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Estimation combining ability of some maize inbred lines using line × tester mating design under two nitrogen levels

Mohamed M. Kamara[1,2*], Ibrahim S. El-Degwy[1] and Hiroyuki Koyama[2]

[1]Agronomy Department, Faculty of Agriculture 33516, Kafrelsheikh University, Kafr El-Sheikh, Egypt
[2]Laboratory of Plant Cell Technology, Faculty of Applied Biological Sciences, Gifu University, Gifu 501–1193, Japan

***Corresponding author: dr_wagid1212@yahoo.com**

Abstract

This study was conducted to estimate general (GCA) and specific (SCA) combining ability effects of some maize inbred lines for grain yield and other agronomic traits by using line × tester analysis under two nitrogen fertilizer levels. Ten white maize inbred lines and three testers; SC10, SC122 and TWC310 were crossed in line × tester scheme in 2012 season. Thirty top crosses plus the two checks; SC128 and TWC324 were evaluated in a randomized complete block design with three replications under two nitrogen fertilizer levels; 80 and 120 kg N/fed in 2013 season. Significant differences were noticed between the two nitrogen fertilizer levels for all the studied traits except ear diameter, indicating these traits were affected by nitrogen fertilizer levels. Mean squares of crosses (C) and their partitioning lines (L), testers (T) and line × tester (L × T) interaction were highly significant for all the studied traits under the two nitrogen levels as well as for the combined data. Significant interaction mean squares for C, L, T and L×T with nitrogen levels were detected for the most studied traits. The non-additive genetic variance was greater than the additive genetic variance in governing the inheritance of all studied traits except number of rows/ear and grain yield (ard/fed). Moreover, the non-additive gene action was more affected by nitrogen levels than the additive gene action for all the studied traits except days to 50% silking. Four top crosses; L3×T1, L6×T2, L1×T1 and L9×T1 were significantly out yielded the check hybrid; TWC324. While, only the top cross L3×T1 was significantly superior to the highest yielding check hybrid; SC128. The inbred lines; L8, L3 and L1 possessed the highest negative and significant GCA effects towards earliness, dwarfness and lower ear placement, respectively. The inbred lines; L1, L3, L6 and L10 exhibited positive and significant GCA effects for grain yield (ard/fed) and most of the other yield component traits. Nine top crosses; L2 ×T2, L2×T3, L3×T1, L4×T2, L5×T1, L6×T2, L8×T3, L9×T1and L10×T3 exhibited desirable SCA effects for grain yield and some of its components' traits. These crosses are valuable and could be used in maize breeding programs for high yielding ability.

Key words: Maize, line × tester, general combining ability, specific combining ability.
Abbreviations: GCA_general combining ability; SCA_specific combining ability.

Introduction

Maize (*Zea mays* L.) is one of the most important strategic cereal crops in the world. It ranks third crop after wheat and rice in both terms of area and production in Egypt. The main objective of the maize breeding program in Egypt is to develop high yielding maize hybrids for commercial use to cover the increasing consumption of maize in human food, animal feeding and poultry industry. One of the most important criteria for identifying high yielding hybrids is the information about parents genetic structure and their combining ability (Ceyhan, 2003). The line × tester analysis method which suggested by Kempthorne (1957) is one of the powerful tools available to estimate general and specific combining ability effects and aids in selecting desirable parents and crosses. The effeteness of this method depends mainly upon the type of tester used in the evaluation. The suitable tester should include simplicity in use, provide information that correctly classifies the relative merit of lines and maximizes the genetic gain (Hallauer, 1975; Menz et al., 1999). However, it is difficult to identify testers having all these characteristics. The heterozygous crosses as the tester have been widely used by several breeders El-Ghawas (1963), Horner et al. (1976), Mosa (2010), Mousa and Aly (2012) and Aly (2013). The two types of combining ability, general (GCA) and specific (SCA) have been recognized in quantitative genetic. General combining ability is regarded as additive gene effects while, specific combining ability reflects the non-additive gene actions (Sprague and Tatum, 1942). Numerous investigators reported that the additive gene effects played an effective role in the inheritance of grain yield (Paul and Debanth, 1999; Irshad-El-Haq et al., 2010 and El-Badawy 2013) and number of rows/ear (Mosa et al., 2009; Mosa, 2010 and Aly et al., 2011). While, Kamara (2012), Aly (2013), El-Badawy (2013) and EL-Hosary and Elgammaal (2013) showed that the non-additive gene effects represented the major role in the inheritance of grain yield and other agronomic traits. The genetic components for a certain trait would depend mainly on the environmental fluctuations under which the breeding genotypes will be tested. Hence, much effort has been devoted by maize breeders to estimate the interactions between genetic components and environments. Nitrogen fertilizer is one important factor, which plays an important role in maize production. It is a key component in many biological and physiological functions and plays a major role in crop yield capacity (Cathcart and Swanton, 2003). Abd El

