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COMBINING ABILITY AND RELATIONSHIPS AMONG HETEROTIC GROUPING CLASSIFICATION METHODS FOR NINE MAIZE INBRED LINES

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ABSTRACT

Information on combining ability and heterotic grouping for maize inbred lines are important to breeding successful hybrids. Nine elite inbred lines were crossed in half diallel mating design to develop 36 crosses in 2021 growing season. These crosses plus one check hybrid were evaluated at Sakha, Sids and Mallawi Agricultural Research Stations using a randomized complete block design with three replications for grain yield/plot in 2022 growing season. The results showed that the general (GCA) and specific (SCA) combining ability effects were important in the inheritance of grain yield/plot. However GCA (additive gene effects) was more important than SCA (non-additive gene effects) in the inheritance of this trait. The desirable inbred lines for GCA effects were Sk5001, Sk5004, Sd41 and Sk13. The correlations between means of crosses with both SCA effects-Griffing's and SCA effects-Yang's were 0.51** and 0.94**, respectively. Hence estimating SCA effects proposed by Yang's is more applicable for breeder, because it was more consistent with means. Placement of inbred lines into groups by four classifications methods showed that, the SCA effects-Griffing method and SCA effects Yang method were corresponding, also these two methods were more similar with HSGCA method than agronomic heterosis method. Comparison of the efficiencies of the four classification methods depending on the percentage of superior high yielding crosses obtained across the total number of inter-heterotic crosses in each classification method, showed that the SCA effects-Griffing, SCA effects-Yang and HSGCA methods were comparable in identifying superior crosses and showed better results than agronomic heterosis method. Seven crosses showed a significant superiority relative to the check. The highest yielding crosses from them were Sd41×Sk13 followed by Sk5001×Sk5004, Sk5004×Sd41 and Sk5001×Sd41. These crosses will be evaluated in an extensive testing in the maize breeding program in Egypt.

Key words: ***Zea mays*, Half diallel, Heterotic groups, Correlaton, Agronomic heterosis.**

INTRODUCTION

Maize (*Zea mays* L.) is currently one of the most important cereal crop in Egypt. Information on germplasm diversity is fundamentally important for hybrid breeding and population improvement programs, characterizing the maize germplasm and assigning them into different heterotic groups (Reif *et al* 2003). An important requirement for a hybrid program to be commercially successful is availability of information on combining ability, heterotic groups, heterotic patterns and mode of inheritance among inbred lines program. Diallel crossing is popular among plant breeders to determine the combining ability effects and variances, also the inheritance of traits and to identify heterotic groups (Kang *et al* 2005, Miranda *et al* 2008, Yao *et al* 2013 and Fan *et al* 2014). The general combining ability effects (GCA) and specific combining ability effects (SCA) are used for genetic diversity evaluation, inbred line selection, heterotic group classification, heterosis estimation and hybrids development (Fan *et al* 2002, Melani and Carena 2005 and Rangel *et al* 2008). Maize grain yield combining ability has been studied intensively and the results have been widely used in maize breeding programs (Menkir *et al* 2004, Melani and Carena 2005 and Fan *et al* 2007). Information on GCA enabled to explore and detect variability of breeding materials, to determine desirable inbred lines (Vacaro *et al* 2002 and Sharma *et al* 2016). While SCA helps in determining heterotic patterns of inbred lines, identifying promising candidates for single crosses and clustering inbred lines into heterotic groups (Abrha *et al* 2013). The classification of maize inbred lines into heterotic group is greatly improves breeding efficiency (Hallaur and Miranda 1988, Fan *et al* 2014 and Fan *et al* 2016). The constitution of heterotic groups is one of the foundation pillars for exploitation of heterosis in maize breeding programs devoted to obtain superior hybrids (Aguiar *et al* 2008). Selection of hybrid performance across environments may require a specific classification of inbred lines into heterotic groups to allow further exploration for generating superior hybrids (Fan *et al* 2010). According to SCA of two parents for grain yield, the inbred lines were divided into different heterotic groups. When two lines possess high SCA, they may be classified into different heterotic groups, otherwise they were in the same group (Vasal *et al* 1992). Based on inbred lines ability to produce superior hybrids, maize parental lines have been grouped into heterotic groups (Fan *et al* 2016). Identification of heterotic groups among maize inbred lines is important to the success of a maize hybrid program. Therefore several methods including pedigree information, SCA effects for grain yield *per se*, heterotic groups SCA and GCA effects (HSGCA), GCA effects, multiple (HGCAMT) and molecular marker techniques are frequently used in maize heterotic groups classification (Smith and Smith 1992, Menkir *et al* 2004, Fan *et al* 2001, Barata and Carena 2006, Delucchi *et al* 2012 and Badu Apraku *et al* 2016). Because of different heterotic group classification methods used, researchers classification of maize germplasm into heterotic groups differ (Fan *et al* 2016). Heterotic groups of genetically similar germplasm could not be identified accurately and reliably with molecular markers. Therefore, extensive field evaluation was suggested to assign unrelated maize inbred lines to heterotic groups (Barata and Carena 2006). Many studies have indicated preponderance of additive gene effects over non additive gene effects in the inheritance of grain yield (Vasal *et al* 1993, Bhatnagar *et al* 2004, Musila *et al* 2010, Badu-Aparku *et al* 2015 and Mosa *et al* 2023). Meanwhile, other studies indicated the non-additive gene effects had the main influence in the inheritance of grain yield (Mosa 2003, Mosa 2006 and Singh and Shahi 2010). Therefore the objectives of this study were to determine combining ability of nine inbred lines, compare between Griffing's and Yang's for estimates of SCA effects, compare between the four methods; SCA-Griffing's, SCA-Yang's, HSGCA and agronomic heterosis for their ability to classify the tested inbreds into heterotic groups and to identify the superior hybrids for grain yield.

