Egypt. J. Plant Breed. 25(1):47– 57(2021)

HETEROTIC GROUPING FOR SOME WHITE MAIZE INBRED LINES VIA COMBINING ABILITY EFFECTS AND HYBRIDS GRAIN YIELD

H.E. Mosa, I.A.I. El-Gazzar, M.A.A. Hassan, S.M. Abo El-Haress, M.A.A. Abd-Elaziz and R.H.A. Alsebaey

Maize Research Dept., Field Crops Research Inst. (FCRI), ARC, Egypt

ABSTRACT

The concept of heterotic groups is fundamental to hybrid breeding theory and practice. In this study, fifty six new white inbred lines of maize were divided into three sets, each set contained 17, 20 and 19 inbred lines, respectively. Inbred lines in each set were top crossed with two inbred lines as testers; Sk-12 and Sk-13 for set-1, Sk-12 and Sd-63 for set-2 and Sd-7 and Sd-63 for set-3. The resulting hybrids in each set plus the hybrid between the two testers and a check commercial hybrid were evaluated at two locations in 2019 season for grain yield. The mean squares due to locations, lines, testers and lines x testers interaction were highly significant for all sets except for testers and lines x testers in set-1. The results of set-1 showed that 14 crosses were not significantly out-yielded the check; three inbred lines were identified as good general combining ability (GCA) effects, three crosses were noted as the highest for specific combining ability (SCA) effects and the tester inbred lines were able to classify 13 of the 17 tested lines into heterotic groups based on SCA effects and test crosses grain yield. In set-2, 13 crosses had significantly higher grain yield than the check, four inbred lines were the best for GCA effects, three crosses were the best for SCA effects, and the tester inbred lines classified 10 of the 20 tested inbred lines into heterotic groups. In set-3, 13 crosses were not significantly out-yielded the check, three inbred lines were the best for GCA effects, three crosses were the best for SCA effects and the testers were able to classify 14 from 19 tested inbred lines into heterotic groups based on SCA effects and crosses mean yield.

Key words: ***Zea mays, Heterotic patterns, Line × tester.***

INTRODUCTION

Maize breeding programs are dependent on the identification and utilization of heterotic groups and heterotic patterns (Melani and Carena 2005). Heterotic groups represent groups of germplasm sources that when crossed with each other produce consistently better crosses than when crosses are made within those groups (Hallauer and Carena 2009). While heterotic patterns, which are crosses between genotypes from different heterotic groups expressing a high level of heterosis and high hybrid performance (Carena and Hallauer 2001, Mendes *et al* 2015 and Fan *et al* 2018). There are several methodologies in common use of heterotic grouping: 1) pedigree analysis, this method is more reliable than others. However it doesn't apply to those materials used in Egypt because some inbred lines doesn't have clear data of pedigree, 2) quantitative genetic analysis, the heterotic performance and variance of F_1 hybrids are usually used in heterotic grouping. SCA of different inbred lines is the principle of this method, it is based on the assumption that SCA of two lines from different heterotic groups is greater than those of same group and 3) molecular markers analysis based on the polymorphism of DNA structure. Barata and Carena (2006) observed large inconsistencies between molecular markers based classification and field trails based classification (test cross and diallel data) of a diverse set of inbreds; they concluded that groups of similar germplasm and heterosis properties could not be identified accurately and reliably with molecular markers. Consequently, they recommended extensive field evaluation across environments to classify inbred lines into heterotic groups. Meanwhile, Beyene *et al* (2005), in a study comparing phenotypic and molecular methods to estimate genetic divergence, concluded that both methods are equally suited to study genetic diversity in maize crop. The general combining ability (GCA) and specific combining ability (SCA) effects have been further used for genetic diversity evaluation, inbred line selection, heterotic pattern classification, heterosis estimation and hybrid development (Sughroue and Hallauer 1997, Melani and Carena 2005 and Barata and Carena 2006). Menkir *et al* (2004) used two testers representing the flint and dent heterotic patterns to test 38 tropical maize inbred lines. The two testers successfully classified 23 of the 38 tested inbred lines into two heterotic groups based on SCA and grain yield. Ceccarelli (2015) used three measurements to compare the breeding efficiency between participatory breeding and conventional plant breeding: (i) the ratio of the number of varieties adopted (or released) to the number of crosses made (ii) the response to selection and (iii) cost benefit ratio. Depending on the number of heterotic groups being utilized in a breeding program, the first and the third criteria are significantly affected by increased number of crosses, but if the heterotic grouping improves the identification of viable commercial hybrids, the per-hybrid cost will actually be reduced. Melchinger (1999) proposed that, when a large number of inbred lines is available and proven testers exist, the relative performance of the lines is testcrossed with proven testers can be used as the main criterion for grouping of the lines.

