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Line × Tester Analysis for Yield and 100-grain Weight Under Normal and Water Stress Conditions in Yellow Maize (*Zea mays* L.)

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Abstract

Maize (*Zea mays* L.) is the third most important cereal grain in Egypt (after wheat and rice) but it is vulnerable to water stress which causes lead losses in both yield and quality. In the current study we evaluated 100 S1-lines along with their top-crosses using two testers under normal and water stress conditions. We used line × tester to assess general (GCA) and specific (SCA) combining ability effects for 100-grain weight and grain yield per plot; In addition, we estimated heritability for both traits. Result of line × tester analysis showed highly significant differences among parents, crosses vs parents., In addition, between testers and lines × testers for both traits under normal and water stress condition. The results, lines showed non-significant for 100-grain weight under normal and water stress condition. Grain yield per plot showed non-significant differences under normal condition while it showed significant under water stress condition. Under normal condition, S1-lines 56 and 88 possessed the highest 100-grain weight while, the highest values of 100-grain weight were found in cross combinations including S1-line 29 × SC162 and S1-line 61× TWC352. On the other hand, S1-lines 65 and 68 possessed the highest grain yield per plot while, the highest values of grain yield per plot were found in cross combinations including S1-line 86 × SC162 and S1-line 37× TWC352. Under normal condition, S1-lines 10 and 99 displayed positive and significant GCA effects for 100-grain weight while, S1-line 86 and 55 exhibited the maximum GCA effect for grain yield per plot. Top-crosses including S1-line 29×SC162 and S1-line 75×TWC352 were good specific combiners for 100-grain weight while, the top-crosses including S1-line 29×SC162 and S1-line 78×TWC352 were good specific combiners for grain yield per plot. Heritability in broad sense showed moderate highly estimates for both traits. Our results indicated the preponderance of dominance gene action in controlling both aforementioned traits. In conclusion, these S1-lines are promising to produce drought tolerant inbred line in the future, which may lead to produce drought tolerant hybrid.

Keywords: *General and specific combining ability, heritability, line × tester, maize, water stress*

Introduction

Zea mays L. is one of the most important cereal crop in the world after wheat and rice Reddy et al.(2012). It is used as food for human and feed for livestock. In 2017 season, the harvested area in the world was 239,614,584 Ha producing 1,393,981,150 MT. The harvested area in Egypt was 920,601 ha producing 7,100,000 MT (FAO, 2017). To meet the ever-increasing demand, maize production can be increased by application of improved agronomic techniques to get varieties with higher qualitative and quantitative traits and resilience to abiotic stresses (Ali *et al.* 2014). Drought is a serious problem, which dramatically decreases crop yield and quality. Drought injury may be alleviated by developing drought-tolerant hybrids adapted to dry environments such as found in the new reclaimed lands. Khalili *et al.* 2013 emphasized that drought stress is one of the most important abiotic stresses, which reduces growth, development and production of plants. Yue *et al.* (2018) found that drought had substantial effects on maize yield as well as other agronomic traits. Briefly, they stated that under water stress, number of rows per ear and 1000-grain weight are efficient traits for screening for drought-tolerant genotypes in maize. Moreover, Khan *et al.* (2001) found reduction in yield and its components including 1000-grain weight under water stress. Furthermore, Zamaninejad *et al.* (2013) reported that drought stress caused significant reduction in grain yield, number of rows per ear, number of grains per row, ear diameter and ear length. The deleterious effects of drought stress on yield attributes, e.g. number of rows per ear, number of grains per row and reduced grain size, cause reduction in yield. Combining ability is a powerful tool that has been extensively used to detect the best combiner parents in a series of its crosses and provides information on the nature and magnitude of gene actions (Uddin *et al.* 2008). There are two constituents of combining ability including general combining ability (GCA) and specific combining ability (SCA). Firstly, GCA is the average performance of parents in a series of crosses, while SCA describes those cases in which certain combinations perform relatively better or worse than would be expected on the basis of average performance of parents (Hundera 2017). Therefore, both constituents of combining ability are informative estimates for breeders in any breeding programs, which aids in identifying the best combinations of parents. Sadalla *et al.* (2017) Found that GCA and SCA mean squares were highly significant for some traits, but the mean squares for reciprocal combining ability were highly significant for 100-grain weight. In addition, Rahman *et al.* (2018) stated that crosses displayed positive SCA effects for 100-grains weight and grain yield could possibly be utilized in maize breeding programs for developing high yielding maize hybrids accompanied with other desirable attributes. Khattab *et el.* (2011) found that general combing ability (GCA) effect indicated that some lines under normal and drought stress condition seem to be good general combiners for increasing yield and yield components of hybrids. The work of Ojo *et al.* (2007) empahsized that GCA mean squares were highly significant for grain yield. Emyhum (2013) stated that Specific combining ability variance was important than general combining ability variance for all traits indicating preponderance of dominance variance in normalling these characters. Bekele *et al.* (2014) found high heritability estimates for both 100-grain weight and grain yield per plot. Furthermore, they detected high genetic advance juxtaposed with high heritability for grain yield per plot. Rafiq *et al.* (2010) reported that most of the traits had high heritability estimates indicating the preponderance of additive gene action; in addition, grain yield per plant and number of grains per row represents additive gene effects. Line × tester mating approach is an effective tool; which permits the inclusion of a set of entries to estimate combining ability, gene action, male and female, and aid to identify desirable parents and crosses (Hundera 2017). Amin *et al.* (2014) reported that Line × tester analysis is an important method randomly used to evaluate the inbred lines. Through line × tester analysis about 50% of the inbred lines can be eliminated (Singh and Chaudhary1985). Genetic information was obtained by different quantitative genetic methods line x tester analysis is a suitable and efficient method with eligible speed (Singh and Chaudhary, 1985). The line x tester analysis method has been widely used by plant breeders (Aly, 2013). The objectives of the current study were to: 1) elucidate the effect of water stress on yield and 100-grain weight in 100 S1 selected lines, 2) estimate genetic variances and heritability and 3) conduct line × tester analysis and estimate general and specific combining abilities for these lines using two testers, namely, SC162 and TWC352.

Materials and Methods

Growing condition

This study was carried out during the period from 2018 to 2019 at Assiut University Farm using one maize population (IY376, imported from India 1969) to study the effect of water stress on agronomic traits, line × tester interaction and combining ability in maize using 100 S_1 lines.

In March 2018, the population was grown, 300 vigorous and disease free plants were selected before silking, and self-pollinated. After harvest, 100 selfed ears (S1's) which had sufficient grains were chosen. Selected S1ears were individually shelled and every S1-line was divided into four equal parts. In August 2018, top-crosses were formed for S1-lines using two testers, single cross 162(SC162) and three way cross352 (TWC352). In 2019 season, 100 S1-lines and their top-crosses with SC162 and TWC 352 testers (302 genotype entry) were evaluated at Assiut University Agricultural Research Station under normal condition (every 10 days) and water stress condition (irrigated every 20 days after 2nd irrig.) using simple lattice design (10 × 10) with three replications. The experimental plot was one row; 3 meters long with 70 cm between rows, planting was in hills spaced 30 cm apart. Seedlings were thinned at one plant/hill before the first condition. Fertilizers were applied at the rate of 120 kg nitrogen/fed., before the first and second conditions. Other cultural practices were carried out as usual during the season.

Traits Studied

Grain yield /plot in grams (gms): weight of grain yield of each plot (10 plants) adjusted to 15.5% moisture content. The 100-grain weight in grams (gms): weight of 100-grains weight were randomly sampled from the aforementioned trait.

Statistical analysis

Statistical analyses were conducted using R software (version 3.6.1) utilizing package AGRICOLAE (De Mendiburu 2014).

Line (L) × tester (T) analysis were performed using the method described by Kempulorne (1957). General (GCA) and specific (SCA) combining ability effects were calculated for grain yield and 100-grain weight. The statistical model used to obtain the different effects was as follows:

$$Y_{ijk} = \mu + \rho_k + l_i + t_j + (l \times t)_{ij} + \varepsilon_{ijk}$$

Where: Y_{ijk} = the value of a character measured on ith × jth progeny in kth replication, μ is the general mean, ρ_k effect of kth replication, l_i is the effect of the ith line, t_j is the effect of the jth tester, $(l \times t)_{ij}$ is the interaction effect of the cross between ith line and jth tester and ε_{ijk} is the error term associated with each observation. Combined analysis of both normal and water stress conditions was not performed due lack of homogeneity of variances according to Bartlett's test (Bartlett 1937).

The combing ability ratio (CAR) was utilized, in the current study, to anticipate the gene action as per Baker (1978) using the following equation:

$$CAR = 2\sigma^2_{GCA} / (2\sigma^2_{GCA} + \sigma^2_{SCA}),$$

where σ^2_{GCA} and σ^2_{SCA} are the GCA and SCA variances, respectively.

Heritability in broad sense (h_b) for both traits was estimated according to Singh and Chaudhary (1985) using the following formula:

$$h_b = \frac{\sigma^2 g}{\sigma^2 p}$$

Where:

$\sigma^2 g$ = genetic variance, and $\sigma^2 p$= phenotypic variance.