MATERIALS AND METHODS

Plant materials included nine elite white maize inbred lines which were divergent in isolation sources and Geographical regions Sk5001, Sk5005, Sk5004 and Sk13 were developed at Sakha Research Station (north Egypt), Sd41, Sd4, Sd1121, Sd7, were developed at Sids Research Station (middle Egypt) and Ism77 was developed at Ismaillia Research Station (east Egypt). A half diallel was generated by crossing the nine inbred lines in all possible combinations in 2021 season at Sakha Research Station. The resulting 36 F_1 hybrids and the check hybrid SC10 were planted in a randomized complete block design with three replications at Sakha, Sids and Mallawi Research Stations. Each plot consisted of one row, 6 m long 0.8 m apart and 0.25 m between hills. All recommended agricultural practices were done in the proper time. The data was recorded on grain yield per plot adjusted at 15.5% grain moisture (kg/plot). After performing homogeneity test, the combined analysis was done across the three locations according to Snedecor and Cochran (1989). The general combining ability (GCA) effects of lines and specific combining ability (SCA) effects of hybrids also their mean squares across three locations were estimated by procedure of Griffing (1956), Method 4, Model 1 (fixed model). Calculation of variances analysis was carried out by using computer application of Statistical Analysis System (SAS, 2008). The relative importance of GCA and SCA was computed by procedure of Baker (1978) which was modified by Hung and Holland (2012): $2K^2$ GCA/ ($2K^2$ GCA + K^2 SCA). The inbred lines were assigned into heterotic groups across three locations based on the four methods; SCA effects-Griffing method (Griffing 1956, Vasal *et al* 1992, Fan *et al* 2004, Pswarayi and Vivek 2008), SCA effects-Yang method from Tian *et al* (2015) according to Yang (1983), using the formula: SCA effects-Yang = $X_{ij}-(\bar{x}_{i.}+\bar{x}_{j.})/2 = S_{ij}+(g_i+g_j)/2$, where X_{ij} is the mean yield of the cross between the i^{th} and j^{th} lines, $\bar{x}_{i.}$ is the mean yield of the i^{th} line in their crosses and $\bar{x}_{j.}$ is the mean yield of the j^{th} line in their crosses, also S_{ij} is the SCA effects of cross and g_i and g_j are the GCA effects of lines, HSGCA method proposed by (Fan *et al* 2009), HSGCA=cross mean (X_{ij}) – tester mean ($X_{i.}$)=GCA effects+SCA effects. Where X_{ij} the mean yield of the cross between the i^{th} tester and the j^{th} line, $X_{i.}$ is the mean yield of the i^{th} tester across the j^{th} lines and by cluster analysis for superiority % to the check or agronomic heterosis method according to Smith *et al* (1990) using Past 4.14 (Hammer *et al* 2001).