-Aty and Darwish (2006) and Mosa et al. (2010) found that the non-additive gene actions for maize grain yield were more affected by nitrogen levels than the additive gene actions. On the contrary, El-Badawy (2013) found that the additive gene effects for grain yield, and some of its components were more influenced by nitrogen levels. The main objectives of the present study were to: (1) estimate general combining ability of lines and testers and specific combining ability of crosses for grain yield and other agronomic traits under two nitrogen fertilizer levels (2) identify the superior inbred lines and crosses to improve the yielding ability in maize breeding program.

Results and Discussion

Analysis of variance

The analysis of variance for all the studied traits under the two nitrogen levels and their combined data are presented in Table 1. Mean squares due to nitrogen levels were significant for all the studied traits except ear diameter trait, indicating over-all differences between the two nitrogen levels and these traits were affected by nitrogen levels. These results agreed with those reported by Abd El-Aty and Darwish (2006), Mosa et al. (2010) and Shrestha (2013). The source of variation for the entries was partitioned into, crosses (C), checks (Ch) and crosses vs checks (C vs Ch). Highly significant differences for crosses were detected for all the studied traits under the two nitrogen levels and their combined data, indicating the tested top crosses varied from each other for such traits. The difference between the check hybrids was significant for all the studied traits except plant height under N1 and N2 levels, ear diameter under N1, N2 levels and combined data, ear length and number of rows/ ear under N1 level. Crosses vs checks (C vs Ch) were highly significant for all the studied traits except ear height under N1, N2 levels and combined data and ear diameter under N1 level. The mean squares due to Lines (L), Testers (T) and (L × T) interaction were highly significant for all the studied traits under the two nitrogen levels as well as for the combined data. This indicates that the inbred lines behaved differently in their respective top crosses, and greater diversity exists among the testers. Meanwhile, significant of (L × T) interaction suggesting that inbred lines performed differently according to the tester which they crossed. These results are in agreement with those obtained by Mosa (2010), Aly et al. (2011), Kustanto et al. (2012) and EL-Hosary and Elgammaal (2013). The (C × N) interaction was significant for all the studied traits revealing that these crosses differed in their order from level of nitrogen fertilizer to another for these traits. The interactions; (Ch × N) and (C vs Ch × N) were not significant for all the studied traits except (C vs Ch × N) for days to 50% silking and ear diameter. Mean squares due to (L × N) interaction were significant to for days to 50% silking, ear length, number of rows/ear and grain yield (ard/fed), indicating that the inbred lines performed differently as reflected in their respective top crosses from nitrogen level to another. Mean squares of (T × N) interaction were not significant for all the studied traits except plant height. While, mean squares of (L × T × N) interaction were significant for all the studied traits except plant height and ear diameter, indicating that the crosses between lines and testers were affected by nitrogen levels.

Mean performance

Mean performance of the 32 entries (30 top crosses and 2 check hybrids) for all of the studied traits over the two nitrogen levels are shown in Table 2. Based on the combined analysis of the two nitrogen levels mean performance of the top crosses for days to 50% silking ranged from 56.5 days for top cross L9×T2 to 70.83 days for top cross L4×T1, the top crosses L9×T2 and L5×T3 were significantly earlier than the earliest check hybrid TWC 324 (58.67).

For plant eight, top crosses ranged from 187.7 cm for top cross L3 ×T3 to 265.7 cm for top cross L9×T1. Four top crosses L3×T3, L9×T2, L7×T2 and L5×T2 were significantly shorter than the shortest check hybrid TWC 324 (233.9 cm). As for ear height five top crosses L3×T3, L1×T3, L5×T2, L7×T2 and L9×T2 had significantly lower ear placement compared with the lower check hybrid TWC 324 (127.0 cm), and the top crosses ranged from 105.7 cm for top cross L3×T3 to 151.2 cm for top cross L9×T1.

Plant shortness in maize decreases lodging percentage and thus increased yield potential (EL-Hosary and Elgammaal, 2013). Concerning ear length, the top crosses mean values ranged from 16.85 cm for L5×T3 to 24.6 cm for L3×T1. Furthermore, the top crosses L3×T1 and L7×T2 were significantly different compared to the longer ear check hybrid SC128. Regarding to ear diameter the top crosses ranged from 4.05 cm for L8×T3 to 5.65cm for L10 × T1 with two top crosses L10×T1 and L1×T1 were significantly different compared to the best check hybrid SC128. For number of rows/ear top crosses ranged from 11.67 for top cross L8×T3 to 15.32 for top cross L1×T1, all top crosses did not differ significantly from the check hybrid SC128. While, four top crosses L1×T1, L7×T2, L7×T1 and L9 ×T1 were significantly different from the check hybrid TWC324. For number of kernels/row the top crosses ranged from 28.9 for top cross L5×T3 to 47.0 for top cross L3×T1.