The objectives of the study were to classify inbred lines into heterotic groups using combining ability and grain yield and identify the best crosses for grain yield.

MATERIALS AND METHODS

New 56 white inbred lines of maize (*Zea mays* L.) developed at the Sakha (Sk) Research Station in Egypt were divided into three sets. The first set included 17 inbred lines were crossed to two inbred lines as testers, Sk-12 and Sk-13, representing each side of flint and dent heterotic groups, respectively. The 34 crosses plus the hybrid between the two testers and the check hybrid SC 10 were evaluated in two divers environments at Sakha and Mallawi Agricultural Research Stations (ARS). The second set included 20 inbred lines that were crossed to two inbred lines testers, Sk 12 and Sd 63, representing each side of flint and semi dent heterotic group. The 40 crosses plus the hybrid between the two testers and the check hybrid SC 10 were evaluated at Sakha and Mallawi, (ARS). The third set included 19 inbred lines that were crossed with the two testers inbred lines Sd 7 and Sd 63, dent and semi dent, respectively. The 38 crosses plus the hybrid between the two testers and the check hybrid SC 2031 were evaluated at Sakha and Sids (ARS). A randomized complete blocks design with four replications was used for all trials. The plot was one row, 6m long and 0.8m apart. Planting was in hills spaced 0.25m. All cultural practices were applied as recommended. Data were taken on grain yield ton/hectare (t/ha) adjusted on 15.5% grain moisture. Before performing the combined analysis, a test of homogeneity of error mean squares between the two locations was done for each set as outlined by Snedecor and Cochran (1967). Line × tester analysis was calculated based on the method described by kempthorne (1957). Classification of inbred lines into heterotic groups was done according to Menkir *et al* (2004) criteria and its modification by Librando and Magulama (2008).

RESULTS AND DISCUSSION

Combined analyses of variance of grain yield for the three sets of line x tester crosses across locations are presented in Table 1. The mean squares of locations (Loc) were highly significant for all sets, indicating the presence of differences between locations in each set which could be due to environmental variation and soil conditions. The mean squares due to lines (L), testers (T) and their interaction (L × T) were highly significant for all sets, except for (T) and (L × T) in set-1. The mean squares due to (L × Loc), (T × Loc) and (L × T × Loc) interactions were significant or highly significant for all sets, except for (T × Loc) and (L × T × Loc) interactions in set-1 and (L × T × Loc) interaction in set-3.

Table 1. Combined analysis of variances of grain yield for the three sets of line × tester crosses across locations.

SOV	Df			Mean squares		
	Set-1	Set-2	Set-3	Set-1	Set-2	Set-3
Location (Loc)	1	1	1	177.28**	693.84**	623.62**
Rep/Loc	6	6	6	1.80	5.76	27.45
Lines (L)	16	19	18	5.18**	8.87**	7.87**
Testers (T)	1	1	1	0.83	360.99**	17.21**
L×T	16	19	18	1.33	2.86**	5.07**
L×Loc	16	19	18	4.36**	2.83**	2.79**
T×Loc	1	1	1	0.02	25.20**	83.60**
L×T×Loc	16	19	18	1.78	1.99**	1.49
Error	210+	246+	234+	1.20	0.99	1.23

**** significant at 0.01 level of probability.**

+ included all crosses.

Mean performance, SCA effects of 34 crosses, GCA effects and heterotic group of 17 inbred lines for grain yield in set-1 are presented in Table 2. The mean performance of crosses ranged from 9.45 t/ha of L2 × Sk 13 to 11.65 t/ha of L9 × Sk 13. Fourteen crosses were not significantly out-yielded the check SC 10; the best from them were L5 × Sk 13, L9 × Sk 13, L10 × Sk 12, L11 × Sk 12, L15 × Sk 13 and L15 × Sk 12. The highest crosses for SCA effects were L3 × Sk 12, L10 × Sk 12 and L14 × Sk 13. The best inbred lines for GCA effects were L7, L9 and L15. The combining ability and grain yield when crossing two testers were used as the basis in classifying the inbred lines into heterotic groups. Any line showing positive SCA effects with first tester (A) but having negative SCA effects with second tester (B) and cross mean yield equal to or greater than the mean of the cross of the two testers (A × B) was placed into the (A) heterotic group. Similarly inbred line displayed positive SCA effects with tester (B) and cross mean yield equal to or greater than the mean of the cross of the testers

(A × B) was put into the (B) heterotic group. Meanwhile any inbred line exhibiting positive GCA effects and means of yield with both testers equal to or greater than the mean of the cross of the testers (A × B) was assigned to both the A and B heterotic groups according to Menkir *et al* (2004) and Librando and Magulama (2008).