Results and Discussion

Line × Tester analysis

One hundred S1-lines were crossed with two testers (SC162 and TWC352) resulted in 200 top-crosses. The lines, testers and top-crosses were evaluated under normal and water stress condition to identify the best drought-tolerant crosses. Analysis of variance for the studied traits under normal and water stress condition are presented in Table (1). Under normal condition, the results showed significant differences for 100-grain weight and grain yield per plot for parents and parents vs crosses. In addition, the crosses showed significant differences for both traits. For lines, both traits revealed non-significant differences. For testers, significant differences were found in both traits. Finally, line × tester of both traits showed significant differences. The greater contributions of lines × tester interaction than testers for both studied traits showed higher estimates of variance due to specific combining ability. In this context, our results were consistent with those found by Akula *et al.* (2018)

Results exhibited significant differences under water stress condition for 100-grain weight and grain yield per plot for parents and parents vs crosses; in addition, the crosses showed significant differences for both studied traits. For lines, 100-grain weight showed non-significant differences; whereas, grain yield per plot exhibited significant differences. For testers, significant differences were found in both studied traits. Finally, for line × tester, all traits showed significant differences. The greater contributions of lines × tester interaction than testers for both studied traits showed higher estimates of variance due to specific combining ability, in this regard, Akula *et al.* (2018) reported similar results.

Table 1. Mean squares of line × tester analysis for 100-grain weight and grain yield per plot under normal and water stress conditions.

Source	DF	MS			
		Normal condition		Water stress condition	
		100-GW	GY	100-GW	GY
Replications	2	1.02^{NS}	83579.26**	3.83^{NS}	51532.76**
Genotypes	301	19.41**	200654.15**	24.41**	172844.67**
Parents	101	21.07**	184517.47**	21.50**	85407.29**
Parents vs. Crosses	1	1474.27**	29304956.27**	2976.76**	33000040.26**
Crosses	199	11.26**	62591.36**	11.05**	52261.65**
Lines	99	10.73^{NS}	59846.23^{NS}	10.23^{NS}	55517.75*
Testers	1	196.69**	996795.66**	345.54**	1073076.94**
Lines × Testers	99	9.92**	55900.08**	8.48**	38694.29**
Error	602	2.19	8567.16	2.11	9294.06
contribution of lines		47.39	47.57	46.07	52.85
contribution of tester		8.77	8.00	15.72	10.32
contribution of line×tester		43.83	44.43	38.31	36.83

*, ** significant at 0.05 and 0.01 levels of probability, respectively.
100-GW = 100-grain weight (g), GY = grain yield per plot (g).

Mean performance

Mean performance of 100 S1-lines for 100-grain weight evaluated under normal condition are presented in Table (2). Data exhibited that S1-lines 56 and 88 possessed the highest 100-grain weight while S1-lines 17 and 52 had the lowest 100-grain weight. For the tester, SC162 it had higher 100-grain weight than TWC352. Mean performances for 100-grain weight of 200 top-crosses under normal condition are presented in Table (3). Results showed that the top-crosses involving TWC352 had higher 100-grain weight than those involving SC162. The highest values of 100-grain weight were found in cross combinations including S1-line 29 × SC162 and S1-line 99 × SC162; in addition to S1-line 31 × TWC352 and S1-line 61× TWC352. Whereas, the lowest 100-grain weight values were observed in cross combinations including S1-line 55 × SC162 and S1-line 68 × SC162; in addition to S1-line 17 × TWC352 and S1-line 29× TWC352. Under water stress condition mean performance of 100 S1-lines for 100-grain weight are shown in Table (4). Data displayed that the highest values of 100-grain weight were observed in S1-lines 34 and 86 unlike S1-lines 55 and 93. For the tester, TWC352 have lower 100-grain weight than SC162. Under water stress condition the mean performance of 200 top-crosses for 100-grain weight are presented in Table (5). Results showed that the top-crosses including TWC352 had higher 100- grain weight than those involving SC162. The highest values of 100-grain weight were observed in cross combinations including S1-line 10 ×SC162 and S1-line 34×SC162; in addition to S1-line 84×TWC352 and S1-line 98×TWC352. Whereas, the lowest values of 100- grain weight were found in cross combinations including S1-line 52×SC162 and S1-line 75×SC162; in addition to S1-line 29× TWC352 and S1-line 95 × TWC352.

Mean performance of 100 S1-lines for grain yield per plot evaluated under normal condition are presented in Table (6). Data exhibited that S1-lines 65 and 68 possessed the highest grain yield per plot while: S1-lines 63 and 77 had the lowest grain yield per plot. For the tester, SC162 had higher grain yield per plot than TWC352. Mean performances for grain yield per plot of 200 top-crosses under normal condition are presented in Table (7). Results showed that the top-crosses involving TWC352 had higher grain yield per plot than those involving SC162.The highest values of grain yield per plot found in cross combinations including S1 line 2× SC162 and S1 line 86×SC162; in addition to S1-line 37 × TWC352 and S1-line 99 × TWC352. However, the lowest grain yield per plot values were observed in cross combinations including S1-line 73 × SC162 and S1-line 85 × SC162; in addition to S1-line 9×TWC352 and S1-line 27× TWC352.

Under water stress condition the mean performance of 100 S1-lines for grain yield per plot are shown in Table (8). Data displayed that the highest values of grain yield per plot were observed in S1-lines 76 and 88 unlike, S1-line 3 and 89. For the tester, TWC352 have lower grain yield per plot than SC162.Under water stress condition mean performance of 200 top-crosses for grain yield per plot are presented in Table (9). Results showed that the top-crosses including TWC352 had higher grain yield per plot than those involving SC162.The highest values of grain yield per plot found in cross combinations including S1-line 34×SC162 and S1-line 98× SC162; S1-line 70×TWC352 and S1-line 98× TWC352. Whereas, the lowest values of grain yield per plot were found in the cross combinations including S1-line 50×SC162 and S1-line 87× SC162; in addition to S1-line 4× TWC352 and S1-line 53×TWC352.

Table 2. Means (M) and their standard error (SE) of 100-grain weight (g) for parents (S1-lines and two testers) under normal condition.

S1-line	M±SE	S1-line	M±SE	S1-line	M±SE
1	20.41±0.88	35	19.98±1.07	69	17.22±1.35
2	26.10±1.18	36	19.00±0.77	70	17.09±0.12
3	20.23±1.02	37	20.88±0.18	71	19.04±1.12
4	21.89±0.63	38	20.86±1.37	72	22.44±1.08
5	19.94±0.31	39	22.59±0.46	73	20.50±1.87
6	16.77±0.89	40	24.59±0.30	74	23.33±1.45
7	21.18±2.06	41	19.54±0.74	75	19.35±0.88
8	18.32±0.44	42	20.68±0.43	76	20.07±0.66
9	20.43±1.30	43	19.95±0.55	77	21.26±1.01
10	24.66±0.70	44	20.14±2.38	78	19.05±0.53
11	19.76±0.81	45	22.49±0.87	79	17.06±0.69
12	23.10±0.50	46	21.11±0.49	80	19.98±1.54
13	20.31±0.93	47	21.93±0.97	81	20.94±0.01
14	17.47±0.67	48	20.40±0.38	82	20.15±0.64
15	16.29±0.95	49	20.18±0.43	83	16.15±0.49
16	19.55±1.02	50	20.79±0.90	84	20.02±0.54
17	16.00±0.58	51	20.99±1.11	85	20.98±0.59
18	14.92±1.16	52	15.35±0.38	86	23.40±0.83
19	21.25±0.40	53	23.87±0.77	87	23.44±0.21
20	21.34±0.33	54	21.28±1.13	88	25.27±0.64
21	24.27±0.64	55	14.39±0.75	89	22.75±0.95
22	16.62±0.31	56	24.73±0.73	90	17.39±1.11
23	20.97±0.79	57	22.46±1.08	91	18.02±1.62
24	20.51±0.84	58	19.95±0.25	92	21.97±1.40
25	21.32±0.75	59	20.84±1.09	93	16.40±1.61
26	23.15±0.35	60	20.93±1.27	94	19.31±0.35
27	17.98±0.58	61	22.52±1.31	95	18.24±1.09
28	21.39±0.69	62	22.11±1.23	96	16.08±0.27
29	19.30±0.75	63	19.32±1.35	97	17.90±0.65
30	19.47±0.47	64	20.71±0.92	98	22.07±1.54
31	22.74±0.88	65	18.66±1.65	99	23.57±0.87
32	20.94±0.75	66	24.58±1.28	100	18.95±2.12
33	22.09±1.09	67	21.66±0.38	SC162	28.73±0.27
34	24.14±0.56	68	17.03±0.53	TWC352	27.23±0.15

Table 3. Means (M) and their standard error (SE) of 100-grain weight (g) for top-crosses (T1= SC162 and T2=TWC352) under normal condition.

