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COMBINING ABILITY, HETEROTIC GROUPING, CORRELATION AND PATH COEFFICIENT IN MAIZE

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ABSTRACT

Combining ability analysis was performed using line × tester design for sixteen new white maize inbred lines which were crossed with two inbred lines as testers in 2020 growing season at Sakha Research Station. The resulting 32 top crosses along with two check hybrids were evaluated at three locations in 2021season. Mean squares due to locations were highly significant for all studied traits. Mean squares due to crosses and their partitions into lines, testers and lines × testers interaction were highly significant for all studied traits, except testers for ear height and line × tester for plant height. The parental lines Sk5002/1, Sk5004/7, Sk5007/10, Sk5008/12, Sk5008/13 and Sk5009/17 possess high GCA effects for grain yield and Sk5008/13 possess desirable GCA effects for earliness, long ear and large ear diameter. The two crosses Sk5007/10× Sd7 and Sk5009/17×Sk12 had desirable SCA effects and high mean performance for grain yield compared to the standard check SC10. These two crosses will be evaluated on a large scale in Egypt. Moreover, it is recommended that the two crosses, previously identified based on mean performance, were undergo further evaluation on a large scale for the commercial release to improve white maize hybrids in Egypt. Number of days to 50% silking, plant height and ear diameter were controlled mainly by additive gene action. Meanwhile, ear height, ear length and grain yield were controlled by non-additive gene action. The inbred lines, based on grain yield and heterotic group using specific and general combining ability (HSGCA) method, were classified into two heterotic groups as follows: group-1 (Sd-7) included Sk5008/15, Sk5009/17, Sk5009/18 and Sk5012/22. While, group-2 (Sk12) included Sk5003/5, Sk5004/7, Sk5007/8, Sk5008/13, Sk5008/14, Sk5008/16, Sk5009/19 and Sk5010/21. These groups could be used in breeding programs for selecting the best parents in developing new crosses. Grain yield showed highly significant and positive correlations with each of ear length, ear diameter, ear height and plant height. It is worthy to note that the effect of ear length and ear diameter proved to be the most effective selection criteria in maize breeding programs aiming at high grain yield capacity.

Key words: ***Zea mays, line × tester, GCA, SCA, heterotic group, correlation, path coefficient***.

INTRODUCTION

Maize (*Zea mays* L.) is one of the three most important cereal crops in the world together with wheat and rice. It is essential for human consumption and livestock. Moreover, it is also used for industrial purposes such as manufacturing starch and cooking oils. The concept of general combining ability (GCA) and specific combining ability (SCA) is useful for characterizing the inbred lines in its crosses as defined by Sprague and Tatum (1942). Combining ability estimates of inbred lines are very important for maize improvement not only in choosing parents and crosses but also in illustrating the relation between additive and non-additive portions of the genetic effects in the available germplasm. Line × tester mating design was developed by Kempthorne (1957), which provides good information of the general and specific combining ability effects of parents and their hybrid combinations in applied breeding programs. This design was widely used in maize by several workers like, Gamea (2015), Motawei *et al* (2019), Abd El-Latif *et al* (2020), Ibrahim *et al* (2021) and Mousa *et al* (2021). The choice of a suitable tester for testing the developed inbred lines is an important decision; it should include simplicity in use, ability to classify the relative merit of lines and maximizes the genetic gain (Hallauer, 1975 and Menz *et al* 1999). However it is difficult to identify testers having all these characteristics. The use of the lines as a tester was suggested by Russell and Earhart (1975). The information on the type of gene effects is very important for the breeder in making decisions for the expected response to selection for different traits. There is no agreement among researchers on the mode of gene effects controlling maize yield or its related characters. Wegary *et al* (2013), Badua-Aprakua *et al* (2015), Hosana *et al* (2015) and Abd El-Latif *et al* (2020) reported that additive gene effects were more important for days to 50% silking. Meanwhile, Akula *et al* (2016), Ejigu *et al* (2017), Singh *et al* (2017), Motawei *et al* (2019) and Abd El-Latif *et al* (2020) showed that non-additive gene effects were predominant in the inheritance of maize grain yield. Heterotic groups and patterns are extremely important in hybrid breeding programs (Melchinger and Gumber 1998). Classifying maize inbred lines into heterotic groups is the initial step in maize breeding programs which would provide maximum exploitation of heterosis *via* determination of the relationship existing among the different inbred lines. Numerous studies on classifying inbred lines into heterotic groups have been reported by Vasal *et al* (1992), Melchinger (1999), Menkir *et al* (2004), Fan *et al* (2009), Legesse *et al* (2009), Motawei *et al* (2019), Abd El-Latif *et al* (2020) and Ibrahim *et al* (2021). Correlation and path coefficient studies between yield and yield components themselves, is a pre-requisite to plan a meaningful breeding programme. Several workers have attempted to determine linkage between the characters on which the selection for high yields can be made and they emphasized the utility of the estimates of genetic components in the response prediction of quantitative characters to selection as well as the correlated response of various traits to grain yield. Sometimes, estimates of correlation coefficients provide misleading results as the correlation between two variables may be due to the involvement of third factor. Also as number of variable increases, the measurement of the contribution of each variable towards the observed correlation is imperative. Therefore, portioning of the observed correlation coefficients into components of direct and indirect influences provide perceptions in the characterization of more complex traits like yield. Under such condition, path coefficient analysis (Dewey and Lu 1959) which partitions the correlation coefficient, provides precise information on the direct and indirect effects in order to perceive the most influencing characters to be utilized as selection criteria in maize breeding programs.