Four top crosses L3×T1, L3×T2, L5×T1 and L4×T2 exhibited significantly increased values compared to the check hybrid TWC324 while, only the two top crosses L3×T1 and L3×T2 out of the previous four top crosses significantly different compared to the best check hybrid SC128. The mean values of the grain yield trait were higher under the high nitrogen level than those under low level of nitrogen (Abd El-Aty and Darwish, 2006 and Mosa et al., 2010) revealed that increasing nitrogen levels led to increasing the grain yield. Tamilarasi and Vetriventhan (2009), El-Badawy (2013) and Shrestha (2013) reported that the increment of maize grain yield with increment of nitrogen level might be due to the simulating effect of nitrogen on the metabolic process in maize plant and increment in all of grain yield attributes. Grain yield (ard/fed) ranged from 18.76 (ard/fed) for top cross L5×T3 to 36.35 (ard/fed) for top cross L3×T1.

Four top crosses L3×T1, L6×T2, L1×T1 and L9×T1 were significantly outyielded the check hybrid TWC324. While, only the top cross L3×T1 was significantly out yielded the highest yielding check hybrid SC128. Generally, the above four crosses exhibited the best values of most yield components, and this suggest the use of these crosses as good hybrids in maize breeding programs.

General combining ability (GCA) effects

Estimates of GCA effects for the ten maize inbred lines and the three testers over the two nitrogen levels are presented in Table 3. Results showed that five inbred lines L1, L5, L8, L9 and L10 possessed negative (desirable) and significant GCA effects for days to 50% silking toward earliness. Also, four

Table 1. Analysis of variance for all the studied traits under the two nitrogen levels and their combined data.

S.O.V	D.F		Days to 50% silking			Plant height (cm)			Ear height (cm)			Ear length (cm)		
	Single	Comb.	N1	N2	Comb.	N1	N2	Comb.	N1	N2	Comb.	N1	N2	Comb.
Nitrogen (N)	-	1	-	-	131.67*	-	-	4985.76*	-	-	2588.67**	-	-	921.38*
Rep/N	-	4	-	-	16.323	-	-	522.17	-	-	18.709	-	-	57.77
Entries (E)	31	31	38.38**	64.78**	84.05**	1171.83**	836.02**	1950.74**	418.881**	374.043**	747.704**	13.97**	12.575**	23.160**
Crosses (C)	29	29	38.164**	64.034**	82.045**	1238.84**	873.204**	2051.59**	442.386**	394.304**	788.590**	14.09**	12.299**	22.795**
Lines (L)	9	9	71.74**	151.02**	164.24**	907.54**	408.27**	1250.57**	283.60**	445.83**	684.06**	5.61**	6.92**	6.75**
Testers (T)	2	2	35.63 **	42.01 **	75.61**	2850.99**	2214.44**	4935.22**	1251.10**	1098.13**	2337.72**	37.01**	29.73**	66.25**
Lines × Testers	18	18	21.66 **	22.99**	41.66**	1225.37**	956.65**	2131.71**	431.92**	290.34**	668.73**	15.78**	13.05**	25.99**
Checks (Ch)	1	1	16.67**	8.17**	24.08**	121.5	91.26	211.68*	112.67*	150.0*	261.333**	1.22	4.335**	5.070**
C vs Ch	1	1	66.35**	143.02**	202.17**	278.87**	502.44**	765.15**	43.45	10.52	48.38	23.12**	28.82**	51.83**
E × N	-	31	-	-	19.113**	-	-	57.108*	-	-	45.22*	-	-	3.382**
Cr × N	-	29	-	-	20.153**	-	-	60.45*	-	-	48.099**	-	-	3.593**
L × N	-	9	-	-	58.519**	-	-	65.24	-	-	45.37	-	-	5.78**
T × N	-	2	-	-	2.04	-	-	130.21*	-	-	11.51	-	-	0.49
L × T × N	-	18	-	-	2.99**	-	-	50.31	-	-	53.53**	-	-	2.84**
Ch × N	-	1	-	-	0.750	-	-	1.08	-	-	1.333	-	-	0.480
C vs Ch × N	-	1	-	-	7.21**	-	-	16.16	-	-	5.58	-	-	0.10
Error	62	124	0.953	0.746	0.850	39.198	28.618	33.91	19.228	30.876	25.052	0.486	0.610	0.548

