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Research Article

Genetic analysis of some topcrosses of yellow maize

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Abstract
Twenty elite yellow maize inbred lines were crossed as female parents with three different testers as male parents, i.e. Gem. Pop. (Broad genetic base), Single cross 101(Narrow genetic base) and Inbred line 100 (Narrow genetic base) at the Experiment Research Station of Moshtohor, Benha University, Egypt during 2014 growing summer season. The resulting 60 crosses with three commercial check hybrids i.e. SC 155, SC Pioneer 3080 and TWC 352 were evaluated in a yield trial in two sowing dates during 2015 growing summer season. The results showed that, sowing dates, crosses, lines, testers and line x testers mean squares were significant for all traits. The seven parental inbred lines (L-4, L-5, L-10, L-12, L-13, L-14 and L-19) possessed high GCA effects for grain yield and six lines (L-1, L-7, L-10, L-13, L-16 and L-18) possessed high GCA effects for earliness. These lines can be utilized as promising inbred lines in a hybridization program to develop high yielding and early maturity maize hybrids. The seven crosses (T-1 × L-7, T-1 × L-13, T-1 × L-17, T-2 × L-4, T-2 × L-5, T-2 × L-10 and T-2 × L-12) which had out-yielded significantly the best check SC. 3080 could be utilized for future breeding work as well as for direct release after confirming the stability of their performances observed in the current study. Hence, the information from this study may possibly be useful for researchers who would like to develop high yielding hybrids of maize.

Key words
Zea mays, Line × tester, Combining ability, Broad genetic base.

INTRODUCTION

Maize (*Zea mays* L.) is one of the most important cereals in Egypt due to its vast grown area, total production and cash value. It is essential for human consumption and livestock. Moreover, it is also used for industrial purposes such as manufacturing starch and cooking oils. Many efforts are devoted nowadays to increase its productivity through genetical improvement. The ultimate goal of most breeding programs is the production of improved hybrids for commercial use through their evaluation for high yielding ability. Evaluating inbred lines is a prime importance for hybrid production. The topcross test is the most common procedure for the evaluation process. Davis (1927), Jinkins (1935) and Sqargue (1939) suggested the method of early testing. Sprague and Tatum (1942) was the first to partition the total combining ability effects of the lines into GCA and SCA. Line × tester analysis is a modification of this method in which several testers are used Kempthorne (1957), which provides good information on the general and specific combining ability effects of parents and their hybrid combinations. The design has widely been used in maize by several researchers like, Sedhom (1992), Mahmoud and Abd El-Azeem (2004), El-Ghonemy (2015), Gamea (2015), Hassan *et al* (2016), Ismail *et al* (2018) and Ismail *et al* (2020) who estimated general and specific combining ability of grain yield and some other characteristics. The objectives of this investigation were to: Provide information of suitable testers for testing inbred lines; Estimate both GCA and SCA combining ability effects of some yellow maize inbred lines, and their interactions with sowing dates and identify the most superior lines and single crosses to be used in hybrid maize breeding programs.

MATERIALS AND METHODS

The material used in this study were twenty elite yellow maize inbred lines developed by Prof. Dr. Ali El-Hosary, Faculty of Agriculture, Benha University, Egypt. These lines were crossed as female parents with three different male parents, i.e. Gem. Pop. represent (Broad genetic base), Single Cross 101(SC 101) and inbred line 100 represent (Narrow genetic base) as testers (**Table 1**).

These materials were crossed according to line x tester technique Kempthorne (1957) to generate 60 F_1 hybrids at the Experiment Research Station of Moshtohor, Benha University, Egypt during 2014 growing summer season. The 60 crosses with the three commercial check hybrids Single Cross 155 (SC. 155), Single Cross Pioneer 3080 (SC. 3080) and Three Way Cross 352 (TWC. 352) were evaluated in a yield trail in two sowing dates, i.e. 15^{th} June and 4^{th} July during 2015growing summer season.

Table 1. The code number, name and origin of yellow maize inbred lines (L1 to L20) and the three testers (T1 to T3) used in the present study.