S1-line	T1	T2	S1-line	T1	T2	S1-line	T1	T2
	M±SE	M±SE		M±SE	M±SE		M±SE	M±SE
1	23.06±1.86	23.34±0.48	35	21.70±1.30	25.01±0.82	69	19.91±0.52	25.23±0.49
2	25.65±0.68	22.76±1.24	36	22.32±0.39	22.10±0.59	70	22.16±0.63	25.39±0.33
3	25.42±0.87	21.73±0.34	37	22.56±0.62	24.55±0.24	71	20.73±0.15	23.84±0.77
4	25.38±1.20	23.49±0.47	38	19.40±0.49	20.87±0.81	72	24.83±0.84	24.40±0.51
5	23.68±1.60	23.72±0.29	39	21.55±0.46	23.45±0.64	73	21.13±0.86	24.80±0.95
6	22.49±0.53	23.35±0.39	40	24.92±0.76	24.87±0.74	74	22.13±0.45	24.10±0.28
7	21.88±1.31	24.81±0.66	41	22.08±0.55	24.55±0.66	75	16.22±0.64	22.64±0.95
8	23.47±0.47	25.34±0.41	42	23.90±0.80	24.33±1.02	76	23.19±0.77	24.94±0.51
9	23.70±1.69	21.54±0.62	43	18.98±0.93	21.30±1.60	77	22.67±0.39	23.93±0.27
10	25.58±0.80	25.12±0.46	44	19.72±0.31	23.33±0.44	78	19.62±0.65	22.62±0.36
11	22.39±0.35	22.83±0.46	45	22.91±0.66	23.31±1.28	79	21.51±0.30	21.52±0.93
12	25.15±1.52	22.57±0.75	46	21.00±0.58	23.75±0.31	80	23.21±0.64	25.52±0.36
13	25.35±0.65	23.43±1.11	47	23.87±0.43	25.89±0.74	81	23.47±0.46	22.87±0.31
14	25.04±0.18	21.14±1.38	48	20.73±0.28	25.50±0.87	82	25.92±0.56	23.97±0.67
15	24.53±1.00	22.24±0.67	49	20.56±0.18	23.73±1.12	83	19.22±0.32	23.90±1.57
16	25.57±1.20	22.81±0.53	50	21.79±0.61	24.45±0.52	84	22.13±0.95	25.43±0.35
17	20.32±1.39	20.00±0.86	51	23.96±1.22	24.08±0.23	85	19.52±1.28	23.66±0.30
18	20.34±0.79	25.70±0.72	52	18.79±0.96	22.65±0.60	86	23.49±0.61	25.71±0.31
19	23.99±0.92	24.93±0.59	53	25.46±0.20	24.06±1.89	87	24.84±0.71	24.61±0.74
20	22.51±0.55	20.72±0.71	54	22.65±0.43	24.47±1.05	88	24.27±0.16	23.13±0.84
21	22.35±0.61	24.19±0.32	55	17.04±0.79	20.40±0.70	89	24.71±1.04	25.15±0.49
22	21.96±0.54	25.84±0.93	56	21.57±0.30	26.07±0.17	90	19.22±0.47	24.00±0.67
23	23.47±0.55	24.83±1.25	57	21.57±1.01	24.59±0.69	91	24.11±0.37	23.66±0.43
24	23.52±0.55	23.97±0.99	58	23.52±0.89	24.87±1.16	92	22.89±0.69	25.78±0.74
25	22.62±0.86	23.37±1.35	59	21.18±1.10	25.86±0.64	93	23.65±0.33	22.00±0.96
26	23.22±1.10	23.43±0.58	60	20.82±1.10	25.68±1.05	94	24.42±0.60	23.23±0.96
27	22.97±1.13	21.61±0.61	61	21.62±1.23	26.61±0.38	95	22.95±0.50	20.10±0.25
28	22.26±0.94	23.07±0.42	62	24.44±0.47	25.19±0.90	96	20.95±0.88	24.45±0.50
29	27.39±0.05	19.56±0.45	63	22.88±0.98	24.27±0.60	97	20.72±1.04	24.73±1.00
30	25.56±0.99	24.97±0.62	64	25.74±0.87	21.74±0.96	98	24.27±0.62	25.45±0.58
31	22.60±0.44	26.26±0.27	65	20.37±0.73	24.27±1.29	99	26.23±0.72	25.02±0.62
32	22.49±1.45	22.56±0.85	66	26.11±0.65	25.87±0.24	100	23.58±0.46	23.73±0.81
33	23.21±1.02	24.69±0.45	67	20.89±0.71	24.23±0.29			
34	25.80±0.77	23.35±1.05	68	18.56±0.71	23.83±0.56	Mean	22.68	23.83

Table 4. Means (M) and their standard error (SE) of 100-grain weight (g) for parents (S1-lines and two testers) under water stress condition.

S1-line	M±SE	S1-line	M±SE	S1-line	M±SE
1	17.58±1.43	35	15.11±0.62	69	13.31±0.07
2	21.18±0.84	36	17.96±0.44	70	15.64±0.53
3	16.56±1.69	37	16.25±0.82	71	17.00±0.58
4	19.22±0.80	38	15.19±0.74	72	20.53±1.62
5	17.41±0.76	39	18.23±0.34	73	18.77±1.02
6	13.53±0.31	40	20.70±0.70	74	19.40±0.39
7	18.69±1.36	41	16.51±0.29	75	15.66±2.39
8	16.65±0.34	42	18.30±0.35	76	15.93±0.85
9	17.21±0.71	43	17.17±0.44	77	15.95±1.07
10	18.90±0.62	44	17.69±1.43	78	16.18±0.48
11	17.17±0.44	45	15.11±1.06	79	14.41±1.21
12	17.33±0.88	46	17.70±0.25	80	16.23±1.86
13	19.03±0.90	47	17.08±0.37	81	18.65±0.36
14	16.43±0.25	48	17.52±0.31	82	18.23±0.66
15	14.46±0.43	49	15.92±0.89	83	12.88±1.05
16	17.19±0.47	50	16.70±0.35	84	15.11±0.95
17	14.25±0.67	51	17.64±0.92	85	17.31±0.56
18	13.11±1.64	52	13.79±0.62	86	22.19±0.62
19	19.00±0.58	53	19.91±0.55	87	17.61±0.21
20	19.26±0.51	54	18.49±0.84	88	21.49±1.33
21	19.80±1.34	55	12.27±0.97	89	20.97±0.80
22	15.48±0.62	56	21.13±0.33	90	16.10±0.95
23	19.42±0.78	57	18.48±1.15	91	15.36±1.75
24	19.60±0.85	58	17.93±1.12	92	18.15±0.11
25	20.22±0.42	59	18.43±0.65	93	10.80±0.47
26	20.42±0.56	60	17.17±1.01	94	17.22±0.40
27	16.04±0.60	61	19.98±0.65	95	15.73±1.19
28	19.55±0.53	62	20.13±1.33	96	14.49±0.36
29	17.96±0.85	63	16.23±1.82	97	15.18±0.92
30	17.55±0.25	64	18.32±1.24	98	19.18±0.66
31	20.10±0.67	65	16.62±1.06	99	20.98±1.09
32	17.26±1.22	66	21.89±1.17	100	16.19 ±1.24
33	17.20±0.83	67	17.91±0.59	SC162	27.47±0.09
34	22.98±0.65	68	12.28±0.50	TWC352	26.50±0.17

Table 5. Means (M) and their standard error (SE) of 100-grain weight (g) for top-crosses (T1= SC162 and T2=TWC352) under water stress condition.

S1-line	T1	T2	S1-line	T1	T2	S1-line	T1	T2
	M±SE	M±SE		M±SE	M±SE		M±SE	M±SE
1	20.28±0.64	21.66±0.33	35	19.89±0.94	22.00±0.90	69	19.21±0.51	22.9±0.33
2	23.03±0.58	20.39±0.75	36	20.42±0.70	20.36±0.31	70	21.63±0.75	24.43±0.25
3	23.95±1.23	20.03±0.21	37	21.49±0.60	22.94±0.13	71	18.77±0.79	21.83±0.54
4	23.09±0.32	21.53±0.74	38	16.78±0.61	20.39±0.49	72	23.61±0.56	23.43±0.48
5	20.38±1.45	21.38±0.59	39	19.40±0.50	22.38±0.18	73	19.44±1.10	23.81±0.98
6	20.45±0.55	21.20±0.53	40	22.85±0.07	21.64±0.95	74	19.66±1.47	21.79±0.54
7	20.50±0.95	23.17±0.55	41	21.06±0.96	22.22±0.54	75	15.72±0.59	20.76±0.36
8	22.42±0.45	21.52±0.25	42	21.19±1.18	23.23±1.08	76	20.95±1.28	23.05±1.78
9	19.50±1.28	20.49±0.58	43	17.32±0.88	20.14±1.50	77	21.34±0.62	23.19±0.39
10	25.07±0.79	23.69±0.27	44	17.57±0.34	21.65±0.26	78	17.68±1.25	21.38±1.04
11	20.20±0.45	21.56±0.57	45	22.25±0.58	21.23±0.63	79	18.67±0.80	19.48±0.93
12	20.55±0.61	21.49±0.81	46	19.13±0.34	21.27±0.80	80	20.40±0.37	22.97±0.70
13	23.19±0.41	20.76±0.64	47	20.86±0.80	23.83±0.74	81	21.89±0.32	20.45±0.53
14	22.22±0.19	18.84±0.65	48	19.32±0.44	23.57±0.72	82	20.77±1.18	23.47±0.70
15	22.67±1.20	21.49±0.59	49	17.96±1.32	22.47±1.29	83	16.15±1.39	22.78±1.56
16	21.12±0.75	20.51±0.64	50	20.63±0.62	22.49±0.70	84	20.05±0.55	24.58±0.21
17	19.70±1.04	19.09±1.12	51	22.29±0.74	22.27±0.49	85	18.82±1.17	21.92±1.13
18	18.86±1.13	24.38±0.76	52	15.85±1.16	21.36±0.70	86	21.27±0.90	24.08±0.51
19	22.06±0.53	21.73±0.74	53	21.58±1.79	21.93±1.83	87	21.33±1.28	23.34±0.28
20	19.92±1.19	20.04±0.78	54	21.60±0.70	23.36±1.13	88	22.55±0.61	22.50±0.78
21	20.65±0.60	20.65±1.35	55	15.59±0.68	18.59±0.12	89	22.51±0.87	24.32±0.40
22	21.01±0.45	24.05±0.56	56	20.42±0.32	23.32±0.43	90	18.82±0.64	22.26±0.59
23	20.92±0.86	21.62±0.29	57	18.64±0.90	23.22±0.22	91	22.09±0.34	21.54±0.58
24	21.90±0.15	21.87±1.44	58	20.53±0.56	23.63±1.20	92	21.21±0.43	25.07±0.62
25	19.79±0.87	21.32±0.76	59	18.21±0.92	24.55±0.56	93	21.78±0.80	21.02±0.77
26	21.77±1.07	21.89±0.97	60	19.40±0.68	24.11±0.53	94	23.47±0.68	22.01±1.15
27	21.85±1.03	20.80±0.65	61	20.65±0.94	25.68±0.23	95	21.88±0.76	18.53±0.73
28	21.65±0.22	22.01±0.77	62	22.42±0.57	23.15±0.49	96	19.29±0.33	22.45±0.45
29	23.73±0.75	18.41±0.58	63	22.13±1.12	23.32±0.50	97	19.44±0.84	23.07±1.25
30	21.63±1.40	24.23±0.40	64	22.36±0.21	21.04±1.02	98	21.99±0.40	24.85±0.37
31	21.55±0.69	25.29±0.38	65	19.24±0.36	23.18±1.39	99	23.19±0.17	23.38±0.86
32	19.63±1.58	21.75±1.11	66	23.49±0.49	24.20±0.63	100	22.45±0.47	22.97±1.06
33	21.22±0.86	23.53±0.23	67	19.75±0.71	22.87±0.14			
34	24.73±0.41	21.26±0.97	68	16.95±1.09	21.3±0.99	Mean	20.68	22.20