The objectives of this current study were to estimate both general (GCA) and specific (SCA) combining ability effects of some white maize inbred lines, to classify the new inbred lines into different heterotic groups for future use in breeding programs, to estimate of the phenotypic correlations between grain yield and other morphological traits and evaluating the direct and indirect effects of morphological traits on grain yield.

MATERIALS AND METHODS

Sixteen new white maize inbred lines derived from different genetic resources were crossed with two white inbred lines developed at Sakha Research Station as testers, *i.e.* Sd-7 and Sk-12 in the 2020 growing season. In the 2021 growing season, the resulting 32 crosses along with two commercial single cross hybrids (SC) as checks (SC 10 and SC 2031) were evaluated in three locations *i.e.* Sakha, Sids and Mallawy Research Stations. A randomized complete block design (RCBD) with three replications was used in evaluation. Plot size was one row, 6 m long, 0.80 m apart and 0.25 m between hills. Cultural practices were done as recommended. Data were recorded on different traits, *i.e.* number of days to 50% silking, plant height (cm), ear height (cm), ear length (cm), ear diameter (cm) and grain yield in ton/hectare (t/ha) adjusted to 15.5% grain moisture. A combined analysis of variance across three locations was performed when the homogeneity test was calculated according to Snedecor and Cochran (1989). Combining ability effects were computed according to line × tester analysis for all traits when the mean squares due to crosses were significant based on the method described by Kempthorne (1957). Calculation of analysis of variance and line × tester analysis were carried out using computer application of Statistical Analysis System (SAS, 2008). Heterotic groups using specific and general combining ability (HSGCA) were identified according to Fan *et al* (2009). The phenotypic correlation coefficients were calculated as described by Snedecor and Cochran (1989) for all possible pairs of the studied characters. The path coefficient analysis was performed for all crosses in order to obtain more information about the relative contribution of the studied characters to grain yield. Partitioning correlation coefficients into direct and indirect effects at phenotypic level was made by determining path coefficients using the method proposed by Wright (1934) and utilized by Dewey and Lu (1959).

RESULTS AND DISCUSSION

A combined analysis of variance for number of days to 50% silking, plant height, ear height, ear length, ear diameter and grain yield across the three locations is presented in Table (1). Highly significant differences were detected between locations (Loc) for all studied traits, indicating that these locations were differing for soil and climate conditions. The mean squares due to genotypes (G) and their partition crosses (Cr) were highly significant for all traits, revealing the existence of variability among crosses. The mean squares due to checks (Ch) were not significant for all traits, except ear diameter which were highly significant. Cr *vs.* Ch mean squares were highly significant for all traits, except plant and ear heights. Mean squares due to G × Loc and Cr× Loc interactions were highly significant for all studied traits, except plant height for G × Loc, indicating that genotypes and crosses performances differ from one location to another for these traits. Those due to Ch × Loc interaction were highly significant for grain yield. Mean squares due to Cr × Ch × Loc were highly significant for plant height and significant for ear height and grain yield. These results are in harmony with those obtained by Ibrahim *et al* (2021) and Mousa *et al* (2021).