Code Number	Name	Origin
L-1	M 319	Egypt
L-2	M 103	Egypt
L-3	M 202-A	Egypt
L-4	M 210-B	Egypt
L-5	M 202-D	Egypt
L-6	M L-156	Egypt
L-7	M 210-B-4	Egypt
L-8	M 210-I	Egypt
L-9	M 1012	Egypt
L-10	M 106	Egypt
L-11	M 101	Egypt
L-12	M 1006	Egypt
L-13	M 161	Egypt
L-14	M 318-J	Egypt
L-15	M 304-2	Egypt
L-16	M 311-4	Egypt
L-17	M 302-f	Egypt
L-18	M 210-2	Egypt
L-19	M 1006-B	Egypt
L-20	M 120-A	Egypt
T-1	Gem. Pop.	Egypt
T-2	SC 101	Egypt
T-3	Inbred line 100	Egypt

A randomized complete block design (RCBD) with three replications was used. Plot size was one row, 5.0 m long, 0.70 m apart and 0.25 m between hills. Two seeds were planted per hill and later thinned out to one plant per hill before the first irrigation. The recommended packages of agronomic practices were followed to achieve a good growth. The data were collected on the number of days to silk emergence (DTS) which was recorded as the number of days from planting date to the time when 50% of plants in the plot produced visible silks, Plant height (PH) measured after flowering on 10 competitive plants plot^{-1} in cm from ground to the point of flag leaf insertion and Ear height (EH) recorded after flowering on 10 competitive plants plot^{-1} as distance in cm from the ground to the ear leaf. Grain yield per acre (GYPA) was estimated and adjusted at 15.5% grain moisture and expressed in Kilo gram (kg) per acre of maize grains. The data recorded were subjected to analysis of variance (ANOVA) according to Steel and Torrie (1980). Bartlett test was used to test the homogeneity of error variance among sowing dates for all studied traits. Analysis of general combining ability and specific combining ability was carried out following the method of Kempthorne (1957).

RESULTS AND DISCUSSION

The combined analyses of variance for the studied traits across the two sowing dates are presented in **Table. 2.** Test of homogeneity revealed the validity of the combined analysis across the two sowing dates. Sowing dates mean squares were highly significant for all traits, indicating that the two sowing dates are varied in climate conditions. These results are in agreement with those reported by Nawar *et al.* (1998), El- Hosary and El-Badawy (2005) and El-Hosary *et al.* (2006).

Crosses mean squares were highly significant for all the studied traits, indicating the wide diversity between the parental materials used in the present study and the crosses were sufficiently different from each other for these traits. Hence, the selection is possible to identify the most desirable crosses. Significant crosses × sowing dates mean squares were obtained for all the studied traits except for ear height, revealing that the tested crosses varied from each other and ranked differently from sowing date to another. Mean squares due to lines, testers and line × tester were significant for all traits, indicating the wide diversity among lines, testers and their resulting crosses. Significant line x sowing dates for all the studied traits except for ear height. Significant tester × sowing dates mean squares were detected for days to 50 % silking and grain yield . These findings indicate that inbred lines and testers differ in their mean performance for all traits and behaved somewhat differently from one sowing date to another. Significant interaction lines × tester × sowing dates mean squares were obtained for all the studied traits, except for ear height. In addition, testers mean squares were much higher than those of lines mean squares for all studied traits, except for days to 50 % silking. Such results revealed that testers contributed much more to the total variation as compared to lines. These results are in agreement with those reported by Abd El-Azeem (2011), Abd El-Moula (2011), Ibrahim *et al* (2012), Gamea (2015), Abo Yousef *et al* (2016) and Motawei *et al* (2016). Mean performance of the 60 top crosses along with three check hybrids (SC 155, SC 3080 and TWC 352) for all the studied traits is presented in **Table. 3**.