Table 2. Mean performance, specific combining ability effects (SCA) of 34 crosses, general combining ability effects (GCA) and heterotic groups of 17 inbred lines for grain yield in set-1.

Inbred line	Grain yield (t/ha)		GCA effects	SCA effects		Heterotic group
	SK 13	Sk 12		SK 13	Sk 12	
L1	10.65	10.64	-0.352	0.007	-0.007	
L2	9.45	9.71	-1.353*	-0.117	0.117	
L3	9.94	11.14	-0.415	-0.555	0.555	Sk 12
L4	10.02	9.95	-0.915*	0.069	-0.069	
L5	11.48	10.94	0.334	0.194	-0.194	Sk 13 Sk 12
L6	10.91	10.40	-0.102	0.382	-0.382	Sk 13
L7	11.42	11.17	0.530*	0.132	-0.132	Sk 13 Sk 12
L8	11.07	11.15	0.397	-0.117	0.117	Sk 13 Sk 12
L9	11.65	11.43	0.772*	0.257	-0.257	Sk 13 Sk 12
L10	10.51	11.44	0.272	-0.492	0.492	Sk 12
L11	10.96	11.61	0.459	-0.430	0.430	Sk 13 Sk 12
L12	10.89	10.85	0.022	0.132	-0.132	Sk 13 Sk 12
L13	10.60	10.17	-0.290	0.069	-0.069	
L14	11.18	9.89	-0.227	0.507	-0.507	Sk 13
L15	11.59	11.53	0.772*	0.007	-0.007	Sk 13 Sk 12
L16	10.99	10.73	0.209	0.069	-0.069	Sk 13
L17	10.78	10.80	-0.102	-0.117	0.117	Sk 12
Sk13		10.80				
Sk12	10.80					
Check SC 10	10.97					
LSD 0.05	1.07		0.53	0.75		

*** Significant at 0.05 level of probability.**

Three inbred lines (L6, L14 and L16) showed positive SCA effects with tester Sk 13 and with cross mean yield (10.91, 11.18 and 10.99 t/ha, respectively) greater than the mean yield of Sk 13 x Sk 12 (10.80 t/ha). These inbred lines were placed into the Sk 13 heterotic group. Three inbred lines (L3, L10 and L17) had positive SCA effects with tester Sk 12 with cross mean yield (11.14, 11.44 and 10.80 t/ha, respectively) equal to or greater than the mean yield of Sk 13 x Sk 12 (10.8 t/ha). These inbred lines were placed into (Sk 12) heterotic groups. Further seven inbred lines (L5, L7, L8, L9, L11, L12 and L15) had positive GCA effects with higher mean yield with both testers than the Sk 13 × Sk 12. These inbred lines were assigned to both (Sk 13 and Sk 12) heterotic groups. Four inbred lines (L1, L2, L4 and L13) were unclassified, where the mean yield of them with the two testers were lower than the mean yield of the cross of the two testers (Sk 13 × Sk 12). The results suggest that the inbred lines evaluated in this study interacted positively for grain yield with the genetic background of the two testers.

Mean performance, SCA effects of 40 crosses, GCA effects and heterotic groups of 20 inbred lines for grain yield (t/ha) in set-2 are presented in Table 3. The mean grain yield varied from 8.51 t/ha to 14.31 t/ha for crosses L36 × Sd 63 and L19 × Sk 12, respectively. Thirteen crosses were significantly higher than the check SC 10 for grain yield. Increasing of yield of these hybrids over the check SC 10 varied from 10.23% to 36.93%. The best from them were L19 × Sk 12, L20 × Sk 12, L24 × Sk 12, L30 × Sk 12 and L31 × Sk 12. The best crosses for SCA effects were L19 × Sk 12, L20 × Sk 12 and L29 × Sd63. Meanwhile, the GCA effects ranged from -1.74 of L36 to 1.61 of L19, the inbred lines L19, L20, L30 and L34 were the best for GCA effects. Ten inbred lines (L19, L20, L21, L24, L25, L26, L30, L31, L34 and L37) showing positive SCA effects with the flint tester Sk 12 but having negative SCA effects with the semi dent tester Sd 63 and with cross mean yields greater than the mean yield of Sk 12 × Sd 63 were placed into the (Sk 12) heterotic group. Ten inbred lines were unclassified since the mean yield with two testers was lower than the the mean yield of the cross of the two testers.