Table 6. Means (M) and their standard error (SE) of grain yield per plot (g) for parents (S1-lines and two testers) under normal condition.

S1-line	M±SE	S1-line	M±SE	S1-line	M±SE
1	688.71±8.15	35	764.00±7.57	69	669.67±5.49
2	352.30±2.06	36	362.77±5.30	70	645.00±4.62
3	234.67±8.67	37	664.00±7.23	71	664.33±4.06
4	311.00±6.66	38	660.67±5.21	72	444.15±4.91
5	280.67±5.49	39	762.33±6.94	73	679.00±5.77
6	710.23±5.72	40	659.33±7.51	74	684.67±5.78
7	704.08±26.39	41	687.33±5.04	75	479.33±4.63
8	642.48±12.00	42	643.30±6.11	76	681.33±4.98
9	634.00±4.36	43	679.67±6.64	77	175.00±6.35
10	260.33±8.69	44	659.00±5.20	78	745.33±6.06
11	657.33±15.72	45	364.26±4.15	79	454.76±4.56
12	371.06±5.77	46	676.33±4.63	80	346.67±5.78
13	666.67±16.44	47	253.33±3.48	81	681.00±5.20
14	614.00±7.21	48	272.67±6.96	82	716.00±6.35
15	657.08±4.23	49	247.67±14.15	83	461.00±6.08
16	375.00±2.89	50	676.33±5.55	84	360.33±6.64
17	261.39±14.21	51	367.67±7.22	85	627.33±4.06
18	235.67±7.45	52	285.25±4.84	86	372.33±5.49
19	365.28±7.82	53	712.33±6.06	87	760.67±5.21
20	652.17±12.83	54	422.90±4.12	88	677.33±7.51
21	322.90±13.20	55	640.67±7.22	89	272.00±4.36
22	270.00±6.35	56	683.22±4.56	90	460.42±6.43
23	736.00±9.54	57	715.33±4.06	91	616.33±3.76
24	625.00±14.43	58	681.38±3.52	92	747.67±5.24
25	323.06±6.74	59	384.33±7.31	93	237.33±4.91
26	681.67±6.98	60	669.33±5.78	94	625.00±4.36
27	281.33±9.84	61	335.33±4.91	95	342.86±9.18
28	343.83±3.61	62	448.52±6.23	96	622.00±3.46
29	641.67±11.57	63	233.44±6.06	97	266.00±5.51
30	725.00±7.00	64	671.00±6.93	98	710.33±5.78
31	727.33±4.63	65	764.67±4.91	99	470.00±4.62
32	490.07±5.31	66	672.83±7.51	100	781.33±5.24
33	673.33±5.24	67	375.67±4.63	SC162	1906.67±23.33
34	733.67±3.48	68	782.00±4.93	TWC352	1576.67±18.56

Table 7. Means (M) and their standard error (SE) of grain yield per plot (g) for top-crosses (T1= SC162 and T2=TWC352) under normal condition.

S1-line	T1	T2	S1-line	T1	T2	S1-line	T1	T2
	M±SE	M±SE		M±SE	M±SE		M±SE	M±SE
1	958.34±39.29	1022.96±93.72	35	810.00±74.97	1126.41±62.73	69	687.26±27.68	961.64±61.65
2	1245.75±84.60	1007.40±145.38	36	683.97±18.45	967.74±143.17	70	786.16±66.66	1145.56±68.59
3	1172.25±106.56	809.22±106.31	37	1105.68±46.78	1244.77±65.43	71	637.90±24.33	914.19±16.41
4	1091.53±17.96	699.53±47.37	38	862.05±67.70	1013.96±58.14	72	777.27±60.76	927.00±22.50
5	943.33±69.81	696.52±44.23	39	807.38±18.31	1068.61±96.36	73	636.87±16.74	916.72±25.28
6	1019.26±96.40	869.64±48.04	40	1007.22±26.95	1035.63±125.35	74	841.03±7.75	888.07±29.97
7	936.93±165.45	954.44±69.96	41	1048.72±82.35	970.64±117.47	75	665.97±26.31	994.94±12.83
8	954.36±43.92	997.54±123.96	42	817.33±54.43	763.38±11.06	76	1012.06±51.75	1031.81±34.46
9	934.20±112.81	672.78±30.48	43	774.33±75.46	1084.37±56.67	77	815.11±44.81	871.78±21.73
10	1033.78±66.93	1020.28±106.04	44	816.57±56.92	859.12±59.98	78	675.76±40.55	1134.83±42.95
11	1152.63±109.50	940.20±24.74	45	877.39±7.52	958.54±135.22	79	934.89±23.47	1143.05±73.38
12	974.95±40.25	1050.00±57.74	46	933.57±115.88	944.04±37.64	80	848.50±55.97	1089.00±62.45
13	1181.48±114.44	882.75±96.50	47	1089.06±58.16	1124.95±40.48	81	750.98±48.89	1073.04±47.14
14	1025.49±21.68	1035.17±42.90	48	923.21±92.33	979.39±60.78	82	1038.14±39.32	1100.42±60.35
15	1072.17±82.80	933.64±52.45	49	730.83±33.40	1006.11±21.55	83	797.96±54.64	870.56±18.32
16	950.65±82.22	987.76±82.67	50	649.44±19.65	964.11±61.40	84	941.48±82.63	962.11±57.19
17	867.22±108.93	842.57±37.81	51	997.44±45.08	1000.44±56.01	85	607.57±64.47	893.33±54.88
18	887.36±71.86	875.22±54.07	52	689.49±75.56	1102.02±68.55	86	1287.10±22.52	1166.78±36.96
19	1008.36±91.06	1203.17±32.56	53	915.78±141.09	906.15±72.70	87	639.50±92.50	961.50±74.09
20	1094.40±113.03	1016.90±81.61	54	798.08±81.02	970.08±22.33	88	953.66±75.97	964.95±32.66
21	940.22±61.08	896.89±28.88	55	830.00±64.32	946.18±56.55	89	811.93±84.60	955.54±82.86
22	932.88±96.54	971.68±61.46	56	666.38±87.88	999.59±57.96	90	866.92±43.21	1117.21±71.24
23	1081.33±1.33	783.70±75.52	57	919.89±27.43	997.30±80.54	91	915.36±33.90	1107.90±57.36
24	968.69±74.90	967.07±26.99	58	1068.94±102.37	1088.71±50.14	92	811.22±12.80	1018.89±22.40
25	1010.13±106.13	1109.00±8.14	59	970.00±85.78	1169.02±37.52	93	837.85±56.12	1088.00±58.60
26	975.32±92.45	826.51±40.09	60	785.00±42.77	1075.33±41.31	94	1005.83±20.22	945.33±23.70
27	805.26±83.98	652.67±59.11	61	643.11±61.76	959.21±28.73	95	914.95±55.95	793.56±35.78
28	890.96±72.25	886.04±16.92	62	787.35±54.41	881.82±40.28	96	762.39±27.79	1002.00±60.08
29	1377.51±12.02	852.45±27.53	63	665.06±11.15	977.05±74.68	97	940.00±9.45	1162.00±30.29
30	1147.22±159.86	1039.03±20.61	64	804.17±106.11	1007.73±13.42	98	998.00±52.14	1186.71±25.98
31	752.22±43.39	920.33±139.43	65	676.44±66.62	1129.50±55.06	99	858.43±74.09	1204.44±45.31
32	897.49±19.21	897.64±16.78	66	922.25±8.52	1021.24±22.31	100	921.33±70.28	833.21±6.35
33	765.23±46.68	877.93±67.10	67	821.10±69.33	883.47±55.35			
34	1060.13±8.40	1119.17±81.52	68	934.31±73.98	1101.33±69.36	Mean	899.20	980.72

Table 8. Means (M) and their standard error (SE) of grain yield per plot (g) for parents (S1-lines and two testers) under water stress condition.