Table 2. Mean squares for days to 50% silking (DTS), plant and ear heights (EH) and grain yield (GYPA) of combined analysis across two sowing dates (2015 growing season)

SOV	d.f	Mean squares			
		DTS	PH (cm)	EH (cm)	GYPA
Sowing Dates (SD)	1	2064.01**	17222.50**	4214.12**	75977.37**
Rep/SD	4	0.89	30.19	287.29	51.16
Crosses (C)	59	7.83**	1025.96**	307.91**	925.39**
Lines (L)	19	12.25**	1279.08**	388.74**	733.38**
Testers (T)	2	3.85**	2906.01**	720.50**	962.21**
Lines x Testers	38	5.83**	800.45**	245.78**	1019.46**
Crosses x SD	59	2.95**	134.48**	57.60	1063.07**
Lines x SD	19	1.40*	156.04**	72.08	1361.00**
Testers x SD	2	2.60*	42.15	2.41	2131.00**
Lines x Testers x SD	38	3.75**	128.56 **	53.27	857.90**
Pooled error	236	0.82	45.72	52.41	37.17

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

Table 3. Mean performance of 60 top crosses as well as three check hybrids for all the studied traits, combined across two sowing dates

Trait	DTS			PH (cm)			EH (cm)			GYPA kg/ac		
Lines	Testers			Testers			Testers			Testers		
	T-1	T-2	T-3	T-1	T-2	T-3	T-1	T-2	T-3	T-1	T-2	T-3
L-1	59.6	60.6	60.6	219.6	226.5	231.3	114.6	115.1	118.5	3202	2940	3080
L-2	63.0	62.5	62.1	214.1	230.3	214.0	110.0	119.8	113.0	2633	2513	2832
L-3	63.0	61.1	64.0	212.1	238.1	231.0	115.5	122.0	101.0	2947	3009	2778
L-4	61.6	63.1	62.6	229.3	244.3	228.3	115.1	128.1	121.3	2862	3485	3067
L-5	63.6	63.1	62.1	229.5	231.6	242.6	120.5	124.1	133.6	3114	3468	2825
L-6	61.5	62.0	61.6	227.6	244.6	243.5	117.0	124.5	128.5	2908	3000	3185
L-7	60.3	60.8	61.8	215.6	217.6	232.0	116.6	117.5	121.8	3518	2733	2821
L-8	62.1	62.8	63.0	229.6	227.3	230.6	116.1	112.1	115.5	3277	2888	2989
L-9	61.6	62.3	61.3	220.0	192.6	223.5	104.8	102.0	116.3	2747	2506	3067
L-10	62.0	61.3	59.8	177.3	222.1	218.1	100.1	112.6	112.3	2874	3528	3324
L-11	61.5	62.1	61.3	214.0	230.6	241.1	107.6	119.6	123.8	2787	2978	3160
L-12	64.6	59.8	60.3	210.6	232.3	226.1	111.1	115,8	118.1	2915	3791	2715
L-13	59.3	60.3	60.0	205.0	229.3	228.5	111.5	121.8	117.2	3836	3048	2869
L-14	62.1	62.3	60.0	236.3	217.3	209.8	122.5	114.8	104.5	3272	3163	2941
L-15	61.1	62.5	61.1	204.5	205.0	234.8	106.6	102.5	120.8	2947	2810	3192
L-16	61.0	61.3	60.3	226.6	214.0	235.3	116.0	105.0	123.5	3160	2437	2954
L-17	62.3	63.3	61.5	233.6	219.0	232.6	120.6	105.5	114.8	3597	2435	3142
L-18	60.5	61.5	60.8	207.9	214.5	230.8	100.8	115.3	114.8	3093	2652	2596
L-19	60.6	60.5	62.8	251.0	236.3	223.0	114.0	115.0	113.3	3345	3024	2877
L-20	61.6	62.0	61.1	229.6	231.0	233.3	112.0	118.3	118.0	2897	3164	2754
SC 155		61.83			253.00			114.50			2950	
SC 3080		61.83			246.17			118.17			3410	
TWC 352		63.33			229.83			118.00			2937	
LSD 0.05		1.02			7.65			8.19			6.90	

(DTS= Days to 50 % Silking, PH= Plant height, EH= Ear height and GYPA= Grain Yield per acre).