Table 3. Mean performance, specific combining ability effects (SCA) of 40 crosses, general combining ability effects (GCA) and heterotic groups of 20 inbred lines for grain yield in set-2.

Inbred line	Grain yield (t/ha)		GCA effects	SCA effects		Heterotic group
	SK 12	Sd 63		SK 12	Sd 63	
L18	11.66	10.08	0.076	-0.279	0.279	
L19	14.31	10.51	1.610*	0.835*	-0.835*	SK 12
L20	13.71	9.99	1.040*	0.801*	-0.801*	SK 12
L21	11.92	9.25	-0.220	0.285	-0.285	SK 12
L22	10.95	9.79	-0.440	-0.488	0.488	
L23	11.41	9.34	-0.420	-0.017	0.017	
L24	12.50	9.46	0.170	0.462	-0.462	SK 12
L25	12.37	9.44	0.100	0.410	-0.410	SK 12
L26	12.21	10.35	0.470	0.128	-0.128	SK 12
L27	10.96	9.44	-0.610*	-0.305	0.305	
L28	11.52	9.71	-0.200	-0.158	0.158	
L29	11.29	10.59	0.130	-0.713*	0.713*	
L30	12.96	10.65	1.000*	0.097	-0.097	SK 12
L31	12.50	9.97	0.440	0.205	-0.205	SK 12
L32	10.85	9.15	-0.800*	-0.214	0.214	
L33	10.70	9.54	-0.690*	-0.483	0.483	
L34	12.26	10.35	0.500*	0.110	-0.110	SK 12
L35	11.64	9.14	-0.420	0.179	-0.179	
L36	9.62	8.51	-1.740*	-0.503	0.503	
L37	12.00	9.64	0.007	0.123	-0.123	SK 12
Sk12		11.67				
Sd 63	11.67					
Check SC 10	10.45					
LSD 0.05	0.97		0.48	0.68		

*** Significant at 0.05 level of probability.**

Table 4, showed that the mean performance of 38 crosses in set-3 ranged from 6.31 t/ha of L48 × Sd 7 to 10.76 t/ha of L39 × Sd 7.

Table 4. Mean performance, specific combining ability effects (SCA) of 38 crosses, general combining ability effects (GCA) and heterotic groups of 19 inbred lines for grain yield in set-3.

Inbred line	Grain yield (t/ha)		GCA effects	SCA effects		Heterotic group
	Sd 7	Sd 63		Sd 7	Sd 63	
L38	10.47	9.86	0.829*	0.069	-0.069	Sd 7 Sd 63
L39	10.76	10.19	1.113*	0.061	-0.061	Sd 7 Sd 63
L40	9.09	7.11	-1.241*	0.739	-0.739	-
L41	9.06	10.04	0.148	-0.722	0.722	Sd 63
L42	10.11	8.10	-0.233	0.770*	-0.770*	Sd 7
L43	9.50	10.22	0.509	-0.605	0.605	Sd 63
L44	9.27	9.12	-0.155	-0.158	0.158	
L45	10.35	8.80	0.224	0.554	-0.554	Sd 7
L46	8.34	8.70	-0.578*	-0.162	0.162	
L47	9.50	9.60	0.201	-0.222	0.222	Sd 63
L48	6.31	8.34	-2.013*	-1.257*	1.257*	
L49	10.65	8.54	0.241	0.818*	-0.818*	Sd 7
L50	9.51	9.60	0.148	-0.262	0.262	Sd 63
L51	9.61	9.00	-0.049	0.059	-0.059	Sd 7
L52	9.91	8.45	-0.168	0.468	-0.468	Sd 7
L53	9.97	8.92	0.093	0.281	-0.281	Sd 7
L54	9.59	9.44	0.202	-0.122	0.122	
L55	9.50	10.41	0.611*	-0.690	0.690	Sd 63
L56	9.98	8.08	0.045	0.361	-0.361	Sd 7
Sd 7	-	9.60				
Sd 63	9.60	-				
Check SC 2031	9.79					
LSD 0.05	1.08		0.54	0.76		

*** Significant at 0.05 level of probability.**

Thirteen crosses were not significantly out-yielded the check SC 2031. The best from them was L39 × Sd 7 followed by L49 × Sd 7, L38 × Sd 7 and L55 × Sd 63, respectively. Meanwhile, the best crosses for SCA effects were L42 × Sd 7, L48 × Sd 63 and L49 × Sd 7.The best inbred lines for GCA effects in set-3 were L38, L39 and L55.