S1-line	M±SE	S1-line	M±SE	S1-line	M±SE
1	246.16±6.40	35	327.83±6.35	69	283.00±5.20
2	215.56±2.42	36	287.33±4.33	70	314.83±34.15
3	112.83±5.29	37	288.67±4.98	71	382.00±4.62
4	117.33±3.84	38	325.67±8.11	72	339.00±5.51
5	169.78±13.83	39	383.00±8.14	73	260.89±5.60
6	343.89±14.13	40	278.33±6.36	74	322.67±3.76
7	251.31±11.67	41	379.67±4.63	75	244.00±5.51
8	290.17±1.59	42	256.05±6.80	76	391.33±3.76
9	258.81±7.65	43	355.00±9.54	77	146.00±6.66
10	159.17±6.51	44	331.50±9.25	78	344.78±5.00
11	191.33±5.93	45	253.07±5.57	79	282.86±5.15
12	223.33±7.51	46	245.43±4.91	80	232.00±4.36
13	373.75±9.21	47	171.44±4.82	81	388.67±5.78
14	238.97±8.89	48	122.67±3.76	82	381.00±5.20
15	156.63±7.61	49	153.67±3.48	83	214.00±5.51
16	255.65±9.70	50	378.67±5.49	84	220.33±4.91
17	148.54±8.58	51	126.67±4.41	85	379.00±5.77
18	177.87±10.32	52	124.56±7.87	86	263.67±4.33
19	220.33±15.6	53	372.67±4.26	87	378.00±6.35
20	220.00±5.77	54	280.11±3.95	88	389.00±4.62
21	258.33±10.14	55	275.25±7.23	89	113.67±3.48
22	182.22±4.01	56	383.00±7.23	90	220.00±3.61
23	312.00±6.24	57	361.00±4.62	91	330.67±4.06
24	376.11±8.73	58	349.67±6.36	92	387.00±4.36
25	279.00±6.66	59	268.33±4.63	93	118.67±5.55
26	245.42±7.92	60	234.33±5.81	94	280.33±5.49
27	125.56±2.42	61	263.24±7.43	95	234.11±5.98
28	261.25±9.21	62	251.67±4.98	96	346.00±8.08
29	352.49±7.70	63	116.00±5.51	97	180.11±8.23
30	354.58±9.02	64	257.67±4.91	98	386.00±4.62
31	364.33±7.54	65	357.33±7.42	99	228.83±5.05
32	305.00±33.18	66	368.33±5.21	100	368.67±4.91
33	230.48±5.79	67	239.33±5.49	SC162	1408.33±36.32
34	378.67±4.67	68	379.67±5.49	TWC352	1240.00±21.79

Table 9. Means (M) and their standard error (SE) of grain yield per plot (g) for top-crosses (T1= SC162 and T2=TWC352) under water stress condition.

S1-line	T1	T2	S1-line	T1	T2	S1-line	T1	T2
	M±SE	M±SE		M±SE	M±SE		M±SE	M±SE
1	748.71±78.03	826.99±9.22	35	572.84±123.99	869.58±58.29	69	505.76±75.68	629.72±15.72
2	878.15±94.40	681.43±34.30	36	502.79±49.04	649.33±37.97	70	490.00±52.73	997.06±65.24
3	828.65±28.52	651.63±41.30	37	814.77±92.12	783.68±86.65	71	573.14±22.71	792.23±35.96
4	576.90±24.34	511.67±60.99	38	586.45±100.84	838.96±91.94	72	790.18±36.37	768.21±24.43
5	625.73±42.81	568.72±22.05	39	703.89±39.70	640.56±31.72	73	585.00±8.39	817.81±17.46
6	831.54±56.66	706.48±35.45	40	889.62±55.62	844.82±29.01	74	499.29±60.89	651.21±14.79
7	645.07±129.16	813.00±77.18	41	785.53±86.28	658.67±83.82	75	549.03±11.84	601.18±37.47
8	703.67±76.61	611.68±51.67	42	618.72±99.92	686.01±47.40	76	842.74±82.46	726.27±51.71
9	533.22±65.79	597.18±28.69	43	588.91±77.28	810.41±111.90	77	723.65±77.84	652.92±42.48
10	798.89±104.08	791.46±55.76	44	626.92±17.05	740.20±74.07	78	452.17±35.01	830.27±68.67
11	851.05±106.85	848.86±26.89	45	670.00±13.32	790.62±84.29	79	646.15±62.26	648.53±55.14
12	660.19±129.26	820.03±45.66	46	700.74±106.30	722.24±13.23	80	581.34±41.30	733.59±47.56
13	860.47±62.82	874.33±41.03	47	620.54±96.91	806.84±32.66	81	594.94±26.40	553.73±44.72
14	668.46±145.81	678.46±125.09	48	620.13±27.92	821.21±98.03	82	534.56±31.65	701.40±53.74
15	691.99±63.09	811.81±26.68	49	432.50±93.19	707.73±109.51	83	496.99±35.16	739.00±33.38
16	548.75±51.37	685.78±63.32	50	417.06±46.58	678.84±31.78	84	696.67±60.64	664.33±76.3
17	649.73±9.30	723.84±77.27	51	729.07±47.85	683.57±45.49	85	529.69±58.12	674.71±66.95
18	666.94±122.50	791.44±52.49	52	409.14±52.48	869.83±81.72	86	1140.00±20.82	826.00±49.96
19	675.35±31.91	766.37±75.27	53	482.50±101.89	487.94±6.50	87	324.04±70.16	628.48±24.85
20	757.49±88.38	783.50±63.18	54	621.01±33.27	647.66±18.53	88	706.28±41.82	688.40±46.10
21	739.47±56.10	681.10±77.25	55	681.35±77.76	687.41±11.76	89	571.69±51.46	843.44±29.69
22	876.54±96.28	800.87±57.16	56	531.43±109.70	733.35±37.16	90	602.67±43.50	921.44±42.35
23	651.86±48.86	657.93±37.60	57	704.30±52.22	879.93±17.67	91	780.27±48.88	567.47±38.13
24	660.24±89.90	782.52±39.82	58	660.39±88.18	915.00±50.53	92	647.55±68.14	726.07±22.37
25	481.04±76.79	945.41±103.93	59	653.08±125.56	868.47±66.67	93	550.35±44.53	714.09±54.51
26	706.21±22.54	723.33±73.73	60	604.02±45.98	677.47±44.33	94	844.57±52.89	701.62±60.94
27	462.40±41.51	554.00±47.16	61	533.71±87.48	773.11±78.79	95	515.48±50.70	582.54±91.00
28	759.51±7.06	677.49±57.85	62	657.74±57.81	752.51±42.60	96	589.74±15.11	882.22±30.21
29	907.77±127.71	639.24±40.60	63	493.11±48.21	705.72±46.90	97	599.67±99.83	966.67±12.44
30	833.83±134.71	865.57±44.44	64	505.13±150.56	763.39±70.53	98	943.48±27.40	1126.33±31.99
31	646.31±9.09	804.42±89.22	65	625.25±51.93	834.32±42.79	99	543.84±99.45	778.33±290.26
32	732.58±115.28	626.07±50.00	66	840.78±16.86	733.33±64.69	100	759.70±77.20	643.17±26.45
33	661.43±29.15	611.00±88.71	67	495.49±96.25	573.33±15.81			
34	952.18±64.87	823.99±82.48	68	618.97±74.75	786.73±55.51	Mean	654.81	739.38

Estimates of general combining ability (GCA) effects

Estimates of GCA effects for 100-grain weight under normal condition (Table 10) showed that S1-lines 55 and 75 showed negative and significant GCA effects with value of – 4.53 and – 3.82, respectively. Conversely, S1-lines 10 and 99 displayed positive and significant GCA effects for 100-GW towards with value of 2.10 and 2.37. For the tester, T2 was the best general combiner, in contrast; T1 was poor general combiner for 100-grain weight. However, under water stress condition, estimates of GCA effects for 100-grain weight (Table 10) revealed that out of 100 S1-lines studied in line × tester cross, Similarly, S1-lines 55 and 75 showed negative and significant effects of GCA under water stress with values of – 4.35 and – 3.20, respectively. However, S1-lines10 and 66 displayed positive and significant GCA effects for 100-GW towards with values of 2.94 and 2.40, respectively. For the tester, T2 was the best general combiner while T1 was poor general combiner for 100-grain weight. Similar to the current findings, positive and negative significant GCA effects for 1000 grain weight were reported by Wali *et al.* (2010).