Table 1. Continue

S.O.V	D.F		Ear diameter (cm)			Number of rows/ear			Number of kernels/row			Grain yield (ard/fed)		
	Single	Comb.	N1	N2	Comb.	N1	N2	Comb.	N1	N2	Comb.	N1	N2	Comb.
Nitrogen (N)	-	1	-	-	3.023	-	-	65.801*	-	-	618.485*	-	-	592.03*
Rep/N	-	4	-	-	11.64	-	-	7.440	-	-	64.176	-	-	39.38
Entries (E)	31	31	0.421**	0.497**	0.837**	3.189**	2.581**	5.410**	68.58**	68.969**	134.384**	57.37**	60.77**	113.330**
Crosses (C)	29	29	0.446**	0.489**	0.862**	3.133**	2.528**	5.293**	66.852**	67.533**	131.0653**	55.28**	59.81**	109.97**
Lines (L)	9	9	0.358**	0.44**	0.711**	2.633**	1.936**	4.142**	59.96**	70.33**	127.02**	42.50**	54.43**	90.62**
Testers (T)	2	2	1.813**	2.36**	4.04**	15.63**	16.956**	32.39**	327.62**	273.32**	599.38**	417.04**	464.18**	879.22**
Lines × Testers	18	18	0.339**	0.305**	0.584**	1.977**	1.222**	2.86**	41.33**	43.27**	81.06**	21.48**	17.57**	34.18**
Checks (Ch)	1	1	0.06	0.06	0.121	0.54	2.16**	2.43**	7.26**	19.80**	25.521**	19.44**	13.86*	33.065**
C vs Ch	1	1	0.06	1.17**	0.83**	7.46**	4.54**	11.78**	180.01**	159.78**	339.49**	155.91**	135.52**	291.035**
E × N	-	31	-	-	0.081*	-	-	0.360*	-	-	3.164*	-	-	4.809**
Cr × N	-	29	-	-	0.073*	-	-	0.369**	-	-	3.319*	-	-	5.12**
L × N	-	9	-	-	0.087	-	-	0.427*	-	-	3.27	-	-	6.31**
T × N	-	2	-	-	0.133	-	-	0.196	-	-	1.56	-	-	2.00
L × T × N	-	18	-	-	0.06	-	-	0.339*	-	-	3.54*	-	-	4.87**
Ch × N	-	1	-	-	0.0001	-	-	0.270	-	-	1.541	-	-	0.235
C vs Ch × N	-	1	-	-	0.40**	-	-	0.218	-	-	0.30	-	-	0.395
Error	62	124	0.033	0.058	0.046	0.2304	0.166	0.198	1.016	2.813	1.915	1.56	2.707	2.133

*,** significant at 0.05 and 0.01 levels of probability, respectively. N1, N2 and Comb refer to first (second nitrogen level and combined analysis, respectively.

Table 2. Mean performance of the 32 entries (30 top crosses and 2 check hybrids) for all the studied traits over the two nitrogen levels.