Classification of 19 inbred lines in set-3 (Table 4) into heterotic groups showed that, seven inbred lines (L42, L45, L49, L51, L52, L53 and L56) had positive SCA effects with tester Sd 7 and with cross mean yields greater than the mean yield of the cross of the two testers (Sd 7 × Sd 63) were placed into the (Sd 7) heterotic group. Five inbred lines (L41, L43, L47, L50 and L55) had positive SCA effects with tester (Sd 63) with cross mean yields higher than the mean of Sd 7 × Sd 63, so they were placed into Sd 63 heterotic group. Two inbred lines (L38 and L39) were placed into both Sd 7 and Sd 63 groups because they had positive GCA effects with mean yield with both testers higher than the mean yield of the cross of the two testers (Sd 7 × Sd 63). Five inbred lines (L40, L44, L46, L48 and L54) were unclassified since the mean yields with the two testers were lower than the mean yield of cross of the two testers. From above results, the testers were able to classify 14 from 19 tested inbred lines into heterotic groups based of SCA effects and crosses mean yield. Bernardo (2001) found that, heterotic group comprises a set of inbred lines that have similar performance when crossed with inbreds from another heterotic group. The inbreds within a heterotic group are often related due to advanced cycle breeding. Two heterotic groups that complement each other comprise a heterotic patterns. In brief, heterotic patterns help breeder for choosing parents of crosses for line development as well as testers to evaluate combining ability of newly developed inbreds. Therefore, it simplifies germplasm management and organization.

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المجاميع الهجينية لبعض سلالات الذرة الشامية البيضاء بإستخدام القدرة على الإئتلاف ومحصول الحبوب للهجن

حاتم الحمادى موسى، إبراهيم عبد النبى إبراهيم الجزار، محمد عرفة على حسن، سعيد محمد أبوالحارس، محمد عبدالعزيز عبدالنبى عبدالعزيز ورفيق حليم عبدالعزيز السباعى

مركز البحوث الزراعية – معهد بحوث المحاصيل الحقلية – قسم بحوث الذرة الشامية

معرفة المجاميع الهجينية تكون مهمة لتربية الهجن نظرياً وتطبيقياً. فى هذه الدراسة تم تقسيم ٥٦ سلالة جديدة بيضاء من الذرة الشامية إلى ثلاث مجاميع الأولى بها ١٧ سلالة والثانية ٢٠ سلالة والثالثة ١٩ سلالة. تم تهجين كل مجموعة مع اثنين من السلالات ككشافات, المجموعة الأولى مع سلالة سخا ١٢ وسخا ١٣ والمجموعة الثانية مع سلالة سخا ١٢ وسدس ٦٣ والمجموعة الثالثة مع السلالة سدس٧ وسدس٦٣. تم تقييم الهجن الناتجة من كل مجموعة بالاضافة الى الهجين المكون من التلقيح بين السلالتين الكشاف كذلك هجين تجارى للمقارنة فى موقعين لصفة المحصول موسم ٢٠١٩. أظهرت النتائج أن التباين بين المواقع والسلالات و الكشافات وتفاعل السلالات مع الكشافات عالى المعنوية لكل المجاميع ماعدا التباين الراجع إلى الكشافات وتفاعل السلالات مع الكشافات فى المجموعة الأولى. من خلال نتائج المجموعة الأولى أظهر ١٤ هجين زيادة غير معنوية عن هجين المقارنة كذلك ثلاثة سلالات أفضلية فى القدرة العامة على الإئتلاف وثلاثة هجن أفضلية فى القدرة الخاصة على الإئتلاف كذلك ظهرت قدرة الكشافات على تحديد ١٣ سلالة من ال ١٧ سلالة المقيمة إلى مجاميع هجينية إعتمادا على القدرة الخاصة على الإئتلاف ومحصول الحبوب للهجن. فى المجموعة الثانية تفوق ١٣ هجين معنوياً عن هجين المقارنة وأربع سلالات هى الأفضل فى القدرة العامة على الإئتلاف وثلاثة هجن هى الأفضل فى القدرة الخاصة على الإئتلاف. كذلك ظهرت قدرة الكشافات فى تحديد ١٠ سلالة من ال ٢٠ سلالة المقيمين إلى مجاميع هجينية. فى المجموعة الثالثة أظهر ١٣ هجين زيادة غير معنوية عن هجين المقارنة وثلاث سلالات أفضلية فى القدرة العامة على الإئتلاف وثلاث هجن أفضلية فى القدرة الخاصة على الإئتلاف. كذلك ظهرت قدرة الكشافات على تحديد ١٤ سلالة من ١٩ سلالة مقيمة الى مجاميع هجينية على أساس القدرة الخاصة على الإئتلاف ومحصول الحبوب للهجن.

المجلة المصرية لتربية النبات ٢٥(١): ٤٧- ٥٧ (٢٠٢١)