RESULTS AND DISCUSSION

The analysis of variance for grain yield/plot (Table 1), showed significant differences ($P\leq0.01$) among locations (L). This confirmed that the three locations were differed in climate and soil conditions. Mean squares due to crosses were significant ($P\leq0.01$), meaning that the crosses were varied in this trait. The partitioning of crosses mean squares into GCA and SCA mean squares showed significance ($P\leq0.01$), indicating that the additive gene effects (GCA) and non-additive gene effects (SCA) were important in the inheritance of this trait. The mean squares due crosses × locations (C × L) and their partitions; GCA × L and SCA × L were significant ($P\leq0.01$), indicating that the crosses and their partitions; GCA and SCA were affected by changing location. GCA sum of squares (74.14%) were larger than SCA sum of squares (25.86%) relative to total sum of squares due to crosses, indicating that GCA was the main component accounting for that differences among the crosses, meaning that additive gene effects were more important than non-additive gene effects in the inheritance of this trait. Pswarayi and Vivek (2008) found that GCA sum of squares were larger than SCA sum of squares for grain yield (87%). Theoretically, estimates of additive variance (σ^2A) and non-additive variance (σ^2D) were not valid from diallel crosses with model-1 or fixed model (Sughroue and Hallauer 1997, Fan *et al* 2008). However Baker (1978) showed that $2K^2$GCA/$2K^2$GCA+K^2SCA (GSR) ratio could be used to indicate whether additive or non-additive gene effects were more important in the inheritance of this trait. Results showed that (GSR) was 0.78, meaning that additive gene effects were more important than non-additive gene effects in controlling this trait and that there is a scope for improvement of this trait by selection. Fan *et al* (2008), Pswarayi and Vivek (2008), Tian *et al* (2015) and Mosa *et al* (2023), found predominance of additive over non-additive gene effects in the inheritance of grain yield.

Table 1. Analysis of variance for 36 crosses of diallel between nine inbred lines for grain yield/plot across three locations.

SOV	df	Grain yield/plot (kg)		
		SS	MS	Explained%
Locations (L)	2	281.00	140.50**	
Rep/L	6	3.90	0.65	
Crosses (C)	35	72.39	2.07**	
GCA	8	53.66	6.71**	74.14
SCA	27	18.72	0.69**	25.86
C×L	70	85.06	1.22**	
GCA×L	16	65.78	4.11**	
SCA×L	54	19.28	0.36**	
Error	210	41.83	0.20	
$2K^2$ GCA/$2K^2$ GCA+K^2 SCA (GSR)			0.78	

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

Mean performance of 36 crosses and superiority% to SC10 for grain yield/plot (kg) across three locations (Table 2), showed that the hybrids ranged from 3.82 kg/plot for (Sd1121×Ism77) to 5.69 kg/plot for (Sd41×Sk 13), with seven hybrids, (Sk5001×Sk5004), (Sk5001×Sd41), (Sk5001×Sd7), (Sk5004×Sd41), (Sk5004×Sk13), (Sd41×Sk13) and (Sd7×Sk13) showed significant superiority to the check SC10.

Table 2. Mean performance of 36 crosses and superiority% to the check hybrid for grain yield/plot (kg) across three locations.