For days to 50% silking, fifteen crosses exhibited significant earliness than the earliest check hybrids SC 155 and SC 3080 (61.83 day). The earliest four crosses were $T_1 \times L_1$ (59.67 day), $T_1 \times L_{13}$ (59.33 day), $T_2 \times L_{12}$ (59.83 day), and $T_3 \times L_{10}$ (59.83 day). Regarding plant height, twenty crosses expressed significant the lowest values as compared with the shortest check hybrid TWC 352 (229.83 cm). Six crosses i.e. $T_1 \times L_{10}$ (177.33 cm), $T_1 \times L_{15}$ (204.50 cm), $T_1 \times L_{18}$ (207.92 cm), $T_2 \times L_9$ (192.67 cm), $T_2 \times L_{15}$ (205.00 cm) and $T_3 \times L_{14}$ (209.83 cm) have expressed the lowest significant plant height values. Plant shortness in maize decreased the lodging degree and increased the yield potentiality. While, the tallest plants are more important for using maize for forage crop or for making silage. Therefore, the two crosses $T_1 \times L_{19}$ (251.00 cm) and $T_2 \times L_6$ (244.67 cm) can be used for silage. Ear height ranged from (100.17 cm) for the cross $T_1 \times L_{10}$ to (133.67 cm) for the cross $T_3 \times L_9$. Nine crosses showed significant lowest ear placement as compared to the lowest check hybrid SC155 (114.50 cm). The four crosses $T_1 \times L_{10}$, $T_1 \times L_{18}$, $T_2 \times L_9$ and $T_2 \times L_{15}$ which had the best values for ear height showed also the most desirable values for plant height. Therefore, these crosses are prospective in maize breeding programs. Seven crosses $T_1 \times L_7$, $T_1 \times L_{13}$, $T_1 \times L_{17}$, $T_2 \times L_4$, $T_2 \times L_5$, $T_2 \times L_{10}$ and $T_2 \times L_{12}$ were significantly out-yielded the best check hybrid SC 3080 (3410 kg/acre) for grain yield trait. Fortunately, the two crosses $T_1 \times L_{13}$ and $T_2 \times L_{12}$ had significant earliness compared to the two check hybrids SC155 and SC 3080. Therefore, it may be used for earliness as well as yielding.

The general combining ability effects ($\hat{g}_i$) of parental inbred lines and three testers for all studied traits are presented in Table 4.

From the breeder's point of view, high negative values for silking, plant and ear heights along with high positive values for yield would be useful for maize breeding program. Six inbred lines (L-1, L-7, L-10, L-13, L-16 and L-18) and the tester T_3 (L 100) expressed significant and the negative ($\hat{g}_i$) effects for days to 50% silking. These inbred lines are considered to be the best combiner for earliness. Consequently, they could be utilized in developing new hybrids characterized by earliness in

Table 4. General combining ability effects (ĝi) of 20 inbred lines and three testers combined across two sowing dates

Lines/Testers	DTS	PH (cm)	EH (cm)	GYPA (Kg/ac)
L-1	-1.31 * *	0.99	0.83	2.23
L-2	0.92 * *	-5.34 * *	-1.00	-15.03 * *
L-3	1.08 * *	2.27	-2.45	-4.52 * *
L-4	0.86 * *	9.16 * *	6.28 * *	4.92 * *
L-5	1.36 * *	9.77 * *	10.83 * *	4.82 * *
L-6	0.08	13.77 * *	8.05 * *	0.48
L-7	-0.64 * *	-3.06	3.39 *	0.18
L-8	1.03 * *	4.38 * *	-0.67	1.32
L-9	0.14	-12.79 * *	-7.56 * *	-8.43 * *
L-10	-0.58 * *	-18.95 * *	-6.89 * *	9.24 * *
L-11	0.03	3.77 *	1.78	-1.87
L-12	-0.03	-1.79	-0.22	5.01 * *
L-13	-1.75 * *	-3.87 *	1.58	11.94 * *
L-14	-0.14	-3.68 *	-1.34	4.40 * *
L-15	-0.03	-10.06 * *	-5.28 * *	-1.54
L-16	-0.75 * *	0.49	-0.45	-7.06 * *
L-17	0.75 * *	3.60 *	-1.61	1.56
L-18	-0.69 * *	-7.09 * *	-4.94 * *	-7.18 * *
L-19	-0.31	11.94 * *	-1.17	2.95 *
L-20	-0.03	6.49 * *	0.83	-3.41 *
SE gi	0.21	1.29	1.70	1.43
SE gi-gj	0.30	2.25	2.41	2.03
T-1	0.04	-5.11 * *	-2.59 * *	3.19 * *
T-2	0.15	0.41	0.32	-0.97
T-3	-0.20 *	4.70 * *	2.27 * *	-2.22 * *
SE gi	0.08	0.61	0.66	0.55
SE gi-gj	0.11	0.87	0.93	0.78