Under normal condition, estimates of GCA effects for grain yield per plot (Table 11) showed that out of the 100 S1-lines studied in line × tester cross, twenty-eight S1-lines exhibited positive and significant GCA effects while twenty-three S1-lines exhibited negative and significant GCA effects. S1-line 86 exhibited the maximum GCA effect with a value of 286.98, whereas 27 and 45 exhibited the lowest GCA effect with a value of -210.99. For the tester, T2 was the best general combiner while T1 was poor general combiner for grain yield per plot. Indicating the existence of the best and the poorest general combiners in the group of S1-lines studied, respectively; in addition, S1-lines identified for good general combining ability could be utilized in maize grain improvement programs for improvement of the traits of interest as these S1-lines have high potential to transfer desirable traits to their cross progenies (Abrha *et al.* 2013). Both positive and negative GCA effects were reported in maize by several investigators (Ahmed and Saleem 2003). Under water stress condition, estimates of GCA effects for grain yield per plot (Table 11) showed that out of the 100 S1-lines studied in line × tester cross eighteen S1-lines exhibited positive and significant GCA effects while twenty S1-lines exhibited negative and significant GCA effects. S1-line 98 exhibited the maximum GCA effect with a value of 337. 81, whereas S1-line 87 exhibited the lowest GCA effect with a value of -220.84. For the tester, T2 was the best general combiner in contrast; T1 was poor general combiner for grain yield per plot. Similar to the current findings, positive and negative significant GCA effects for grain yield per plot were reported by Asif *et al.* (2014).

Table 10. General combining ability effects (GCA) for 100-grain weight for 100 S1-lines and the two testers (SC162 and TWC352) under normal and water stress conditions.

S1-lines / testers	100-GWC	100-GWS	S1-lines / testers	100-GWC	100-GWS	S1-lines / testers	100-GWC	100-GWS
1	-0.05	-0.48	35	0.10	-0.50	68	-2.06**	-2.32**
2	0.95	0.27	36	-1.04	-1.05	69	-0.68	-0.39
3	0.32	0.55	37	0.30	0.77	70	0.52	1.59**
4	1.19*	0.87	38	-3.12**	-2.86**	71	-0.97	-1.15
5	0.45	-0.56	39	-0.75	-0.55	72	1.36*	2.08**
6	-0.33	-0.62	40	1.64**	0.80	73	-0.29	0.18
7	0.09	0.39	41	0.06	0.20	74	-0.14	-0.72
8	1.15	0.53	42	0.86	0.76	75	-3.82**	-3.20**
9	-0.63	-1.45*	43	-3.12**	-2.71**	76	0.81	0.56
10	2.10**	2.94**	44	-1.73**	-1.84**	77	0.05	0.82
11	-0.64	-0.56	45	-0.14	0.30	78	-2.13**	-1.91**
12	0.61	-0.43	46	-0.88	-1.24*	79	-1.74**	-2.37**
13	1.14	0.53	47	1.63**	0.90	80	1.11	0.24
14	-0.16	-0.91	48	-0.14	0.00	81	-0.09	-0.27
15	0.13	0.64	49	-1.11	-1.23*	82	1.69**	0.68
16	0.94	-0.63	50	-0.13	0.12	83	-1.69**	-1.98**
17	-3.09**	-2.05**	51	0.77	0.84	84	0.53	0.87
18	-0.23	0.18	52	-2.53**	-2.84**	85	-1.66**	-1.08
19	1.21*	0.45	53	1.51*	0.31	86	1.35*	1.23*
20	-1.64**	-1.46*	54	0.31	1.04	87	1.47*	0.89
21	0.02	-0.79	55	-4.53**	-4.35**	88	0.45	1.08
22	0.65	1.09	56	0.57	0.42	89	1.68**	1.97**
23	0.90	-0.17	57	-0.17	-0.52	90	-1.64**	-0.90
24	0.50	0.44	58	0.94	0.63	91	0.63	0.37
25	-0.26	-0.89	59	0.26	-0.06	92	1.08	1.70**
26	0.07	0.38	60	0.00	0.31	93	-0.43	-0.04
27	-0.96	-0.12	61	0.86	1.72**	94	0.57	1.30*
28	-0.59	0.39	62	1.56**	1.34*	95	-1.73**	-1.24*
29	0.22	-0.37	63	0.32	1.28*	96	-0.55	-0.57
30	2.01**	1.49*	64	0.49	0.26	97	-0.53	-0.19
31	1.18*	1.98**	65	-0.94	-0.24	98	1.61**	1.98**
32	-0.73	-0.75	66	2.74**	2.40**	99	2.37**	1.84**
33	0.70	0.93	67	-0.69	-0.13	100	0.40	1.27*
34	1.32*	1.56**						
S.E.(gca for line)	0.60	0.59	T1(SC 162)	-0.57**	-0.76**	S.E. (gca for tester)	0.09	0.08
S.E. (gi - gj)line	0.85	0.88	T2(TWC352)	0.57**	0.76**	S.E. (gi - gj)tester	0.12	0.12

100-GWC = 100-grain weight under normal condition, 100-GWS = 100-grain weight under water stress condition.

Table 11. General combining ability effects (GCA) for grain yield per plot for 100 S1-lines and the two testers (SC162 and TWC352) under normal and water stress conditions.

S1-lines / testers	GYC	GYS	S1-lines / testers	GYC	GYS	S1-lines/ testers	GYC	GYS
1	50.70	90.76*	35	28.25	24.11	68	77.86*	5.75
2	186.62**	82.69*	36	-114.10**	-121.04**	69	-115.51**	-129.36**
3	50.78	43.05	37	165.81**	102.13**	70	25.90	46.43
4	-44.43	-152.81**	38	115.69**	15.60	71	-163.91**	-14.41
5	-120.04**	-99.88*	39	-21.40	-24.88	72	-87.82*	82.10*
6	4.49	71.91	40	12.32	170.12**	73	-163.17**	4.31
7	5.73	31.94	41	-7.44	25.00	74	-75.41*	-121.85**
8	35.99	-39.42	42	27.92	-44.74	75	-109.51**	-121.99**
9	-136.47**	-131.90**	43	119.61**	2.56	76	81.97*	87.41*
10	87.07*	98.08*	44	-39.04	-13.54	77	-96.51*	-8.81
11	106.46**	152.86**	45	-210.99**	33.21	78	-34.66	-55.88
12	72.52	43.01	46	-51.46	14.39	79	99.01**	-49.76
13	92.16*	170.30**	47	175.02**	16.60	80	28.79	-39.64
14	90.37*	-23.64	48	153.17**	23.57	81	-27.95	-122.77**
15	62.95	54.80	49	-103.68**	-126.98**	82	129.32**	-79.12*
16	29.25	-79.83*	50	-42.39	-149.15**	83	-105.70**	-79.11*
17	-85.06*	-10.31	51	-118.38**	9.22	84	11.84	-16.60
18	-58.67	32.10	52	149.69**	-57.62	85	-189.51**	-94.90*
19	165.81**	23.76	53	28.25	-211.88**	86	286.98**	285.90**
20	115.69**	73.40	54	-114.10**	-62.76	87	-139.46**	-220.84**
21	-21.40	13.19	55	235.27**	-12.72	88	19.35	0.24
22	12.32	141.61**	56	-1.95	-64.71	89	-56.23	10.47
23	-7.44	-42.20	57	-1.96	95.01**	90	52.11	64.96
24	27.92	24.28	58	81.47*	90.60**	91	71.67	-23.23
25	119.61**	16.13	59	69.72	63.68	92	-24.90	-10.29
26	-39.04	17.67	60	-149.60**	-56.35	93	22.97	-64.88
27	-210.99**	-188.90**	61	-10.61	-43.69	94	35.62	76.00
28	-51.46	21.40	62	-102.11**	8.03	95	-85.70*	-148.09**
29	175.02**	76.41	63	-21.99	-97.68*	96	-57.76	38.89
30	153.17**	152.60**	64	-1.15	-62.84	97	111.04**	86.07*
31	-103.68**	28.27	65	167.04**	32.69	98	152.40**	337.81**
32	-42.39	-17.78	66	11.35	89.96*	99	91.48*	-36.01
33	-118.38**	-60.88	67	-71.49	-162.69**	100	-62.69	4.34
34	149.69**	190.98**						
S.E.(gca for line)	37.79	39.36	T1(SC 162)	-40.76**	-42.29**	S.E. (gca for tester)	5.34	5.57
S.E. (gi - gj) line	53.44	55.66	T2(TWC352)	40.76**	42.29**	S.E. (gi - gj) tester	7.56	7.87

GYC = Grain yield per plot under normal condition, GYS = Grain yield per plot under water stress condition.

Estimation of specific combining ability (SCA)

Under normal condition, estimates of SCA effects for 100-grain weight (Table 12), both negative and positive significant estimates were detected among the top-crosses. Top-cross including S1-line 29×SC162 and S1-line 75×TWC352 were good specific combiners, whereas, top-cross including S1-line 29×TWC352 and S1-line 75×SC162 were poor specific combiners. Under water stress condition, estimates of SCA effects for 100-grain weight (Table 13), both negative and positive and significant estimates of SCA effects were detected among the top-crosses. Top-crosses including S1-line 29× SC162 and S1-line 83×TWC352 were good specific combiners, however, the top-crosses including S1-line 29×TWC352 and S1-line 83×SC162 were poor specific combiners. Crosses with positive and significant SCA effects for this trait are desirable as this trait directly contributes to grain yield of maize. In line with the present results, significant SCA effects in maize inbred lines evaluated in line x tester were reported by other researchers Uddin *et al.* (2006).