Cross	Grain yield/plot (kg)	Superiority% to the check SC10
Sk5001×Sk5005	4.49	-6.74
Sk5001×Sk5004	5.54	15.14*
Sk5001×Sd41	5.44	13.00*
Sk5001×Sd4	3.98	-17.38*
Sk5001×Sd1121	4.65	-3.35
Sk5001×Sd7	5.24	8.91*
Sk5001×Sk13	4.81	-0.09
Sk5001×Ism77	4.61	-4.20*
Sk5005×Sk5004	4.85	0.83
Sk5005×Sd41	4.94	2.59
Sk5005×Sd4	4.13	-14.10*
Sk5005×Sd1121	4.37	-9.30*
Sk5005×Sd7	3.96	-17.66*
Sk5005×Sk13	4.74	-1.52
Sk5005×Ism77	4.41	-8.47*
Sk5004×Sd41	5.49	14.15*
Sk5004×Sd4	4.51	-6.30
Sk5004×Sd1121	4.32	-10.18*
Sk5004×Sd7	4.51	-6.30
Sk5004×Sk13	5.42	12.70*
Sk5004×Ism77	4.79	-0.44

Table 2. Cont.

Cross	Grain yield/plot kg)	Superiority% to the check SC10
Sd41×Sd4	5.02	4.22
Sd41×Sd1121	4.40	-8.66*
Sd41×Sd7	4.96	3.00
Sd41×Sk13	5.69	18.26*
Sd41×Ism77	5.00	3.86
Sd4×Sd1121	4.32	-10.20*
Sd4×Sd7	4.20	-12.74*
Sd4×Sk13	4.76	-1.27
Sd4×Ism77	4.15	-13.83*
Sd1121×Sd7	4.34	-9.74*
Sd1121×Sk13	4.71	-2.10
Sd1121×Ism77	3.82	-20.61*
Sd7×Sk13	5.35	11.10*
Sd7×Ism77	4.64	-3.65
Sk13×Ism77	4.86	0.97
Check SC10	4.81	-
LSD 0.05	0.41	

*** Indicate significant at 0.05 level of probability.**

The highest yielding crosses from them were (Sd41×Sk13) 5.69 kg/plot followed by (Sk5001×Sk5004) 5.54 kg/plot, (Sk5004×Sd41) 5.49 kg/plot and (Sk5001×Sd41) 5.44 kg/plot. From previous results five from seven highest yielding crosses involved one parental line developed from middle Egypt (Sids) and another from north Egypt (Sakha). Some researchers found that crosses between parents from different geographical areas can result in high level heterosis (Grant and Beversdorf 1985 and Tian *et al* 2015).

Estimates of GCA effects of nine inbred lines for grain yield/plot across three locations are presented in (Table 3). The desirable inbred lines with significant positive values of GCA effects were Sk5001, Sk5004, Sd41 and Sk13. From above results the highest seven crosses for grain yield/plot, one or both of their parents were related to the above four inbred lines. Same result was obtained for the inbred lines with significant negative values of GCA effects; namely Sk5005, Sd4, Sd1121 and Ism77. It is observed that the lowest crosses for grain yield were (Sd1121× Ism 77), (Sk 5005×Sd7), (Sk5001×Sd4), (Sk5005×Sd4) and (Sd4×Ism77) (Table 2). In conclusion, the GCA effects of inbred lines play a key role in determining mean grain yield.

Table 3. Estimates of GCA effects of nine inbred lines for grain yield/plot across three locations.

Inbred line	GCA effects
Sk5001	**0.16****
Sk5005	**-0.25****
Sk5004	**0.26****
Sd41	**0.47****
Sd4	**-0.37****
Sd1121	**-0.39****
Sd7	**-0.06**
Sk13	**0.38****
Ism77	**-0.20****
LSD g_i 0.05	**0.10**
LSD g_i 0.01	**0.14**
LSD g_i-g_j 0.05	**0.16**
LSD g_i-g_j 0.01	**0.21**

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

Estimates of SCA effects of 36 crosses according to both Griffing and Yang methods for grain yield/plot across three locations are presented in (Table 4). Six and eight crosses had significant and positive values of SCA effects for grain yield/plot according to Griffing and Yang methods, respectively.

Table 4. Estimates of SCA effects of 36 crosses according to both Griffing and Yang methods for grain yield/plot across three locations.