Cross	Days to 50% silking	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	Number of rows/ ear	Number of kernels /row	Grain yield (ard/fed)		
								N1	N2	Comb
L1 × T1	62.33	248.8	131.5	20.60	5.60	15.32	38.50	31.50	35.20	33.35
L1 × T2	61.83	252.4	131.0	21.90	4.70	13.33	35.15	27.66	30.51	29.09
L1 × T3	62.50	244.7	111.1	18.30	4.80	12.82	32.55	22.41	27.32	24.87
L2 × T1	64.00	257.6	141.5	18.00	5.12	14.42	32.25	25.09	26.82	25.96
L2 × T2	65.33	245.7	127.3	20.70	4.50	12.52	38.50	26.80	29.22	28.01
L2 × T3	65.33	248.8	134.1	21.95	4.30	11.98	29.35	20.90	24.15	22.53
L3 × T1	69.17	257.7	139.9	24.60	4.90	13.97	47.00	35.10	37.60	36.35
L3 × T2	66.00	256.7	133.9	19.30	4.80	13.67	44.95	28.11	32.00	30.06
L3 × T3	63.33	187.7	105.7	18.50	4.50	12.67	33.40	25.00	27.00	26.00
L4 × T1	70.83	258.0	139.9	18.70	5.35	13.80	31.25	26.67	29.50	28.08
L4 × T2	68.83	260.2	145.3	22.25	4.40	12.65	41.85	28.17	33.20	30.68
L4 × T3	70.00	240.3	123.8	19.00	5.10	13.65	33.50	22.30	24.37	23.33
L5 × T1	69.17	243.3	132.2	23.10	4.65	13.50	43.05	28.20	34.50	31.35
L5 × T2	65.50	215.5	113.8	20.40	4.90	13.95	37.35	27.90	29.38	28.64
L5 × T3	56.83	250.2	136.2	16.85	5.20	13.65	28.90	17.31	20.20	18.76
L6 × T1	65.67	260.3	139.7	19.00	5.30	14.15	39.65	30.10	32.50	31.30
L6 × T2	67.83	254.5	138.6	20.50	5.30	13.50	39.25	32.45	34.95	33.70
L6 × T3	66.33	243.0	131.8	19.80	4.60	12.30	34.60	19.50	25.60	22.55
L7 × T1	66.17	257.8	142.2	20.10	5.20	14.82	35.35	24.58	30.10	27.34
L7 × T2	67.33	209.0	114.6	24.25	5.20	14.98	30.70	24.25	28.50	26.38
L7 × T3	64.83	250.7	141.6	17.20	4.90	12.48	29.90	20.50	22.70	21.60
L8 × T1	60.50	257.5	146.5	20.80	4.90	13.17	37.65	24.90	28.31	26.61
L8 × T2	59.50	257.4	143.2	19.70	4.90	12.48	35.35	21.20	23.72	22.46
L8 × T3	58.67	256.5	143.5	20.00	4.05	11.67	31.00	19.91	21.52	20.72
L9 × T1	65.50	265.7	151.2	19.85	5.50	14.67	39.65	32.56	33.00	32.78
L9 × T2	56.50	202.5	116.2	19.20	4.80	12.02	38.20	24.65	30.74	27.70
L9 × T3	62.33	249.2	137.7	17.80	4.80	12.82	32.60	20.50	22.10	21.30
L10 × T1	62.00	261.5	144.8	23.35	5.65	14.17	32.50	26.50	32.10	29.30
L10 × T2	62.50	250.6	136.6	19.90	5.00	13.82	39.25	23.80	32.13	27.97
L10 × T3	63.00	247.8	137.1	20.50	4.90	13.38	38.25	24.60	30.20	27.40
SC 128	61.50	242.3	136.3	23.00	5.30	14.88	43.00	32.50	35.40	33.95
TWC324	58.67	233.9	127.0	21.70	5.10	13.98	40.08	28.90	32.36	30.63
LSD 0.05	1.04	6.59	5.66	0.84	0.24	0.50	1.57	2.04	2.68	1.65
LSD 0.01	1.37	8.67	7.46	1.10	0.32	0.66	2.06	2.71	3.57	2.18

N1, N2 and Comb refer to first, second nitrogen level and combined analysis, respectively.

inbred lines L3, L5, L7 and L9 had negative (desirable) and significant GCA effects for plant height toward shorter plants (dwarfness) and three inbred lines L1, L3 and L5 had negative and significant GCA effects for ear height toward lower ear placement. On the other hand, positive (desirable) and significant GCA effects were obtained by the inbred lines L3 and L10 for ear length; L1, L6, L7, L9 and L10 for ear diameter; L1, L5, L7 and L10 for number of rows/ear; L3, L6 and L9 for number of kernels/row and L1, L3, L6 and L10 for grain yield (ard/fed). These lines could be used as good combiners to produce new high yielding crosses in the maize breeding program. It is worth noting that the inbred line which possessed high GCA effects for grain yield showed the desirable effect for one or more of the traits contributing to grain yield. Selecting inbred lines with positive GCA effects in all or most of the yield components traits will have greater chance to obtain crosses with higher grain yield (Fan et al., 2008). Concerning the testers, the best combiner tester for favorable GCA effects was TWC310 for days to 50% silking, TWC310 and SC122 for plant and ear heights, which possessed negative (desirable) and significant GCA values for these traits. While, the tester SC10 for ear diameter and number of rows/ear and the testers SC10 and SC122 for ear length, number of kernels/row and grin yield (ard/fed) had positive (desirable) and significant GCA effects for these traits. The superiority of single crosses as good testers was reported by El-Ghawas (1963), Horner et al. (1976), El-Shenawy and Mosa (2005), Mosa (2010) and Aly (2013).

