.92
0.01	8.03	5.22	8.03	5.22

* & ** denote significance at 0.05 and 0.01 levels of probability, respectively.

With respect to grain yield, 17 of the crosses (of 28 total) under regular irrigation and 18 under drought stress exhibited positive and significant or highly significant SCA effects. It can be worth noting that the highest specific combinations for grain yield under both irrigation regimes were evident in the hybrids (P-17×P-96), (P-8×P-96), (P-8×P-171), (P-24×P-86), (P-86×P-96), (P-86×P-171), and (P-96×P-171), all of which involve at least one parent as a good general combiner. A number of studies have also found desirable SCA effects for grain yield under normal irrigation and drought stress (Patel 2022, Murtadha et al 2018).

3.4 Heterobeltiosis and standard heterosis

The heterotic performances of F_1 crosses in comparison to the superior parent (heterobeltiosis) for grain yield (ardeb/feddan) under the two different irrigation conditions, i.e., normal irrigation vs. drought conditions, are presented in **Table 9**. Grain yield heterosis percentages ranged from 0.98% (P-53×P-96) to 125.77% (P-8×P-171) and -24.12% (P-17×P-171) to 174.10% (P-8×P-96) under normal and drought treatments, respectively.

All the crosses under either of the two irrigation treatments showed positive additionally significant or highly significant heterobeltiotic effects for grain yield (ardeb/feddan), except the cross (P-86×P-137) under normal irrigation, the crosses (P-24×P-171) and (P-53×P-171) under drought stress, and the hybrids (P-17×P-24), (P-17×P-171), and (P-53×P-96) under the two irrigation regimes. Several studies have also shown significant levels of heterosis over better parent for grain yield in maize under normal irrigation and drought conditions (Fayed et al 2019).

Heterosis, as compared to the check variety (SC-10) for grain yield under both conditions, is presented in **Table 9**. The standard heterosis percentage for grain yield ranged from -52.07% (P-53×P-96) to 2.97% (P-86×P-96) and from -65.38% (P-17×P-171) to 5.43% (P-86×P-96) under normal and drought conditions, respectively.

None of the new single crosses (28 total) significantly exceeded the check SC-10. However, the highest positive (insignificant) standard heterosis was detected by the cross (P-86×P-96) under both irrigation environments. Similar results were obtained by Keimeso et al (2020).

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