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

flowering. The desirable ($\hat{g}_i$) effects for plant height were obtained by the parental inbred lines (L-2, L-9, L-10, L-13, L-14, L-15 and L-18) and the parental tester T_1 (Gem. Pop.). Meanwhile, the lines L-4, L-5, L-6 and L-19 gave significant positive ($\hat{g}_i$) effects for plant height. Therefore, they could be used in breeding programs for developing new hybrids for silage. For ear height, four parental inbred lines (L-9, L-10, L-15 and L-18) and one parental tester T_1 (Gem. Pop.) exhibited significant and negative ($\hat{g}_i$) effects. The inbred lines L-9 and L-15 were the best combiners for both traits (plant and ear heights). Therefore, they could be of great value in breeding programs for developing new hybrids with short plant to avoid lodging. Significant and positive ($\hat{g}_i$) effects were obtained by the tester T_1 (Gem. Pop.) and seven inbred lines (L-4, L-5, L-10, L-12, L-13, L-14, and L-19) for grain yield. Hence, it could be concluded that these inbred lines should be of great values in breeding programs for improving grain yield.

Specific combining ability effects of the 60 crosses for all the studied traits are presented in **Table 5**. Regarding to days to 50% silking date, one, three and three crosses exhibited significant and negative SCA effects obtained for the tester T-1 (Gem. Pop.), T-2 (SC 100) and T-3 (L 100), respectively. Moreover, the most desirable SCA effects for this trait were obtained by the two crosses T-2 × L-3 and T-2 × L-12. It could be concluded that the tester T-2 (SC 100) was the best among all testers for silking date since it exhibited the largest number of significantly negative SCA effects.

Table 5. SCA effects of 60 top-crosses for the four traits in the combined across two sowing dates.