Specific combining ability (SCA) effects

Estimates of SCA effects of the 30 top crosses for all of the studied traits over the two nitrogen levels are presented in Table 4. The desirable SCA effects were obtained by the crosses L1×T1, L2×T1, L3×T3, L4×T2, L5×T3, L6×T1, L7×T1, L9×T2 and L10×T1 for days to 50% silking (toward earliness); L1×T1, L3×T3, L4×T1, L4×T3, L5×T2, L6×T3, L7×T2, L8×T1 and L9 ×T2 for plant height (toward shorter plants); L1×T3, L3×T3, L4×T3, L5×T2, L6×T1, L7×T2, L8×T1 and L9 ×T2 for ear height (toward lower ear placement); L1×T2, L2×T3, L3×T1, L4×T2, L5×T1, L6×T3, L7×T2, L8×T3 and L10 ×T1 for ear length;L1×T1, L2×T1, L4×T3, L5×T3, L6×T2, L7×T2, L8×T2, L9×T1 and L10 ×T1 for ear diameter; L1×T1, L2×T1, L4×T3, L5×T2, L5×T3, L7×T2 and L9 ×T1 for number of rows/ear; L1×T1, L2×T2,

Table 3. General combining ability effects (GCA) for the ten inbred lines and the three testers over the two nitrogen levels.

Lines and testers	Days to 50% silking	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	Number of rows/ear	Number of kernels /row	Grain yield (ard/fed) N1	N2	Comb
Lines										
L1	-2.10**	2.249	-9.208**	0.063	0.106*	0.412**	-0.648*	1.753**	2.039**	1.896**
L2	0.567**	4.316**	0.552	0.013	-0.289**	-0.438**	-2.682**	-1.174**	-2.241**	-1.708**
L3	1.844**	-12.357**	-7.233**	0.597**	-0.194**	0.023	5.735**	3.966**	3.229**	3.598**
L4	5.567**	6.449**	2.591*	-0.220	0.023	-0.043	-0.515	0.274	0.051	0.163
L5	-0.489*	-10.046**	-6.349**	-0.087	-0.011	0.290**	0.385	-0.967*	-0.945	-0.956**
L6	2.289**	6.232**	2.962*	-0.437*	0.140**	-0.093	1.785**	1.913**	2.045**	1.979**
L7	1.789**	-7.201**	-0.961	0.313	0.173**	0.684**	-4.065**	-2.327**	-1.871**	-2.099**
L8	-4.767**	10.738**	10.65**	-0.037	-0.311**	-0.971**	-1.382**	-3.434**	-4.455**	-3.944**
L9	-2.878**	-7.273**	1.260	-1.253**	0.106*	-0.243*	0.768*	0.466	-0.358	0.054
L10	-1.822**	6.893**	5.738**	1.047**	0.256**	0.379**	0.618	-0.470	2.505**	1.018**
LSD (g_i) 0.05	0.426	2.690	2.312	0.342	0.099	0.206	0.639	0.832	1.096	0.675
LSD (g_i) 0.01	0.561	3.541	3.044	0.450	0.130	0.271	0.842	1.106	1.457	0.888
Testers										
T1 (SC10)	1.211**	10.439**	7.206**	0.607**	0.289**	0.787**	1.637**	3.083**	2.992**	3.037**
T2 (SC122)	-0.206	-5.939**	-3.719**	0.607**	-0.077**	-0.118*	2.007**	1.062**	1.464**	1.263**
T3 (TWC310)	-1.01**	-4.501**	-3.487**	-1.213**	-0.212**	-0.668**	-3.643**	-4.144**	-4.456**	-4.300**
LSD (g_i) 0.05	0.233	1.473	1.266	0.187	0.054	0.113	0.350	0.456	0.600	0.370
LSD (g_i) 0.01	0.307	1.940	1.667	0.247	0.071	0.148	0.461	0.606	0.798	0.486

*, ** significant at 0.05 and 0.01 levels of probability, respectively. N1, N2 and Comb refer to first, second nitrogen level and combined analysis, respectively.

L3×T1, L3×T2, L4×T2, L4×T3, L5×T1, L7×T1, L7×T3, L8×T1, L9×T1 and L10 ×T3 for number of kernels/row and L1 ×T1, L2 ×T2, L2×T3, L3×T1, L4×T2, L5×T1, L6×T2, L8×T3, L9×T1and L10×T3 for grain yield (ard/fed). These top crosses might be of interest in breeding programs as most of them involved at least one good combiner for the traits in view.