Table 1. Analysis of variance for number of days to 50% silking, plant height, ear height, ear length, ear diameter and grain yield across three locations.

SOV	df	Number of days to 50% silking	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	Grain yield (t/ha)
Location (Loc)	2	306.00**	159171.23**	33600.20**	703.20**	19.37**	426.87**
Rep/Loc	6	2.67	1657.57	569.87	5.48	0.03	7.88
Genotypes (G)	33	27.98**	425.86**	413.73**	11.20**	0.31**	22.30**
Crosses (Cr)	31	28.82 **	435.69**	428.74**	10.72**	0.29**	23.41**
Checks (Ch)	1	0.22	0.89	102.72	3.21	0.22**	0.11
Cr. *Vs.* Ch	1	29.81**	546.00	259.42	33.99**	0.88**	10.34**
G × Loc	66	4.58**	204.39	196.67**	2.11**	0.07**	4.84**
Cr × Loc	62	4.77**	185.53**	188.11**	2.23**	0.07**	4.73**
Ch × Loc	2	1.72	238.39	235.72	0.16	0.01	10.23**
Cr. *Vs.* Ch × Loc	2	1.47	755.18**	423.16*	0.44	0.01	2.93*
Error	198	1.66	159.97	107.05	1.08	0.04	0.94

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

Line × tester analysis of variance for number of days to 50% silking, plant height, ear height, ear length, ear diameter and grain yield across the three locations is presented in Table (2). The mean squares due to crosses (Cr) and their partition into lines (L), testers (T) and L × T interaction were highly significant for all studied traits, except tester for ear height and line × tester for plant height, indicating the presence of wide diversity among lines, testers and the lines differ in their performance when crossed with two testers for these traits. The mean squares due to Cr × Loc, L × Loc and T × Loc were highly significant for all traits, except Cr × Loc and L × Loc for plant height and T× Loc for plant height and ear height. The mean squares due to L × T × Loc were highly significant for grain yield. These results are in accordance with those obtained by El-Hosary (2014), Gamea (2015), Abo Yousef *et al* (2016), Ibrahim *et al* (2021) and Mousa *et al* (2021)

Table 2. Line × tester analysis of variance for number of number of days to 50% silking, plant height, ear height, ear length, ear diameter and grain yield across three locations.

SOV	df	Number of days to 50% silking	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	Grain yield (t/ha)
Location (Loc)	**2**	**288.72****	**148075.69****	**30569.86****	**656.91****	**18.456****	**413.67****
Rep/Loc	**6**	**2.78**	**1676.39**	**559.38**	**4.20**	**0.03**	**8.01**
Crosses (Cr)	**31**	**28.82 ****	**435.69****	**428.74****	**10.72****	**0.29****	**23.41****
Lines (L)	**15**	**38.67****	**484.72****	**568.57****	**13.90****	**0.25****	**20.20****
Testers (T)	**1**	**220.50****	**2074.75****	**340.17**	**40.75****	**3.39****	**72.52****
L × T	**15**	**6.19****	**277.40**	**294.81****	**5.55****	**0.13****	**23.34****
Cr × Loc	**62**	**4.77****	**185.53**	**188.10****	**2.23****	**0.07****	**4.73****
L × Loc	**30**	**3.01****	**217.76**	**285.91****	**2.05****	**0.10****	**4.71****
T × Loc	**2**	**65.64****	**44.63**	**159.21**	**18.69****	**0.20****	**50.59****
L × T × Loc	**30**	**2.48**	**162.70**	**92.23**	**1.31**	**0.04**	**1.69****
Error	**186**	**1.63**	**166.13**	**109.75**	**1.06**	**0.04**	**0.94**