	DTS			PH (cm)			EH (cm)			GYPA (kg/ac)		
	Testers			Testers			Testers			Testers		
Lines	T-1	T-2	T-3	T-1	T-2	T-3	T-1	T-2	T-3	T-1	T-2	T-3
L-1	-0.71	0.18	0.53	-1.05	0.26	0.80	1.15	-1.26	0.11	2.13	-4.61	2.48
L-2	0.40	-0.21	-0.19	-0.22	10.43**	-10.20**	-1.68	5.24	-3.55	-4.29	-5.10*	9.40**
L-3	0.23	-1.71**	1.48**	-9.83**	10.65**	-0.82	5.26	8.85**	-14.11**	-1.68	5.04*	-3.36ss
L-4	-0.88*	0.51	0.36	0.45	9.93**	-10.37**	-3.79	6.29*	-2.50	-14.71**	15.44**	-0.73
L-5	0.62	0.01	-0.64	0.00	-3.35	3.35	-3.02	-2.26	5.28	-4.11	14.81**	-10.70**
L-6	-0.27	0.12	0.14	-5.83*	5.65*	0.18	-3.74	0.85	2.89	-8.32**	-0.31	8.63**
L-7	-0.71	-0.32	1.03**	-1.00	-4.52	5.52*	0.59	-1.49	0.89	17.42**	-11.18**	-6.24*
L-8	-0.54	0.01	0.53	5.56*	-2.30	-3.26	4.15	-2.76	-1.39	6.24*	-5.82*	-0.42
L-9	-0.16	0.40	-0.25	13.06**	-19.80**	6.74*	-0.29	-6.04*	6.34*	-6.16*	-6.50**	12.65**
L-10	0.90*	0.12	-1.03**	-23.44**	15.87**	7.57**	-5.63	3.96	1.67	-18.53**	12.88**	5.65*
L-11	-0.21	0.35	-0.14	-9.50**	1.65	7.85**	-6.79*	2.29	4.50	-11.02**	1.09	9.94**
L-12	3.01**	-1.93**	-1.08**	-7.28**	8.87**	-1.59	-1.29	0.46	0.84	-12.57**	28.11**	-15.54**
L-13	-0.60	0.29	0.31	-10.86**	7.95**	2.91	-2.77	4.65	-1.89	18.87**	-9.84**	-9.04**
L-14	0.62	0.68	-1.30**	20.28**	-4.24	-16.04**	11.15**	0.57	-11.72**	2.93	2.52	-5.45*
L-15	-0.49	0.74*	-0.25	-5.17	-10.19**	15.35**	-0.74	-7.82**	8.56**	-4.67	-6.26*	10.93**
L-16	0.07	0.29	-0.36	6.45*	-11.74**	5.30	3.76	-10.15**	6.39*	9.72**	-16.24**	6.51**
L-17	-0.10	0.79 *	-0.69	10.33**	-9.85**	-0.48	9.59**	-8.49**	-1.11	19.26**	-25.00**	5.75*
L-18	-0.49	0.40	0.09	-4.72	-3.66	8.38**	-6.88*	4.67	2.21	6.99**	1.31	-8.30**
L-19	-0.71	-0.99**	1.70**	19.33**	-0.85	-18.48**	2.48	0.57	-3.05	7.41**	-0.71	-6.70**
L-20	0.01	0.24	-0.25	3.45	-0.74	-2.70	-1.52	1.90	-0.39	-4.92*	10.37**	-5.46*
SE SCA		0.36			2.76			2.95			2.48	
SE Sij-sik		0.52			3.90			4.17			3.51	

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

Regarding to plant height, five, four and four topcrosses expressed significant negative $\hat{S}_{ij}$ effects for the tester T-1 (Gem. Pop.), T-2 (SC 100) and T-3 (L 100), respectively. The cross T-1 x L-10 expressed significant negative $\hat{S}_{ij}$ effects for plant height and expressed the lowest significant values in mean performance. So that this hybrid could be used towards short plants in order to decrease lodging. The crosses T-1 × L-11, T-1 × L-18, T-2 x L-9, T-2 × L-15, T-2 × L-16, T-2 × L-17, T-3 × L-3 and T-3 × L-14 expressed desirable significant negative SCA effects for ear height.

For grain yield, twenty one crosses showed positive significant SCA. The best $\hat{S}_{ij}$ effects were obtained from the two crosses T-2 × L-12 and T-1 × L-17. These two crosses significantly out-yielded the best check hybrid SC 3080 (24.36 ard/acre). According to that these crosses are recommended for release after further evaluation.

It is concluded that the parental lines (L-10 & L-13) possess high GCA effects for grain yield and) possess high GCA effects for earliness. They can be utilized as promising inbred lines in a hybridization programs to develop high yielding and early maturity maize hybrids. Most crosses that are selected based on desirable SCA effects also had high mean performance for grain yield, namely the seven crosses (T-1 × L-7, T-1 × L-13, T-1 × L-17, T-2 × L-4, T-2 × L-5, T-2 × L-10 and T-2 × L-12) which had out-yielded significantly the best check SC 3080. These crosses could be utilized for future breeding work as well as for direct release after confirming the stability of their performances across different environments. Hence, the information from this study may possibly be useful for researchers who would like to develop high yielding hybrids of maize.

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