Genetic parameters

Estimates of the variance due to general combining ability (GCA), specific combining ability (SCA) and their interaction with nitrogen for all the studied traits, over the two nitrogen levels are illustrated in Table 5. The results revealed that GCA variance was higher than SCA variance and GCA/SCA ratio was more than unity for the number of rows/ear and grain yield. This would indicate that the additive gene action played the major role than non-additive gene action in governing the inheritance of these traits. This result supports the finding of (Sanghi et al., 1983, Paul and Debanth, 1999; Irshad-El-Haq et al., 2010 and El-Badawy 2013) for grain yield and (Fan et al., 2008; Mosa et al., 2009; Mosa, 2010 and Aly et al., 2011) for the number of rows/ear. The SCA variance was higher than GCA variance and GCA/SCA ratio was less than unity for days to 50% silking, plant height, ear height, ear length, ear diameter and number of kernels/row, indicating that non-additive gene action important than additive gene action in the inheritance of these traits. Similar results were obtained by Joshi et al. (1998) and Kumar et al. (1998) for silking date and Kamara (2012), Aly (2013) and EL-Hosary and Elgammaal (2013) for plant height, ear height, ear diameter and number of kernels/row. The magnitude of the interaction of SCA × N was higher than GCA × N for all the studied traits except days to 50% silking. Consequently, the non-additive gene action seemed greatly affected by nitrogen fertilizer than the additive gene action. These results are of good agreement with those obtained Abd El -Aty and Darwish (2006) and Mosa et al. (2010) they found that SCA × N interaction was larger than GCA × N interaction.

Materials and Methods

Plant materials

The materials used in this study consisted of ten white maize inbred lines provided by maize research program, Field Crops Research Institute (FCRI), Agricultural Research Center (ARC). These inbred lines were; G-336 (L1), G-504B (L2), G-516 (L3), Rg-5 (L4), Rg-14 (L5), Rg-15 (L6), Rg-33 (L7), Rg-37 (L8), L-226A (L9) and Rg-41 (L10). The pedigree of these inbred lines are presented in the supporting information (Supplementary Table).

Field experiments and Recorded traits

In the 2012 summer season, the ten inbred lines were top crossed to the three testers; SC10 (T1), SC122 (T2) and TWC310 (T3). In the 2013 summer season, the resulting thirty top crosses and the two commercial check hybrids; SC128 and TWC324 were evaluated in two separate experiments under two nitrogen levels; 80 (N1) and 120 (N2) kg N/fed at the experimental farm of faculty of Agriculture, Kafrelsheikh University, Egypt. A randomized complete block design (RCBD) with three replications was used in the two experiments. Each plot consisted of two rows, 6 m long, 70 cm width. Planting was made in hills spaced at 25 cm with three kernels per hill on one side of the row. The seedlings were thinned to one plant per hill after 21 days from planting. The cultural practices were followed as usual for ordinary maize field in the area. Data were recorded for the number of days to 50% silking (day), plant height (cm), ear height (cm), ear length (cm), ear diameter (cm), number of rows/ ear, number of kernels/ row and grain yield (ard/fed) adjusted to 15.5% grain moisture content (1 ardab = 140 Kg and 1 feddan = 4200 m^2).

Statistical analysis

Analysis of variance was performed for each nitrogen level as well as for combined data after the homogeneity test across the two nitrogen levels according to Steel and Torrie (1980).

Table 4. Specific combining ability effects (SCA) of the 30 top crosses for all of the studied traits over the two nitrogen levels.