Cross	SCA effects-Griffing	SCA effects-Yang
Sk5001×Sk5005	-0.12	-0.17
Sk5001×Sk5004	0.43**	0.64**
Sk5001×Sd41	0.11	0.42**
Sk5001×Sd4	-0.52**	-0.63**
Sk5001×Sd1121	0.18	0.06
Sk5001×Sd7	0.42**	0.47**
Sk5001×Sk13	-0.44*	-0.17
Sk5001×Ism77	-0.06	-0.07
Sk5005×Sk5004	0.14	0.14
Sk5005×Sd41	0.01	0.12
Sk5005×Sd4	0.05	-0.26*
Sk5005×Sd1121	0.30*	-0.02
Sk5005×Sd7	-0.43**	-0.59**
Sk5005×Sk13	-0.10	-0.03
Sk5005×Ism77	0.15	-0.08
Sk5004×Sd41	0.06	0.43**
Sk5004×Sd4	-0.08	-0.14
Sk5004×Sd1121	-0.25*	-0.32*
Sk5004×Sd7	-0.39**	-0.29*
Sk5004×Sk13	0.08	0.40**
Sk5004×Ism77	0.03	0.06

Table 4. Cont.

Cross	SCA effects-Griffing	SCA effects-Yang
Sd41×Sd4	0.21*	0.26*
Sd41×Sd1121	-0.39**	-0.35**
Sd41×Sd7	-0.15	0.05
Sd41×Sk13	0.13	0.56**
Sd41×Ism77	0.02	0.16
Sd4×Sd1121	0.37**	-0.01
Sd4×Sd7	-0.07	-0.29*
Sd4×Sk13	0.03	0.04
Sd4×Ism77	0.01	-0.27*
Sd1121×Sd7	0.09	-0.14
Sd1121×Sk13	0.01	0.01
Sd1121×Ism77	-0.30*	-0.59**
Sd7×Sk13	0.32*	0.48**
Sd7×Ism77	0.19	0.06
Sk13×Ism77	-0.03	0.06
LSD S_{ij} 0.05	0.25	
LSD S_{ij} 0.01	0.34	
LSD S_{ij}-S_{ik} 0.05	0.38	
LSD S_{ij}-S_{ik} 0.01	0.51	
LSD S_{ij}-S_{kl} 0.05	0.35	
LSD S_{ij}-S_{kl} 0.01	0.46	

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

The highest five crosses of SCA effects according Griffing were (Sk5001×Sk5004) followed (Sk5001×Sd7), (Sd4×Sd1121), (Sd7×Sk13) and (Sk5005×Sd1121), their yields ranked 2nd, 7th, 30th, 6th and 27th, respectively. While the highest five crosses of SCA effects according Yang were (Sk5001×Sk5004), (Sd41×Sk13), (Sk5001×Sd7), (Sd7×Sk13) and (Sk5004×Sd 41), their yields ranked 2nd, 1st, 7th, 6th and 3rd, respectively. Also the lowest five crosses of SCA effects were (Sk5001×Sd4), (Sk5005×Sd7), (Sk5004×Sd7), (Sd41×Sd1121) and (Sd1121×Ism77), their yields ranked 34th, 35th, 23rd, 26th and 36th according to Griffing, (Sk5001×Sd4), (Sd1121×Ism77), (Sk5005×Sd7), (Sd4×Sd1121) and (Sk5004×Sd1121), their yield ranked 34th, 36th, 35th, 30th and 29th according to Yang. From above results the SCA effects are more corresponded with yield of crosses according to Yang method than Griffing method.

Simple correlation coefficients between means of crosses, SCA effects-Yang and SCA effects-Griffing for grain yield/plot are presented in (Table 5). The correlation coefficient between SCA effects of Griffing and SCA effects of Yang was highly significant and positive (0.76**), indicating that the two methods were going in the same direction. Simple correlation coefficients between means of crosses with both SCA effects- Griffing and SCA effects-Yang were significant and positive (0.51** and 0.94**), respectively, indicating that SCA effects of Yang were more correlated with means of crosses than SCA effects of Griffing. Hence this research recommends using the method of estimating specific combining ability proposed by Yang (1983) and with its applicability as well, because it was consistent with means. Rong (1983) and Wu *et al* (2006) stated that the combining ability analysis by Yang's method is more applicable in breeding programs.

Table 5. Simple correlation coefficients between means of crosses, SCA effects-Yang and SCA effects-Griffing for grain yield/plot across three locations.