Under normal condition, estimates of SCA effects for grain yield per plot (Table 14), both negative and positive significant estimates of SCA effects were detected among the top-crosses. Top-crosses including S1-line 29×SC162 and S1-line 78×TWC352 were good specific combiners, whereas, top-crosses involving S1-line 29×TWC352 and S1-line 78×SC162 were poor specific combiners. Under water stress condition, estimates of SCA effects for grain yield per plot are shown in Table (15), both negative and positive and significant estimates were detected among the top-crosses. Top-crosses including S1-line 86×SC162 and S1-line 70×TWC352 were good specific combiners, whereas, the top-crosses including S1-line 86×TWC352 and S1-line 70×SC162 were poor specific combiners. Abrha *et al.* (2013**)** stated that top-crosses with highly positive and significant estimates of SCA effect could be utilizes in maize breeding programs. The results of the current study are partly consistent with the findings of (Iqbal *et al.* 2007; Rahman *et al.* 2018) for grain yield in maize.

Table 12. Specific combining ability effects of the 200 top-crosses using two testers (SC162 and TWC352) for 100-grain weight under normal condition.

S1-line	SC162	TWC352	S1-line	SC162	TWC352	S1-line	SC162	TWC352
1	0.44	-0.44	35	-1.08	1.08	68	-2.06^{*}	2.06^{*}
2	2.02^{**}	-2.02^{**}	36	0.68	-0.68	69	-2.09^{*}	2.09^{*}
3	2.42^{**}	-2.42^{**}	37	-0.42	0.42	70	-1.04	1.04
4	1.52	-1.52	38	-0.16	0.16	71	-0.98	0.98
5	0.55	-0.55	39	-0.38	0.38	72	0.79	-0.79
6	0.14	-0.14	40	0.60	-0.60	73	-1.26	1.26
7	-0.89	0.89	41	-0.66	0.66	74	-0.41	0.41
8	-0.37	0.37	42	0.35	-0.35	75	-2.64^{**}	2.64^{**}
9	1.65	-1.65	43	-0.59	0.59	76	-0.30	0.30
10	0.80	-0.80	44	-1.24	1.24	77	-0.06	0.06
11	0.35	-0.35	45	0.37	-0.37	78	-0.92	0.92
12	1.86^{*}	-1.86^{*}	46	-0.80	0.80	79	0.57	-0.57
13	1.53	-1.53	47	-0.44	0.44	80	-0.58	0.58
14	2.52^{**}	-2.52^{**}	48	-1.81^{*}	1.81^{*}	81	0.87	-0.87
15	1.72^{*}	-1.72^{*}	49	-1.01	1.01	82	1.55	-1.55
16	1.96^{*}	-1.96^{*}	50	-0.76	0.76	83	-1.77^{*}	1.77^{*}
17	0.73	-0.73	51	0.52	-0.52	84	-1.08	1.08
18	-2.11^{*}	2.11^{*}	52	-1.36	1.36	85	-1.50	1.50
19	0.10	-0.10	53	1.27	-1.27	86	-0.54	0.54
20	1.47	-1.47	54	-0.33	0.33	87	0.69	-0.69
21	-0.35	0.35	55	-1.11	1.11	88	1.14	-1.14
22	-1.37	1.37	56	-1.68^{*}	1.68^{*}	89	0.35	-0.35
23	-0.11	0.11	57	-0.94	0.94	90	-1.82^{*}	1.82^{*}
24	0.35	-0.35	58	-0.10	0.10	91	0.80	-0.80
25	0.20	-0.20	59	-1.77^{*}	1.77^{*}	92	-0.87	0.87
26	0.47	-0.47	60	-1.86^{*}	1.86^{*}	93	1.40	-1.40
27	1.25	-1.25	61	-1.92^{*}	1.92^{*}	94	1.17	-1.17
28	0.17	-0.17	62	0.20	-0.20	95	1.99^{*}	-1.99^{*}
29	4.49^{**}	-4.49^{**}	63	-0.12	0.12	96	-1.18	1.18
30	0.87	-0.87	64	2.57^{**}	-2.57^{**}	97	-1.43	1.43
31	-1.26	1.26	65	-1.38	1.38	98	-0.02	0.02
32	0.54	-0.54	66	0.70	-0.70	99	1.17	-1.17
33	-0.17	0.17	67	-1.09	1.09	100	0.50	-0.50
34	1.80^{*}	-1.80^{*}	S.E.(SCA effect)		0.85	S.E.(sij - skl)tester		1.21

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

Table 13. Specific combining ability effects of the 200 top-crosses using two testers (SC162 and TWC352) for 100-grain weight under water stress condition.

S1-line	SC162	TWC352	S1-line	SC162	TWC352	S1-line	SC162	TWC352
1	0.07	-0.07	35	-0.30	0.30	68	-1.42	1.42
2	2.08*	-2.08*	36	0.79	-0.79	69	-1.09	1.09
3	2.72**	-2.72**	37	0.03	-0.03	70	-0.64	0.64
4	1.54	-1.54	38	-1.05	1.05	71	-0.77	0.77
5	0.26	-0.26	39	-0.73	0.73	72	0.85	-0.85
6	0.38	-0.38	40	1.37	-1.37	73	-1.42	1.42
7	-0.58	0.58	41	0.18	-0.18	74	-0.31	0.31
8	1.21	-1.21	42	-0.26	0.26	75	-1.76*	1.76*
9	0.26	-0.26	43	-0.65	0.65	76	-0.29	0.29
10	1.45	-1.45	44	-1.28	1.28	77	-0.16	0.16
11	0.08	-0.08	45	1.27	-1.27	78	-1.09	1.09
12	0.29	-0.29	46	-0.31	0.31	79	0.35	-0.35
13	1.97*	-1.97*	47	-0.72	0.72	80	-0.53	0.53
14	2.45**	-2.45**	48	-1.37	1.37	81	1.48	-1.48
15	1.35	-1.35	49	-1.50	1.50	82	-0.59	0.59
16	1.06	-1.06	50	-0.17	0.17	83	-2.56**	2.56**
17	1.06	-1.06	51	0.77	-0.77	84	-1.50	1.50
18	-2.00*	2.00*	52	-2.00*	2.00*	85	-0.79	0.79
19	0.92	-0.92	53	0.58	-0.58	86	-0.65	0.65
20	0.70	-0.70	54	-0.12	0.12	87	-0.24	0.24
21	0.76	-0.76	55	-0.74	0.74	88	0.79	-0.79
22	-0.76	0.76	56	-0.69	0.69	89	-0.15	0.15
23	0.41	-0.41	57	-1.53	1.53	90	-0.96	0.96
24	0.77	-0.77	58	-0.79	0.79	91	1.04	-1.04
25	0.00	0.00	59	-2.41**	2.41**	92	-1.17	1.17
26	0.70	-0.70	60	-1.60	1.60	93	1.14	-1.14
27	1.28	-1.28	61	-1.76*	1.76*	94	1.49	-1.49
28	0.58	-0.58	62	0.39	-0.39	95	2.43**	-2.43**
29	3.42**	-3.42**	63	0.16	-0.16	96	-0.82	0.82
30	-0.54	0.54	64	1.42	-1.42	97	-1.05	1.05
31	-1.11	1.11	65	-1.21	1.21	98	-0.67	0.67
32	-0.30	0.30	66	0.41	-0.41	99	0.66	-0.66
33	-0.40	0.40	67	-0.80	0.80	100	0.50	-0.50
34	2.49**	-2.49**	S.E.(SCA effect)		0.84	S.E.(sij - skl)tester		1.19

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

Table 14. Specific combining ability effects of the 200 top-crosses using two testers (SC162 and TWC352) for grain yield per plot under normal condition.

S1-line	SC162	TWC352	S1-line	SC162	TWC352	S1-line	SC162	TWC352
1	8.45	-8.45	35	-117.44*	117.44*	68	-42.75	42.75
2	159.93**	-159.93**	36	-101.12	101.12	69	-96.43	96.43
3	222.27**	-222.27**	37	-28.78	28.78	70	-138.93**	138.93**
4	236.75**	-236.75**	38	-35.19	35.19	71	-97.38	97.38
5	164.16**	-164.16**	39	-89.85	89.85	72	-34.10	34.10
6	115.57*	-115.57*	40	26.55	-26.55	73	-99.16	99.16
7	32.00	-32.00	41	79.80	-79.80	74	17.24	-17.24
8	19.16	-19.16	42	67.73	-67.73	75	-123.72**	123.72**
9	171.46**	-171.46**	43	-114.26*	114.26*	76	30.88	-30.88
10	47.50	-47.50	44	19.48	-19.48	77	12.42	-12.42
11	146.97**	-146.97**	45	0.18	-0.18	78	-188.77**	188.77**
12	3.23	-3.23	46	35.52	-35.52	79	-63.31	63.31
13	190.12**	-190.12**	47	22.81	-22.81	80	-79.49	79.49
14	35.92	-35.92	48	12.67	-12.67	81	-120.26*	120.26*
15	110.02*	-110.02*	49	-96.88	96.88	82	9.61	-9.61
16	22.20	-22.20	50	-116.57*	116.57*	83	4.46	-4.46
17	53.08	-53.08	51	39.25	-39.25	84	30.44	-30.44
18	46.82	-46.82	52	-165.50**	165.50**	85	-102.12	102.12
19	-56.64	56.64	53	45.57	-45.57	86	100.91	-100.91
20	79.50	-79.50	54	-45.24	45.24	87	-120.24*	120.24*
21	62.42	-62.42	55	-17.33	17.33	88	35.11	-35.11
22	21.35	-21.35	56	-125.84*	125.84*	89	-31.04	31.04
23	189.57**	-189.57**	57	2.05	-2.05	90	-84.38	84.38
24	41.56	-41.56	58	30.87	-30.87	91	-55.51	55.51
25	-8.67	8.67	59	-58.74	58.74	92	-63.07	63.07
26	115.16*	-115.16*	60	-104.40	104.40	93	-84.31	84.31
27	117.05*	-117.05*	61	-117.28*	117.28*	94	71.00	-71.00
28	43.22	-43.22	62	-6.47	6.47	95	101.45	-101.45
29	303.28**	-303.28**	63	-115.23*	115.23*	96	-79.04	79.04
30	94.85	-94.85	64	-61.02	61.02	97	-70.24	70.24
31	-43.29	43.29	65	-185.77**	185.77**	98	-53.59	53.59
32	40.68	-40.68	66	-8.73	8.73	99	-132.24*	132.24*
33	-15.59	15.59	67	9.57	-9.57	100	84.82	-84.82
34	11.24	-11.24	S.E.(SCA effect)		53.44	S.E.(sij - skl)tester		75.57

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

Table 15. Specific combining ability effects of the 200 top-crosses using two testers (SC162 and TWC352) for grain yield per plot under water stress condition.

