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ASSESSMENT OF COMBINING ABILITY AND HETEROTIC GROUPS OF NEW WHITE MAIZE INBRED LINES

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ABSTRACT

The identification of the best combiner lines in the breeding programe is important. Thus, new nineteen white maize inbred lines were crossed as female parents with two inbred lines as testers, i.e. SK-9 and Sk-13 at Sakha Agricultural Research Station, Field Crops Research Institute, Agricultural Research center during 2020 growing summer season. The 38 crosses with the commercial check hybrid SC 10 were evaluated at three locations, i.e. Sakha, Sids and Mallawy Research Stations during 2021 growing season. A randomized complete block design with three replications was used. The data were collected on number of days to 50 % silk emergence (DTS), plant height (PH) and grain yield per feddan (GYPF). The results showed that, locations (Loc), crosses (C), lines (L), Testers (T), lines x testers (L x T), (C x Loc), (L x Loc), (T x Loc) and (L x T x Loc) mean squares were significant for all traits, except (T) for DTS and (L x T x Loc) for DTS and PH traits. The parental inbred lines (L-1, L-4, L-6, L-7 and L-14) possessed high GCA effects for grain yield and (L-3, L-12 and L-13) showed desirable GCA effects for both earliness and short plant. The cross L-1 x SK-9 possessed desirable SCA effects and they also out-yielded, significantly, the check hybrid SC 10. Thus, this cross could be utilized for hybrids breeding program. The parental inbred lines were grouped into two groups based on heterotic group specific and general combing ability (HSGCA) method for (GYPF) trait. The group one was for tester SK-9 included (L-4, L-10, L-11, L-13, L-16, L-17 and L-19) while the group two was for tester SK-13 included (L-2, L-3, L-8, L-9, L-12, L-15 and L-18). These groups could be used in a breeding program for selecting the best parents to make crosses in other combinations.

Key words: ***Zea mays L., Line x tester, Heterotic group, Corn, Crosses, Combining ability.***

INTRODUCTION

Maize is the queen of cereal crops due to high yielding potential and enormous genetic diversity (Prasanna 2012). It has great yield potential and attained the leading position among the cereals based on production as well as productivity (Singh *et al.* 2012). In Egypt, maize is essential for human consumption and livestock. Moreover, it is also used for industrial purposes such as manufacturing starch and cooking oils. However, the local production of maize is insufficient to the local demand. Egypt should narrow the gap between the production and consumption. The expansion of corn cultivated area is difficult in Egypt due to limited cultivated land and limited water resources. Therefore, increasing productivity would be solely by genetic improvement through development of high yielding resilient hybrids and development of agronomic practices in different environmental conditions. Evaluating inbred lines is of prime importance for hybrid production. Hence, the identification of the best combiner line is of foremost important step in developing hybrids. Combining ability is a useful biometric tool to plant breeders for formulating efficient breeding programs

(Hallauer and Miranda 1981). Line x tester analysis by (Kempthome 1957) has widely been used for evaluation of inbred lines (Singh *et al* 2013, Jahan *et al* 2014, Rastgari *et al* 2014, El-Ghonemy 2015, Gamea 2015, Kumar *et al* 2015, Hassan *et al* 2016, Baudh Bharti *et al* 2017, Ismail *et al* 2018, Darshan and Marker 2019, Sharma *et al* 2019 and Badr *et al* 2022). Classifying maize inbred lines into heterotic groups is the initial step in maize breeding due to maximizing the exploitation of heterosis by determining the relationship among the diverse inbred lines (Menkir *et al* 2004, Fan *et al* 2009, Legesse *et al.* 2009 and Mosa *et al* 2017).

The objectives of present study were a) to estimate GCA and SCA effects for new promising white inbred lines, b) to identify the most superior lines and single crosses to be used in hybrid maize breeding programs and c) to classify the nineteen inbred lines into heterotic groups.