	Means of crosses	SCA effects-Yang
Mean of crosses	-	
SCA effects-Yang	**0.94****	-
SCA effects-Griffing	**0.51****	**0.76****

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

Four methods; SCA effects-Griffing, SCA effects-Yang, HSGCA and agronomic heterosis were used to classify inbred lines into heterotic groups. The highest significant and positive SCA effects for grain yield indicate that inbred lines are in opposite heterotic groups while significant and negative SCA effects indicate that inbred lines are in the same heterotic group (Vasal *et al* 1992, Pswarayi and Vivek 2008 and Tian *et al* 2015). The cross Sk5001×Sk5004 showed the maximum SCA effects for grain yield/plot, hence Sk5001 and Sk5004 were used to classify the inbred lines into heterotic groups. Based on SCA effects-Griffing method and SCA effects-Yang method the nine inbred lines were classified into heterotic groups, on the basis of positive or negative SCA effects and the significant absolute value of the differences of SCA effects between hybrids of parent Sk5001 and parent Sk5004, hence according to SCA effects Griffing method (Table 6), the inbred lines Sk5005, Sd4 and Sk13 could be classified as group A (Sk5001), while inbred lines Sd1121 and Sd7 could be classified as group B (Sk5004). The inbred lines Sd41 and Ism77 were not significant for their absolute values, indicating the need to identify more testers and classify more heterotic groups than currently used. Same results were obtained based on SCA effects Yang method (Table 7).

Table 6. Absolute values of the differences for SCA effects-Griffing between hybrids of a parent with Sk5001 and Sk5004 for grain yield/plot across three locations.

Parent	Sk5005	Sk5004	Sd41	Sd4	Sd1121	Sd7	Sk13	Ism77
Sk5001 (A)	**-0.12**	**0.43**	**0.11**	**-0.52**	**0.18**	**0.42**	**-0.44**	**-0.06**
Sk5004 (B)	**0.14**	**-**	**0.06**	**-0.08**	**-0.25**	**-0.39**	**0.08**	**0.03**
Absolute value	**0.26**	**-**	**0.05**	**0.44**	**0.43**	**0.81**	**0.52**	**0.09**
LSD 0.05	**0.25**	**-**	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**

Table 7. Absolute values of the differences for SCA effects-Yang between hybrids of a parent with Sk5001 and Sk5004 for grain yield/plot across three locations.

Parent	Sk5005	Sk5004	Sd41	Sd4	Sd1121	Sd7	Sk13	Ism77
Sk5001 (A)	-0.17	0.64	0.42	-0.63	0.06	0.49	-0.17	-0.17
Sk5004 (B)	0.14	-	0.43	-0.14	-0.32	-0.29	0.40	0.06
Absolute value	0.31	-	0.01	0.49	0.38	0.78	0.57	0.23
LSD 0.05	0.25	-	0.25	0.25	0.25	0.25	0.25	0.25

The inbred lines were divided into groups depending on their specific combining ability effects plus their general combining ability effects with every tester (HSGCA) (Table 8), according to Fan *et al* (2009) as per the following steps: step 1, all inbred lines placed into each tester heterotic group, step 2, keeping the inbred line with the heterotic group where its HSGCA had the smallest value or largest negative value, step 3 , if the inbred line had positive HSGCA effects with all testers, it will be cautious to assign that line to any heterotic group to get final groups. Hence the group A (Sk5001) included the inbred lines Sk5005, Sd4, Ism77, the group B (Sk5004) included the inbred lines Sd1121 and Sd7, while this method was not able to classify the inbred lines Sd41 and Sk13.

Table 8. HSGCA values for seven inbred lines with the two testers Sk5001 and Sk5004 for grain yield/plot across three locations.