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

Mean performance of the 32 top crosses and the two check hybrids for all studied traits is presented in Table (3). For days to 50% silking, nineteen crosses were significantly earlier than the earlier check hybrid SC2031 the earliest crosses were Sk5003/5×Sk12 (61.33 days), Sk5008/15×Sk12 (61.44 days) and Sk5008/11×Sk12 (61.67 days). Plant height ranged from 235.89 cm for the cross (Sk5007/8×Sk12) to 266.89 cm for the cross (Sk5004/7×Sd7) out of 32 top crosses, eight crosses were significantly shorter than the check hybrid SC2031. Ear height ranged from 124.78 cm for the cross (Sk5008/15×Sd7) to 152.89 cm for the cross (Sk5008/12×Sd7). Three crosses (Sk5008/15×Sd7, Sk5007/8×Sk12 and Sk5008/14×Sk12) possessed significantly lower ear placement than the check hybrid SC2031. Regarding ear length, the mean value ranged from 18.47 cm for the cross (Sk5009/18×Sd7) to 23.16 cm for the cross (Sk5008/13×Sk12). The cross Sk5008/13×Sk12 had the best values among all crosses and checks.

Tabel 3. Mean performance of crosses along with two checks for number of days to 50% silking, plant height, ear height, ear length, ear diameter and grain yield across three locations.

Crosses	Number of days to 50% silking	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	Grain yield (t/ha)
Sk5002/1× Sd7	65.22	256.67	143.11	21.40	4.80	11.09
Sk5002/1× Sk12	64.00	256.11	138.44	20.89	4.93	12.45
Sk5003/5× Sd7	63.89	265.33	138.33	19.60	4.67	10.38
Sk5003/5× Sk12	61.33	253.89	136.89	20.58	5.02	10.88
Sk5004/7× Sd7	65.11	266.89	142.78	21.02	4.69	11.45
Sk5004/7× Sk12	62.22	254.33	138.11	22.24	5.02	11.01
Sk5007/8× Sd7	64.89	252.56	139.44	21.67	4.64	10.51
Sk5007/8× Sk12	64.00	235.89	129.44	21.96	4.80	10.43
Sk5007/10× Sd7	63.78	260.33	141.89	21.84	4.89	12.42
Sk5007/10× Sk12	63.89	258.11	131.89	21.20	4.87	11.36
Sk5008/11× Sd7	64.11	254.89	135.44	19.98	4.73	10.42
Sk5008/11× Sk12	61.67	246.67	132.33	20.56	4.82	11.26
Sk5008/12× Sd7	65.33	264.56	152.89	22.31	4.82	10.86
Sk5008/12× Sk12	64.33	257.78	143.44	21.80	4.87	12.57
Sk5008/13× Sd7	63.56	264.44	151.89	22.47	4.71	12.30
Sk5008/13× Sk12	62.22	253.22	138.67	23.16	5.04	10.20
Sk5008/14× Sd7	62.89	255.33	134.78	20.53	4.62	11.00
Sk5008/14× Sk12	62.00	248.11	129.22	21.07	4.76	9.88
Sk5008/15× Sd7	63.44	246.78	124.78	19.76	4.73	9.18
Sk5008/15× Sk12	61.44	248.11	130.44	20.18	4.93	12.22
Sk5008/16× Sd7	62.67	254.11	131.11	19.56	4.40	9.27
Sk5008/16× Sk12	62.67	248.78	132.11	20.31	4.76	9.23
Sk5009/17× Sd7	66.89	256.11	136.00	20.60	4.62	9.89
Sk5009/17× Sk12	65.44	258.44	143.00	21.38	4.78	13.23
Sk5009/18× Sd7	68.89	243.56	132.22	18.47	4.24	4.10
Sk5009/18× Sk12	64.67	259.89	151.44	22.56	4.91	11.56
Sk5009/19× Sd7	66.78	261.56	144.00	20.29	4.80	9.35
Sk5009/19× Sk12	63.56	256.56	147.22	21.18	4.96	10.15
Sk5010/21× Sd7	64.67	257.44	139.44	19.33	4.82	10.87
Sk5010/21× Sk12	63.22	244.89	133.11	19.84	4.91	10.61
Sk5012/22× Sd7	67.78	253.33	136.00	19.82	4.42	8.85
Sk5012/22× Sk12	65.22	247.22	133.56	21.80	4.71	10.98
SC 10	65.56	260.33	144.22	21.91	4.89	11.48
SC 2031	65.33	259.89	139.44	22.76	5.11	11.33
LSD 0.05	1.19	11.91	9.56	0.96	0.19	0.90