MATERIALS AND METHODS

The material used in this study that were new nineteen white maize inbred lines developed at Sakha Research Station were crossed with two inbred lines as testers, *i.e.* SK-9 and SK-13 according to line x tester technique (Kempthorne 1957) to generate 38 F_1 hybrids at Sakha Research Station, Agricultural Research Center, during 2020 growing season. The resultant 38 crosses with the commercial check hybrid SC 10 were evaluated at three locations, i.e. Sakha, Sids and Mallawy Research Stations during 2021 growing season. The experiment was laid out in a randomized complete block design (RCBD) with three replications. Plot size was one row, 6.0 m long, 0.80 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 at the proper time to achieve a good growth. The data were collected on 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) was measured after flowering on 10 competitive plants plot^{-1} in cm from ground to the point of flag leaf insertion. Grain yield per feddan (GYPF) was estimated and adjusted at 15.5% grain moisture and expressed in ardab per feddan (ard/fed), (One ardab = 140 kg)(one feddan= 4200 m^2) of maize grains. The data recorded were subjected to combined analysis of variance (ANOVA) according to Snedecor and Cochran (1967) after testing the homogeneity of error variance among locations for all studied traits. Analysis of general combining ability (GCA) and specific combining ability (SCA) were computed according to line x tester analysis based on the method described by Kempthorne (1957). Grouping of inbred lines was performed using a factorial mating design based on heterotic group specific and general combining ability (HSGCA) method according to Fan *et al* (2009).

RESULTS AND DISCUSSION

Analysis of variance

Combined analysis of variance for the three traits across three locations are presented in Table (1) Locations (loc) mean squares were highly significant for all traits, indicating that the three locations are varied in soil and climate conditions. These results are in agreement with those reported by Abd El-Azeem (2011), Ibrahim *et al* (2012) and Abd El-Mottalb (2014), El-Ghonemy (2015), Abo Yousef *et al* (2016), Hassan *et al* (2016), Ismail *et al* (2018).

Table 1. Mean squares for days to 50 % silking, plant height and grain yield of combined analysis across three locations.

SOV	df	Mean squares		
		DTS	PH (cm)	GYPF
Locations (Loc)	2	1014.7 **	59669.3 **	2032.5 **
Rep/Loc	6	4.25	939.3	78.4
Crosses (C)	38	5.82 **	702.2 **	82.6 **
Lines (L)	18	9.28 **	948.3 **	113.7 **
Testers (T)	1	2.29	2534.4 **	304.9 **
L x T	18	2.42 **	194.2 **	39.2 **
C x Loc	76	2.07 **	233.2 **	32.0 **
L x Loc	36	2.95 **	281.1 **	43.4 **
T x Loc	2	5.88 **	1407.2 **	67.7 **
L x T x Loc	36	0.83 ns	60.9 ns	20.0 **
Pooled error	228	1.18	71.5	9.50

*** and ** indicate significant at 0.05 and 0.01 probability levels, respectively.**
(DTS= Days to 50% silking, PH= Plant height and GYPA= Grain yield per feddan).

Crosses (C) mean squares were highly significant for all the studied traits, indicating that, the crosses were sufficiently different from each other for the studied traits. Hence, selection is possible to identify the most desirable crosses. Significant C x loc mean squares were exhibited for all the studied traits, revealing that the tested crosses ranked differently from location to another. Mean squares due to lines (L), testers (T) and line x tester (L x T) were significant for all traits, except the tester mean square for days to 50% silking (DTS), indicating the wide diversity among lines and testers and their resulting crosses. Significant L x loc and T x loc mean squares were detected for all traits. These findings indicate that inbred lines and testers behaved somewhat differently from one location to another. Significant interaction L x T x loc mean squares were obtained for the grain yield (GYPF) trait. 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), Ismail *et al* (2018).