Parent	Sk5005	Sd41	Sd4	Sd1121	Sd7	Sk13	Ism77
HSGCA for Sk5001 (A)	-0.26	0.69	-0.77	-0.10	0.49	0.06	-0.14
HSGCA for Sk5004 (B)	0.01	0.65	-0.33	-0.52	-0.33	0.58	-0.05

Grouping inbred lines based on superiority to the check or agronomic heterosis method by cluster analysis for grain yield/plot is presented in Figure 1. Results showed that the nine inbred lines divided into two heterotic groups as follow, group (A) included inbred lines Sk5001, Sk5004, Sd41, Sk13 while group (B) included Sd4, Sd1121, Sd7, Sk5005 and Ism77. From above results, grouping of inbreds and relationships among heterotic grouping methods showed that the SCA effects of Griffing and SCA effects of Yang methods were inter-corresponding, also these two methods were more corresponding with HSGCA method than agronomic heterosis method.

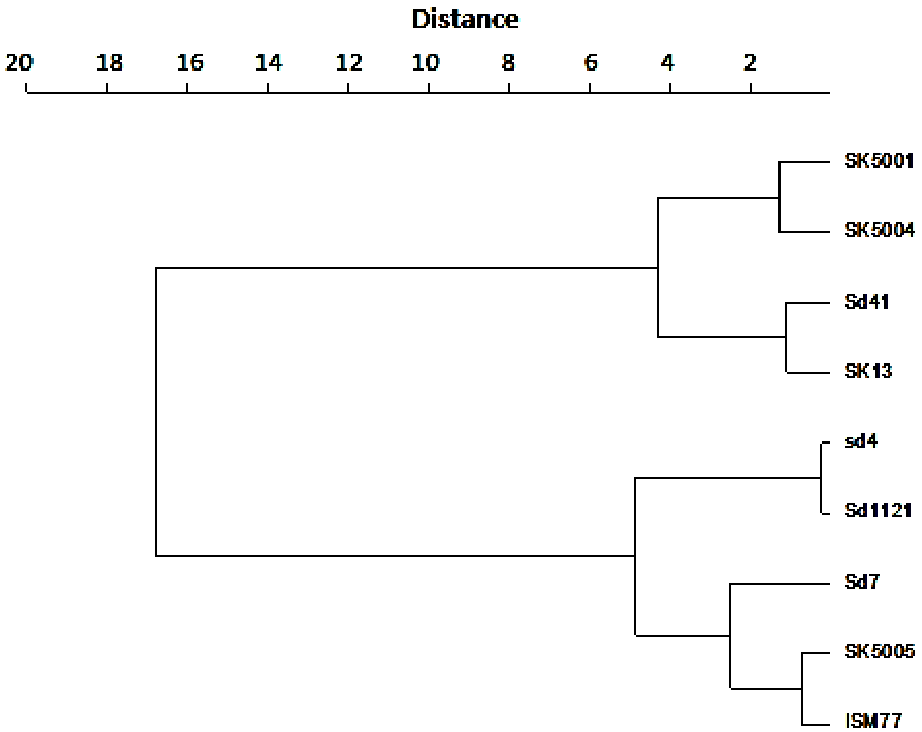

Fig. 1. Clustering inbred lines using agronomy heterosis for grain yield/plot

For comparing breeding efficiency between different heterotic groups methods (Table 9), the crosses were divided into two groups depending on their yield, the first yield group included the highest yielding crosses over grand mean ranging from 4.76 to 5.69 (kg/plot). Second group yielded from 3.82 to 4.75 (kg/plot). Breeding efficiency can be defined as the percentage of superior high yielding crosses obtained across the total number of inter-heterotic crosses, hence the best heterotic grouping method is the one that allowed inter-heterotic group crosses to produce more of the superior hybrids than the within-group crosses (Fan *et al* 2009 and Tian *et al* 2015).

Table 9. Number of crosses classified by the mean grain yield/plot for four heterotic groups methods across three locations.