S1-line	SC162	TWC352	S1-line	SC162	TWC352	S1-line	SC162	TWC352
1	3.15	-3.15	35	-106.08	106.08	68	-41.59	41.59
2	140.65*	-140.65*	36	-30.98	30.98	69	-19.69	19.69
3	130.80*	-130.80*	37	57.84	-57.84	70	-211.24**	211.24**
4	74.91	-74.91	38	-83.97	83.97	71	-67.25	67.25
5	70.79	-70.79	39	73.96	-73.96	72	53.28	-53.28
6	104.82	-104.82	40	64.69	-64.69	73	-74.12	74.12
7	-41.68	41.68	41	105.72	-105.72	74	-33.67	33.67
8	88.29	-88.29	42	8.65	-8.65	75	16.21	-16.21
9	10.31	-10.31	43	-68.46	68.46	76	100.52	-100.52
10	46.01	-46.01	44	-14.35	14.35	77	77.66	-77.66
11	43.38	-43.38	45	-18.02	18.02	78	-146.76**	146.76**
12	-37.63	37.63	46	31.54	-31.54	79	41.10	-41.10
13	35.36	-35.36	47	-50.86	50.86	80	-33.84	33.84
14	37.29	-37.29	48	-58.25	58.25	81	62.90	-62.90
15	-17.62	17.62	49	-95.33	95.33	82	-41.13	41.13
16	-26.22	26.22	50	-88.60	88.60	83	-78.72	78.72
17	5.24	-5.24	51	65.04	-65.04	84	58.46	-58.46
18	-19.96	19.96	52	-188.06**	188.06	85	-30.22	30.22
19	-3.22	3.22	53	39.57	-39.57	86	199.29**	-199.29**
20	29.29	-29.29	54	28.97	-28.97	87	-109.93	109.93
21	71.48	-71.48	55	39.26	-39.26	88	51.23	-51.23
22	80.13	-80.13	56	-58.67	58.67	89	-93.59	93.59
23	39.25	-39.25	57	-45.52	45.52	90	-117.10	117.10
24	-18.85	18.85	58	-85.02	85.02	91	148.69**	-148.69**
25	-189.90**	189.90**	59	-65.41	65.41	92	3.03	-3.03
26	33.73	-33.73	60	5.56	-5.56	93	-39.58	39.58
27	-3.51	3.51	61	-77.41	77.41	94	113.77	-113.77
28	83.30	-83.30	62	-5.09	5.09	95	8.76	-8.76
29	176.56**	-176.56**	63	-64.02	64.02	96	-103.95	103.95
30	26.42	-26.42	64	-86.84	86.84	97	-141.21*	141.21*
31	-36.77	36.77	65	-62.24	62.24	98	-49.14	49.14
32	95.55	-95.55	66	96.01	-96.01	99	-74.96	74.96
33	67.50	-67.50	67	3.37	-3.37	100	100.56	-100.56
34	106.38	-106.38	S.E.(SCA effect)		55.66	S.E.(sij - skl)tester		78.71

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

Table 16. Variances of both GCA and SCA along with broad-sense heritability and combining ability ration (CAR) for studied traits under normal and water stress conditions.

	Normal condition		Water stress condition	
	100-GW	GY	100-GW	GY
h_b	0.7798	0.6948	0.7521	0.7609
σ^2_{gca}	0.0029	14.8944	0.0057	30.2002
σ^2_{sca}	2.5783	15777.6400	2.1242	9800.0770
CAR	0.0022	0.0018	0.0053	0.0061

Heritability in broad sense along with variances for both GCA and SCA are shown in Table (16). Briefly, under normal condition heritability in broad sense was higher than under water stress condition for 100-grain weight, while heritability in broad sense under water stress it was higher than under normal condition for grain yield per plot. Similar results for both traits, (Al-Naggar *et al.* (2016) found that heritability was increased in stressful environments. In contrast, Worku (2005) reported a decrease in heritability under stressed environments.

Under normal and water stress condition, specific combining ability variance was important than general combining ability variance for 100-grain weight and grain yield per plot indicating preponderance of dominance variance in controlling these characters. For both traits, which showed the preponderance of dominance variance, the CAR was lower than unity. Similar results were reported by Emyhum (2013) who found that variance due to SCA was more important than variance due to GCA for 100-grain weight and grain yield per plot.

Conclusion

In conclusion, the current study revealed that S1-lines 10, 99, 86, and 55 are good combiners for both 100-grain weight and grain yield per plot based on GCA under normal condition. The top-cross including S1-line 29×SC162 is a good specific combiner for both traits under normal condition. Heritability in broad sense showed moderately high estimates for both aforementioned traits. Furthermore, we concluded that the dominance gene action is preponderance in controlling both studied traits. Finally, these S1-lines are promising to produce drought-tolerant inbred lines, which may be used to produce drought tolerant hybrid in the future.

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تحليل السلالة×الكشاف للمحصول ووزن ال ١٠٠ حبة تحت ظروف الري العادي والجفاف في الذرة الشامية الصفراء

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الملخص

يعتبر الذرة الشامية ثالث اهم محصول للحبوب في مصر بعد القمح والارز ولكنه يتعرض للجفاف مما يؤدى الى نقص في المحصول والجودة. في الدراسة الحالية تم تقييم ١٠٠ سلالة من الجيل الذاتى الاول مع اثين كشاف بالإضافة للهجن القمية تحت ظروف الري العادي والجفاف. تم استخدام تحليل السلالة × الكشاف لتقييم القدرة العامة والخاصة على الائتلاف لوزن الـ ١٠٠ حبة ومحصول الحبوب للخط بالإضافة الى تقدير درجة التوريث لهاتين الصفتين. نتائج تحليل السلالة × الكشاف اظهرت معنوية عالية في المعاملات، الاباء، الاباء ضد الهجن، الهجن، الكشافات، السلالات مع الكشافات لهاتين الصفتين تحت ظروف الري العادي والجفاف، أظهرت النتائج ان السلالات كانت غير معنوية لوزن ال ١٠٠ حبة تحت ظروف الري العادي والجفاف، فيما يتعلق بمحصول الحبوب للخط كانت غير معنوية تحت ظروف الري العادي بينما اظهرت معنوية تحت ظروف الجفاف. أما تحت ظروف الري العادي بالنسبة لوزن ال١٠٠ حبة كانت السلالتين رقم ٥٦ و٨٨ الأعلى بينما اعلى قيمة لوزن ال ١٠٠ حبة التي وجدت في الهجن كانت بين السلالة ٢٩× الهجين الفردي ١٦٢ والسلالة ٦١× مع الهجين الثلاثي ٣٥٢،من ناحية اخرى كانت السلالتين رقم ٦٥ و ٦٨ الاعلى في محصول الحبوب للخط ، بينما اعلي قيمة في الهجن كانت بين السلالة ٨٦× الهجين الفردي ١٦٢ والسلالة ٣٧ × مع الهجين الثلاثي ٣٥٢.تحت ظروف الري العادي بالنسبة للقدرة العامة على الائتلاف أظهرت السلالتين ١٠ و ٩٩ أعلى تأثير موجب ومعنوي بالنسبة لوزن ال ١٠٠ حبة و السلالتين ٨٦ و ٥٥ أعلى تأثير موجب ومعنوي لمحصول الحبوب للخط. بالنسبة للقدرة الخاصة على الائتلاف كانت الهجن القمية بين السلالة ٢٩× الهجين الفردي ١٦٢ والسلالة ٧٥ × مع الهجين الثلاثي ٣٥٢ الافضل بالنسبة لوزن الـ ١٠٠ حبة والهجن القمية بين السلالة ٢٩× الهجين الفردي ١٦٢ والسلالة ٧٨ × مع الهجين الثلاثي ٣٥٢ كانت الافضل بالنسبة لمحصول الحبوب للخط. درجة التوريث العامة اظهرت ارتفاع نسبى لوزن الـ ١٠٠ حبة وهذه النتائج تعبر عن تفوق التباين السيادي في التحكم في هاتين الصفتين. في الختام تعتبر سلالات الجيل الذاتي الاول مبشرة لإنتاج سلالات متحملة للجفاف في المستقبل والتي تستخدم في انتاج هجن متحملة للجفاف.