For ear diameter, the crosses ranged from 4.24 to 5.11 cm for Sk5009/18×Sd7 and SC2031, respectively. For grain yield, the four crosses Sk5002/1×Sk12, Sk5007/10×Sd7, Sk5008/12×Sk12 and Sk5009/17×Sk12 significantly out-yielded the best check hybrid SC10. Meanwhile the crosses Sk5008/13×Sd7 and Sk5008/15×Sk12 did not significantly differ from the best check SC10. These crosses are recommended for further evaluation to accurately identify the promising crosses as future commercial hybrids for high yielding.

General combining ability effects for parental inbred lines and two testers are presented in Table (4). Positive GCA effects are desirable for improvement of grain yield and yield component traits, while negative GCA effects are desirable when selecting for earliness, short plants and lower ear placement. For days to 50% silking, the tester Sk12 and six inbred lines Sk5003/5, Sk5008/11, Sk5008/13, Sk5008/14, Sk5008/15 and Sk5008/16 exhibited negative and highly significant for GCA effects, indicating these inbred lines are considered the best combiner for earliness. For plant height, tester Sk12 and lines Sk5007/8 and Sk5008/15 had significant and negative GCA effects toward shortness. For ear height, significant or highly significant and negative GCA effects toward lower ear placement were obtained for the three inbred parents Sk5008/14, Sk5008/15 and Sk5008/16. For ear length, the tester Sk12 and the five inbred lines Sk5004/7, Sk5007/8, Sk5007/10, Sk5008/12 and Sk5008/13 had significant and positive GCA effects. Regarding ear diameter, the tester Sk12 and the five lines Sk5002/1, Sk5007/10, Sk5008/13, Sk5009/19 and Sk5010/21 exhibited significant and positive GCA effects. In case of grain yield, the inbred tester Sk12 and the six inbred lines Sk5002/1, Sk5004/7, Sk5007/10, Sk5008/12, Sk5008/13 and Sk5009/17 had significant or highly significant and positive GCA effects. Hence above inbred lines which exhibited desirable GCA effects are recommended for plant breeding programs. These results are in agreement with other investigations (Dar *et al* 2017, Hundera 2017, Motawei *et al* 2019 and Abd El-Latif *et al* 2020), who reported significant and positive GCA effects for grain yield and its components and negative and significant GCA effects for days to 50% silking, plant height and ear height (desirable).

Tabel 4. General combining ability effects of 16 inbred lines and two testers for number of days to 50% silking, plant height, ear height, ear length, ear diameter and grain yield across three locations.

Inbred line	Number of days to 50% silking	Plant height	Ear height	Ear length	Ear diameter	Grain yield
Sk5002/1	0.493	1.955	2.858	0.228	0.095*	1.146**
Sk5003/5	-1.507**	5.177	-0.309	-0.828**	0.072	0.005
Sk5004/7	-0.451	6.177*	2.524	0.716**	0.084	0.605**
Sk5007/8	0.326	-10.212**	-3.476	0.894**	-0.050	-0.155
Sk5007/10	-0.285	4.788	-1.031	0.605**	0.106*	1.265**
Sk5008/11	-1.229**	-3.656	-4.031	-0.650*	0.006	0.217
Sk5008/12	0.715*	6.733*	10.247**	1.139**	0.072	1.093**
Sk5008/13	-1.229**	4.399	7.358**	1.894**	0.106*	0.628**
Sk5008/14	-1.674**	-2.712	-5.920*	-0.117	-0.083	-0.187
Sk5008/15	-1.674**	-6.990*	-10.309**	-0.950**	0.061	0.076
Sk5008/16	-1.451**	-2.990	-6.309*	-0.984**	-0.194**	-1.376**
Sk5009/17	2.049**	2.844	1.580	0.072	-0.072	0.936**
Sk5009/18	2.660**	-2.712	3.913	-0.402	-0.198**	-2.794**
Sk5009/19	1.049**	4.622	7.691**	-0.184	0.106*	-0.870
Sk5010/21	-0.174	-3.267	-1.642	-1.328**	0.095*	0.118
Sk5012/22	2.382**	-4.156	-3.142	-0.106	-0.205**	-0.707**
LSD g_{ij} 0.05	0.59	5.99	4.87	0.50	0.09	0.45
0.01	0.78	7.91	6.43	0.63	0.12	0.60
LSD $g_i - g_j$ 0.05	0.84	8.48	6.89	0.68	0.13	0.65
0.01	1.11	11.18	9.01	0.89	0.17	0.86
Tester 1 (Sd7)	0.875**	2.684*	1.087	-0.376**	-0.109**	-0.502**
Tester 2 (Sk12)	-0.875**	-2.684*	-1.087	0.376**	0.109**	0.502**
LSD g_{ij} 0.05	0.21	2.12	1.72	0.17	0.03	0.16
0.01	0.28	2.80	2.27	0.22	0.04	0.21
LSD $g_i - g_j$ 0.05	0.30	3.00	2.44	0.24	0.05	0.23
0.01	0.39	3.95	3.21	0.32	0.06	0.30