Yield group	Cross type	SCA effects-Griffing	SCA effects-Yang	HSGCA	Agronomic heterosis
4.76-5.69 kg/plot	Inter group	14	14	16	10
	Within group	2	2	-	6
3.82-4.75 kg/plot	Inter group	13	13	11	10
	Within group	7	7	9	10

The SCA effects-Griffing method, SCA effects-Yang method, HSGCA method and the agronomic heterosis method identified; 14, 14, 16 and 10 high yielding crosses, respectively, from a total of 54 intergroup crosses for yield group (1) and it identified 13, 13, 11 and 10 high yielding crosses, respectively, from a total identified 47 intergroup crosses for yield group 2, hence the four methods differed in identifying superior hybrids. The SCA effect Griffing method, SCA effects-Yang method and HSGCA method were comparable in identifying superior crosses, these methods showed better results than agronomic heterosis method. Fan *et al* (2009) found that an efficient heterotic grouping method is expected to identify groups which allow inter-heterotic group crosses to display higher heterosis than within group crosses, also found HSGCA method was better than the SCA effects method, while Tian *et al* (2015) stated that SCA effects of Griffing and SCA effects of Yang were better than HSGCA. Badu-Apraku *et al* (2015) found that the grouping of the inbred lines by SNP markers was closely related to their pedigree data and their combining ability and proved more effective than HSGCA.

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القدرة على الإئتلاف والعلاقات بين طرق تقسيم المجاميع الهجينية لتسع سلالات من الذرة الشامية

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تعتبر القدرة على الإئتلاف والمجاميع الهجينية لسلالات الذرة الشامية من العوامل الهامة لتربية الهجن المتفوقة. تم التهجين بين تسعة سلالات من الذرة الشامية فى نظام التزاوج النصف الدائرى للحصول على ٣٦ هجين فى موسم ٢٠٢١ . قيمت الهجن الناتجة بالإضافة لهجين المقارنة فى ثلاث محطات بحثية هى سخا وسدس وملوى فى تصميم القطاعات الكاملة العشوائية فى ثلاث مكررات لصفة محصول الحبوب (كجم) للقطعه التجريبية موسم ٢٠٢٢ . أظهرت النتائج أن كلاً من القدرة العامة والخاصة على الإئتلاف لها أهمية فى وراثة صفة محصول الحبوب ومع ذلك كانت القدرة العامة على الإئتلاف (الفعل الوراثى المضيف) أكثر أهمية من القدرة الخاصة على الإئتلاف (الفعل الوراثى غير المضيف) فى وراثة هذه الصفة. أفضل السلالات فى تأثيرات القدرة العامة على الإئتلاف هى سخا٥٠٠١ و سخا٥٠٠٤ وسدس٤١ وسخا١٣ . كان التلازم بين محصول الحبوب للهجن وكلاً من تأثيرات القدرة الخاصة على الإئتلاف طبقاً لطريقة Griffing وطبقاً لطريقة Yang ٠,٥١ و ٠,٩٤ على التوالى

وبالتالى تظهر النتائج أن تقدير تأثيرات القدرة الخاصة على الإئتلاف بطريقة Yang عملية للمربى لأنها أكثر تلازماً مع المتوسطات. تقسيم السلالات إلى مجاميع هجينية على حسب طريقة تأثيرات القدرة الخاصة على الإئتلاف لـــ Griffing وعلى حسب طريقة تأثيرات القدرة الخاصة على الائتلاف لـــ Yang كانت متطابقة وأكثر تماثلاً مع طريقة القدرة الخاصة والعامة على الائتلاف HSGCA ومختلفة عن طريقة قوة الهجين بالنسبة للصنف القياسى. ولمقارنة فاعلية الأربع طرق للتقسيم إعتماداً على نسبة الهجن المتفوقة فى المحصول المتحصل عليها من التهجين بين سلالات المجاميع المختلفة لكل طريقة تقسيم. أوضحت النتائج أن طريقة تأثيرات القدرة الخاصة على الإئتلاف لـــ Griffing وطريقة تأثيرات القدرة الخاصة على الإئتلاف لـــ Yang وطريقة تأثيرات القدرة الخاصة والعامة على الإئتلاف HSGCA متماثلة ومتفوقة عن طريقة قوة الهجين. أظهرت سبعة هجن تفوقاً معنوياً فى محصول الحبوب للقطعة التجريبية عن هجين المقارنة أفضلها (سدس١٤ × سخا١٣) و (سخا١٠٠٥ × سخا٤٠٠٥) و (سخا٤٠٠٥× سدس١٤) و (سخا١٠٠٥× سدس١٤). هذه الهجن سوف يتم تقييمها على نطاق واسع فى برنامج تربية الذرة الشامية فى مصر.

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