Mean performance:

Mean performance of the 38 crosses along with the check hybrid SC 10 for all the studied traits is presented in Table (2). For days to 50 % silking, sixteen crosses exhibited significant earliness than the check hybrid SC 10 (64.3 day). The earliest two crosses were L-12 x SK-13 (61.6 day) and L-8 x SK-9 (62.0 day). Regarding plant height, thirty three crosses out of thirty eight crosses showed significantly the lowest values as compared with the check hybrid SC 10 (256.2 cm). The two crosses L-12 x SK-13 (219.4 cm) and L-13 x SK-9 (225.1 cm) had the lowest values for plant height. Meanwhile, the two crosses L-7 x SK-9 (260.0 cm) and L-1 x SK-9 (252.6 cm) had the highest values for this trait. The cross L-1 x SK-9 significantly out-yielded (37.7 ard/fad) the check hybrid SC 10 (34.6 ard/fad) for grain yield. Thus, this hybrid will be advanced for further evaluation. Five crosses i.e. (L-4 x SK-13, L-7 x SK-9, L-7 x SK-13, L-10 x SK-13 and L-14 x SK-13) revealed insignificantly higher yield than the check hybrid SC 10. These crosses could be used in maize hybrids breeding program.

Table 2. Mean performance of 38 crosses and the check hybrid (SC 10) for all the studied traits, combined across three locations.

Line	DTS		PH (cm)		GYPF	
	Tester		Tester		Tester	
	SK-9	SK-13	SK-9	SK-13	SK-9	SK-13
L-1	63.6	63.4	252.6	231.6	37.7	34.3
L-2	63.7	64.6	249.2	243.0	31.5	31.6
L-3	63.0	62.7	230.8	227.7	29.8	28.8
L-4	64.4	63.6	237.6	233.2	30.4	35.8
L-5	64.1	63.2	252.3	234.4	32.0	32.7
L-6	63.6	63.1	234.1	237.0	34.0	32.8
L-7	63.2	63.0	260.0	250.7	37.3	36.5
L-8	62.0	62.3	244.1	237.4	30.4	31.5
L-9	63.8	63.7	228.7	232.2	29.1	28.7
L-10	63.6	64.7	236.7	239.6	27.9	34.9
L-11	62.4	62.7	236.8	228.8	30.4	32.9
L-12	62.3	61.6	230.3	219.4	26.8	27.9
L-13	62.1	62.4	225.1	225.9	29.4	32.7
L-14	62.7	63.0	235.7	228.8	30.9	36.3
L-15	63.3	64.9	239.8	233.2	32.9	32.3
L-16	63.8	63.3	237.7	230.6	28.3	33.6
L-17	63.4	64.6	235.8	233.4	24.8	30.5
L-18	63.3	64.4	232.9	234.1	30.6	31.7
L-19	63.8	64.1	235.8	231.3	26.5	31.2
SC 10	64.3		256.2		34.6	
LSD 0.05	1.0		7.8		2.8	
LSD 0.01	1.3		10.2		3.7	

DTS = Days to 50% silking, PH= Plant height and GYPF= Grain yield per feddan.

Combining ability

General combining ability effects:

The general combining ability effects ($\hat{g}_i$) of parental inbred lines and two testers for the studied traits are presented in Table (3).

Table 3. General combining ability effects ($\hat{g}_i$) of 19 inbred lines and two testers across three locations.

Lines	DTS	PH (cm)	GYPF
L-1	0.15	6.05*	4.51*
L-2	0.76*	10.11*	0.03
L-3	-0.52*	-6.78*	-2.19*
L-4	0.65*	-0.61	1.63*
L-5	0.32	7.39*	0.85
L-6	-0.02	-0.45	1.87*
L-7	-0.24	19.33*	5.39*
L-8	-1.18*	4.77*	-0.60
L-9	0.37	-5.56*	-2.60*
L-10	0.76*	2.11	-0.09
L-11	-0.80*	-3.23	0.13
L-12	-1.41*	-11.11*	-4.15*
L-13	-1.07*	-10.50*	-0.47
L-14	-0.52*	-3.78	2.10*
L-15	0.76*	0.50	1.05
L-16	0.20	-1.89	-0.57
L-17	0.65*	-1.39	-3.86*
L-18	0.54*	-2.50	-0.37
L-19	0.59*	-2.45	-2.67*
LSD gi 0.05	**0.50**	**3.91**	**1.42**
LSD gi-gj 0.05	**0.70**	**5.52**	**2.01**
Tester SK-9	- 0.08	2.72*	-0.94*
Tester SK-13	0.08	-2.72*	0.94*
LSD gi 0.05	**0.16**	**1.27**	**0.46**
LSD gi-gj 0.05	**0.23**	**1.79**	**0.65**