Cross	Days to 50% silking	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	Number of rows/ear	Number of kernels /row	Grain yield (ard/fed)		
								N1	N2	Comb
L1 × T1	-1.10**	-10.27**	-0.20	-0.27	0.28**	0.71**	1.46**	1.23	1.20	1.21*
L1 × T2	-0.18	9.73**	10.19**	1.03**	-0.26**	-0.37*	-2.26**	-0.59	-1.96*	-1.28*
L1 × T3	1.28**	0.54	-9.99**	-0.75*	-0.02	-0.34	0.79	-0.64	0.77	0.06
L2 × T1	-2.10**	-3.55	0.005	-2.82**	0.19*	0.66**	-2.75**	-2.26**	-2.90**	-2.58**
L2 × T2	0.65	0.91	-3.30	-0.12	-0.06	-0.34	3.13**	1.48*	1.03	1.25*
L2 × T3	1.45**	2.64	3.31	2.95**	-0.13	-0.32	-0.37	0.78	1.88	1.33*
L3 × T1	1.79**	13.21**	6.22**	3.19**	-0.12	-0.25	3.58**	2.61**	2.41*	2.51**
L3 × T2	0.04	28.65**	11.07**	-2.11**	0.14	0.35	1.16*	-2.35**	-1.66	-2.01**
L3 × T3	-1.83**	-41.86**	-17.30**	-1.09**	-0.02	-0.10	-4.74**	-0.26	-0.74	-0.50
L4 × T1	-0.27	-5.25*	-3.68	-1.89**	0.11	-0.35	-5.92**	-2.13**	-2.51*	-2.32**
L4 × T2	-0.85*	13.26**	12.72**	1.66**	-0.47**	-0.60**	4.31**	1.39	2.71**	2.05**
L4 × T3	1.12**	-8.01**	-9.04**	0.23	0.36**	0.95**	1.61**	0.73	-0.20	0.27
L5 × T1	4.12**	-3.44	-2.40	2.38**	-0.56**	-0.99**	4.98**	0.65	3.48**	2.06**
L5 × T2	1.87**	-14.89**	-9.92**	-0.32	0.06	0.37*	-1.09	2.37**	-0.11	1.13
L5 × T3	-5.99**	18.33**	12.32**	-2.05**	0.50**	0.62**	-3.89**	-3.02**	-3.37**	-3.19**
L6 × T1	-2.16**	-2.73	-4.19*	-1.37**	-0.06	0.05	0.18	-0.33	-1.51	-0.92
L6 × T2	1.43**	7.84**	5.57**	0.13	0.31**	0.30	-0.59	4.04**	2.47*	3.25**
L6 × T3	0.73	-5.11*	-1.38	1.25**	-0.26**	-0.35	0.41	-3.71**	-0.96	-2.33**
L7 × T1	-1.16**	8.20**	2.23	-1.02**	-0.19*	-0.06	1.73**	-1.61*	0.01	-0.80
L7 × T2	1.43**	-24.22**	-14.51**	3.13**	0.18*	1.01**	-3.29**	0.08	-0.06	0.01
L7 × T3	-0.27	16.02**	12.27**	-2.10**	0.01	-0.94**	1.56**	1.53*	0.06	0.79
L8 × T1	-0.27	-10.06**	-5.10*	0.03	-0.01	-0.06	1.35*	-0.19	0.80	0.31
L8 × T2	0.15	6.17**	2.50	-1.07**	0.36**	0.16	-1.32*	-1.86*	-2.26*	-2.06**
L8 × T3	0.12	3.88	2.60	1.05**	-0.36**	-0.10	-0.02	2.05**	1.46	1.75**
L9 × T1	2.84**	16.12**	8.96**	0.29	0.18*	0.71**	1.20*	3.57**	1.39	2.48**
L9 × T2	-4.74**	-30.68**	-15.11**	-0.36	-0.16	-1.03**	-0.62	-2.31**	0.66	-0.83
L9 × T3	1.89**	14.56**	6.15**	0.06	-0.02	0.32	-0.57	-1.26	-2.06*	-1.66**
L10 × T1	-1.71**	-2.23	-1.85	1.49**	0.18*	-0.41*	-5.80**	-1.55*	-2.37*	-1.96**
L10 × T2	0.21	3.23	0.79	-1.96**	-0.11	0.15	0.58	-2.23**	-0.81	-1.52*
L10 × T3	1.51**	-1.01	1.06	0.46	-0.07	0.26	5.23**	3.78**	3.18**	3.48**
LSD S_{ij} 0.05	0.74	4.66	4.00	0.59	0.17	0.36	1.11	1.44	1.90	1.17
LSD S_{ij} 0.01	0.97	6.13	5.27	0.78	0.23	0.47	1.46	1.92	2.52	1.54

*, ** significant at 0.05 and 0.01 levels of probability, respectively.N1, N2 and Comb refer to first, second nitrogen level and combined analysis, respectively.

Table 5. Estimates of the variance due to general combining ability GCA, specific combining ability SCA and their interaction with nitrogen for all the studied traits, over the two nitrogen levels.

Genetic parameters	Days to 50% silking	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	Number of rows/ear	Number of kernels /row	Grain yield (ard/fed)
K^2 GCA	3.053	79.277	38.098	0.922	0.060	0.463	9.264	12.38
K^2 SCA	6.802	355.11	107.28	4.240	0.090	0.444	13.191	5.34
K^2 GCA/ K^2 SCA	0.449	0.223	0.355	0.217	0.666	1.044	0.702	2.32
K^2 GCA × N	1.509	4.956	0.174	0.133	0.003	0.006	0.026	0.104
K^2 SCA × N	0.713	16.410	9.493	0.764	0.005	0.047	0.542	0.912

The procedure of the line × tester analysis according to Kempthorne (1957) was used for estimating general and specific combining ability effects and variances as described by Singh and Chaudhary (1985).

Conclusions

This study clarified that four top crosses L3×T1, L6×T2, L1×T1 and L9×T1 significantly out yielded the check hybrid TWC324 and only the top cross L3×T1 significantly outperformed the best check hybrid SC128. These crosses should be tested further under different locations and environments. The inbred lines L1, L3, L6 and L10 were good combiners for grain yield and most of the yield component traits. The best SCA effects for grain yield were L1×T1, L2×T2, L2×T3, L3×T1, L4×T2, L5×T1, L6×T2, L8×T3, L9×T1and L10×T3. These top crosses might be of interest in breeding programs to improve grain yield

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