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

Specific combining ability effects of 32 crosses for studied traits are presented in Table (5).

Tabel 5. Specific combining ability effects of 32 crosses for number of days to 50% silking, plant height, ear height, ear length, ear diameter and grain yield across three locations.

Crosses	Number of days to 50% silking	Plant height	Ear height	Ear length	Ear diameter	Grain yield
Sk5002/1× Sd7	-0.264	-2.406	1.247	0.632	0.042	-0.176
Sk5002/1× Sk12	0.264	2.406	-1.247	-0.632	-0.042	0.176
Sk5003/5× Sd7	0.403	3.038	-0.365	-0.113	-0.069	0.252
Sk5003/5× Sk12	-0.403	-3.038	0.365	0.113	0.069	-0.252
Sk5004/7× Sd7	0.569	3.594	1.247	-0.235	-0.058	0.722*
Sk5004/7× Sk12	-0.569	-3.594	-1.247	0.235	0.058	-0.722*
Sk5007/8× Sd7	-0.431	5.649	3.913	0.232	0.031	0.542
Sk5007/8× Sk12	0.431	-5.649	-3.913	-0.232	-0.031	-0.542
Sk5007/10× Sd7	-0.931*	-1.573	3.913	0.698*	0.120	1.034**
Sk5007/10× Sk12	0.931*	1.573	-3.913	-0.698*	-0.120	-1.034**
Sk5008/11× Sd7	0.347	1.427	0.469	0.087	0.064	0.085
Sk5008/11× Sk12	-0.347	-1.427	-0.469	-0.087	-0.064	-0.085
Sk5008/12× Sd7	-0.375	0.705	3.635	0.632	0.086	-0.352
Sk5008/12× Sk12	0.375	-0.705	-3.635	-0.632	-0.086	0.352
Sk5008/13× Sd7	-0.208	2.927	5.524	0.032	-0.058	1.550**
Sk5008/13× Sk12	0.208	-2.927	-5.524	-0.032	0.058	-1.550**
Sk5008/14× Sd7	-0.431	0.927	1.691	0.109	0.042	1.062**
Sk5008/14× Sk12	0.431	-0.927	-1.691	-0.109	-0.042	-1.062**
Sk5008/15× Sd7	0.125	-3.351	-3.920	0.165	0.009	-1.015**
Sk5008/15× Sk12	-0.125	3.351	3.920	-0.165	-0.009	1.015**
Sk5008/16× Sd7	-0.875*	-0.017	-1.587	-0.002	-0.069	0.521
Sk5008/16× Sk12	0.875*	0.017	1.587	0.002	0.069	-0.521
Sk5009/17× Sd7	-0.153	-3.851	-4.587	-0.013	0.031	-1.169**
Sk5009/17× Sk12	0.153	3.851	4.587	0.013	-0.031	1.169**
Sk5009/18× Sd7	1.236**	-10.851*	-10.698**	-1.665**	-0.228**	-3.226**
Sk5009/18× Sk12	-1.236**	10.851*	10.698**	1.665**	0.228**	3.226**
Sk5009/19× Sd7	0.736	-0.184	-2.698	-0.068	0.031	0.101
Sk5009/19× Sk12	-0.736	0.184	2.698	0.068	-0.031	-0.101
Sk5010/21× Sd7	-0.153	3.594	2.080	0.121	0.064	0.635
Sk5010/21× Sk12	0.153	-3.594	-2.080	-0.121	-0.064	-0.635
Sk5012/22× Sd7	0.403	0.372	0.135	-0.613	-0.036	-0.567
Sk5012/22× Sk12	-0.403	-0.372	-0.135	0.613	0.036	0.567
LSD $s_{ij\ 0.05}$	0.84	8.48	6.89	0.68	0.13	0.65
0.01	1.11	11.18	9.01	0.89	0.17	0.86
LSD $s_{ij} - s_{kl\ 0.05}$	1.19	11.99	9.74	0.96	0.19	0.91
0.01	1.57	15.81	12.26	1.26	0.25	1.22