*** indicate significant at 0.05 probability level.**
(DTS= Days to 50% silking, PH= Plant height and GYPA= Grain yield per feddan).

From the breeder's point of view, high negative values for silking emergence and plant height along with high positive values for yield would be useful for maize breeding program. Six inbred lines (L-3, L-8, L-11, L-12, L-13 and L-14) out of 19 inbred lines expressed negatively significant ($\hat{g}_i$) effects for days to 50 % silking. These inbred lines are considered to be the best combiners for earliness. The desirable ($\hat{g}_i$) effects for plant height were obtained by the parental inbred lines (L-3, L-9, L-12 and L-13) and the parental tester SK-13. Significant and positive ($\hat{g}_i$) effects were obtained by the tester SK-13 and five inbred lines (L-1, L-4, L-6, L-7 and L-14) for grain yield. Hence, it could be concluded that these inbred lines should be considered of great values in breeding programs for improving grain yield.

Specific combining ability effects

Specific combining ability effects of the 38 crosses for all traits is presented in Table (4).

Table 4. Estimates of SCA effects of 38 top-crosses for all the studied traits across three locations.

Line	DTS		PH (cm)		GYPF	
	Tester		Tester		Tester	
	SK-9	SK-13	SK-9	SK-13	SK-9	SK-13
L-1	0.14	-0.14	7.78**	-7.78**	2.62*	-2.62*
L-2	-0.36	0.36	0.39	-0.39	0.92	-0.92
L-3	0.25	-0.25	-1.17	1.17	1.44	-1.44
L-4	0.53	-0.53	-0.56	0.56	-1.76	1.76
L-5	0.53	-0.53	6.22*	-6.22*	0.62	-0.62
L-6	0.30	-0.30	-4.17	4.17	1.53	-1.53
L-7	0.19	-0.19	1.94	-1.94	1.39	-1.39
L-8	-0.08	0.08	0.61	-0.61	0.39	-0.39
L-9	0.14	-0.14	-4.50	4.50	1.11	-1.11
L-10	-0.47	0.47	-4.17	4.17	-2.54*	2.54*
L-11	-0.03	0.03	1.28	-1.28	-0.34	0.34
L-12	0.47	-0.47	2.72	-2.72	0.41	-0.41
L-13	-0.08	0.08	-3.11	3.11	-0.71	0.71
L-14	-0.08	0.08	0.72	-0.72	-1.76	1.76
L-15	-0.70*	0.70*	0.56	-0.56	1.24	-1.24
L-16	0.30	-0.30	0.83	-0.83	-1.67	1.67
L-17	-0.47	0.47	-1.56	1.56	-1.87	1.87
L-18	-0.47	0.47	-3.33	3.33	0.36	-0.36
L-19	-0.08	0.08	-0.50	0.50	-1.40	1.40
LSD Sij 0.05	0.7		5.52		2.01	
LSD Sij-Sik	1.00		7.81		2.84	

*** indicate significant at 0.05 probability levels.**

(DTS= Days to 50% Silking, PH= Plant height and GYPA= Grain yield per feddan).

The cross L-15 x SK-9 showed desirable with respect to SCA effects for earliness. The two crosses L-1 x SK-13 and L-5 x SK-13 expressed significant and negative $\hat{S}_{ij}$ effects for plant height. Thus, those two hybrids could be used for breeding towards short plants in order to decrease lodging. For grain yield, the two crosses (L-1 x SK-9 and L-10 x SK-13) had significant and positive SCA effects. Also, the cross L-1 x SK-9 significantly out-yielded the best check hybrid SC 10. Therefore, these crosses could be used by Maize Research Program after further testing and evaluation in a wide range of environments.

Heterotic Group

Estimates of heterotic groups based on specific and general combining ability (HSGCA) effects for DTS, PH and GYPF across three locations are presented in Table (5). According to Fan *et al* (2009), the inbred lines were grouped for DTS trait as following, group 1 (Tester SK-9) included the inbred lines (L-8, L-11, L-13 and L-14) while the group 2 (Tester SK-13) included the lines (L-3, L-5, L-6, L-7, 12 and L-16). Nevertheless, this method was unable to classify the inbred lines (L-1, L-2, L-4, L-9, L-10, L-15, L-17, L-18 and L-19). For plant height (PH), group 1 (Tester SK-9) included the inbred lines (L-3, L-4, L-6, L-9, L-10, L-13, L-17, L-18 and L-19) while the group 2 (Tester SK-13) included the lines (L-1, L-11, L-12, L-14 and L-16). However, this method could not group the inbred lines (L-2, L-5, L-7, L-8 and L-15). For grain yield per feddan (GYPF), group 1 (Tester SK-9) included the inbred lines (L-4, L-10, L-11, L-13, L-16, L-17 and L-19) while the group 2 (Tester SK-13) included the lines (L-2, L-3, L-8, L-9, L-12, L-15 and L-18). Meantime, the method was unable to classify the inbred lines (L-1, L-5, L-6, L-7 and L-14).

In the context, Lee (1995) and Mosa *et al* (2017) stated that, the heterotic group is a collection of closely related inbred lines which tend to result in vigorous hybrids when crossed with lines from a different heterotic group, but not when crossed to other lines of the same heterotic group. Hence, Heterotic group method could be recommended in breeding programs for selecting the diverse parents to make crossing between them.

Table 5. Estimates of heterotic groups using specific and general combining ability (HSGCA) method for DTS, PH and GYPF across three locations.

Lines	DTS		PH (cm)		GYPF	
	Tester		Tester		Tester	
	SK-9	SK-13	SK-9	SK-13	SK-9	SK-13
L-1	0.29	0.01	13.83	-1.73	7.13	1.89
L-2	0.4	1.12	10.5	9.72	0.95	-0.89
L-3	-0.27	-0.77	-7.95	-5.61	-0.75	-3.63
L-4	1.18	0.12	-1.17	-0.05	-0.13	3.39
L-5	0.85	-0.21	13.61	1.17	1.47	0.23
L-6	0.28	-0.32	-4.62	3.72	3.4	0.34
L-7	-0.05	-0.43	21.27	17.39	6.78	4
L-8	-1.26	-1.1	5.38	4.16	-0.21	-0.99
L-9	0.51	0.23	-10.06	-1.06	-1.49	-3.71
L-10	0.29	1.23	-2.06	6.28	-2.63	2.45
L-11	-0.83	-0.77	-1.95	-4.51	-0.21	0.47
L-12	-0.94	-1.88	-8.39	-13.83	-3.74	-4.56
L-13	-1.15	-0.99	-13.61	-7.39	-1.18	0.24
L-14	-0.6	-0.44	-3.06	-4.5	0.34	3.86
L-15	0.06	1.46	1.06	-0.06	2.29	-0.19
L-16	0.5	-0.1	-1.06	-2.72	-2.24	1.1
L-17	0.18	1.12	-2.95	0.17	-5.73	-1.99
L-18	0.07	1.01	-5.83	0.83	-0.01	-0.73
L-19	0.51	0.67	-2.95	-1.95	-4.07	-1.27

(DTS= Days to 50% silking, PH= Plant height and GYPA= Grain yield per feddan).

CONCLUSION

Results concluded that the parental lines (L-1, L-4, L-6, L-7 and L-14) possess high GCA effects for grain yield and (L-3, L-12 and L-13) possess desirable GCA effects for earliness, and short plant. These inbreds could be utilized as promising inbred lines in a hybridization programs to develop high yielding and early maturity maize hybrids. The cross L-1 x SK-9 possessed desirable SCA effects and also had out-yielded significantly the check hybrid SC 10. This cross could be utilized for future breeding work as well as for direct release after confirming the stability of their performances across different environments. The parental inbred lines were grouped into two groups based on heterotic group specific and general combing ability (HSGCA) method for grain yield per feddan (GYPF) trait; The group one was for tester SK-9 included (L-4, L-10, L-11, L-13, L-16, L-17 and L-19). While, the group two was for tester SK-13 included (L-2, L-3, L-8, L-9, L-12, L-15 and L-18). These two groups could be used in the breeding program for selecting the best parents for making crosses.

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تقدير القدرة على الائتلاف والمجاميع الهجينية لسلالات جديدة من الذرة الشامية البيضاء

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هجنت ١٩ سلالة بيضاء جديدة قمياً مع سلالتين هم (سخا ٩، سخا ١٣) ككشافات بمحطة البحوث الزراعية بسخا فى موسم ٢٠٢٠. تم تقييم عدد ٣٨ هجين بالإضافة إلى هجين المقارنة فردى ١٠ فى تجارب حقلية بمحطات البحوث الزراعية بسخا وسدس وملوى وذلك فى موسم٢٠٢١. تم أستخدام تصميم القطاعات الكاملة العشوائية فى ثلاث مكرارت ، وتم أخذ صفات عدد الأيام حتى ظهور حرائر ٥٠٪ من النورات المؤنثة، إرتفاع النبات ومحصول الحبوب بالأردب للفدان. وقد أوضحت نتائج التحليل التجميعى عبر المواقع أن هناك فروق معنوية بين المواقع، الهجن، السلالات، الكشافات وكذلك التفاعل بين السلالات والكشافات و التفاعل بين الهجن والمواقع، السلالات والمواقع، والتفاعل بين الكشافات والمواقع والتفاعل بين السلالات والكشافات والمواقع لجميع الصفات المدروسة ما عدا صفة عدد الأيام حتى ظهور حرائر ٥٠٪ من النورات المؤنثة للكشافات وتفاعل السلالات في الكشافات في المواقع كذلك ارتفاع النبات لتفاعل السلالات مع الكشافات مع المواقع. وقد أظهرت السلالات أرقام (١, ٤, ٦, ٧ و ١٤) أعلي قدرة عامة على الائتلاف لصفة المحصول واظهرت السلالات أرقام (١٢،٣ و ١٣) أعلى قدرة عامة على الائتلاف لصفات التبكير وقصر النباتات لذلك يمكن إستخدام هذه السلالات فى برامج التربية للهجن عالية المحصول والتبكير. كما أوضحت الدراسة أن الهجين (سخا ٩ X سلالة ١) أظهر أعلى متوسط إنتاجية حيث تفوق معنوياً عن هجين المقارنة (هجين فردى ١٠) فى صفة المحصول كذلك أعلى قيمة للقدرة الخاصة على الائتلاف لصفة المحصول ولذلك يمكن إستخدام هذا الهجين فى برامج التربية للهجن. تم توزيع السلالات الى مجموعتين هجينتين بالنسبة لصفة المحصول حيث تضمنت المجموعة الأولى للكشاف سلالة سخا ٩ السلالات (٤, ١٠, ١١, ١٣, ١٦, ١٧ و ١٩) بينما تضمنت المجموعة الثانية للكشاف سلالة سخا ١٣ السلالات (٢, ٣, ٨, ٩, ١٢, ١٥ و ١٨) ويمكن الإستفادة من هذه المجاميع الهجينية في إختيار افضل الاباء لتكوين الهجن الجديدة.

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