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

The results showed that three crosses *i.e.* Sk5007/10×Sd7, Sk5008/16×Sd7 and Sk5009/18×Sk12 showed earliness while, the cross Sk5009/18×Sd7 had desirable SCA effects for short plants and lower ear placement. Two crosses *i.e.* Sk5007/10×Sd7 and Sk5009/18×Sk12 for ear length and the cross Sk5009/18×Sk12 for ear diameter showed significant or highly significant and positive SCA effects. For grain yield, data revealed that the seven crosses *i.e.* Sk5004/7×Sd7, Sk5007/10×Sd7, Sk5008/13×Sd7, Sk5008/14×Sd7, Sk5008/15×Sk12, Sk5009/17×Sk12 and Sk5009/18×Sk12 had significant or highly significant and positive SCA effects. The current results are in general agreement with the findings of many researchers such as Dar *et al* (2017), Larièpe *et al* (2017), Motawei *et al* (2019) and Abd El-Latif *et al* (2020).

Estimates of K^2GCA or additive gene effects and K^2SCA or non-additive gene effects for studied traits across the three locations are presented in Table (6). The K^2 GCA or additive gene effects were the most important component controlling the inheritance of days of 50% silking, plant height and ear diameter, while the K^2SCA or non-additive gene effects played the important role of ear height, ear length and grain yield. These results are in agreement with those obtained by many researchers; among them Wegary *et al* (2013), Badua-Aprakua *et al* (2015), Hosana *et al* (2015), Abd El-Latif *et al* (2020) and Mousa *et al* (2021) for days to 50% silking, Akula *et al* (2016), Ejigu *et al* (2017), Singh *et al* (2017), Motawei *et al* (2019), Abd El-Latif *et al* (2020), Ibrahim *et al* (2021) and Mousa *et al* (2021) for grain yield and Mosa *et al* (2017) for ear diameter.

Table 6. Estimates of additive gene effects (K^2GCA) and non-additive gene effects (K^2SCA) for studied traits across the three locations.

Genetic component	Number of days to 50% silking	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	Grain yield (t/ha)
K^2GCA	**1.58**	**13.75**	**4.25**	**0.32**	**0.02**	**0.56**
K^2SCA	**0.51**	**12.36**	**20.56**	**0.50**	**0.01**	**2.49**

Estimates of heterotic groups based on specific and general combining ability effects (HSGCA) for grain yield across the three locations are presented in Table (7). Fan *et al* (2009) proposed a method of heterotic grouping based on specific and general combining ability effects (HSGCA) while, inbred lines were divided into groups as follows: Step-1 placed all tested inbred lines in the same heterotic group as their tester. Step-2, kept the inbred lines with heterotic group where its HSGCA effects had the smallest value (or largest negative value) and removed it from other heterotic group. Step-3, if the inbred line had positive HSGCA effects with all representative testers, it will be cautious to assign that line to any heterotic group because the line might belong to a heterotic group different from the testers used in the investigation.

Tabel 7. Estimates of heterotic groups using specific and general combining ability method (HSGCA) for grain yield across the three locations.

line	Sd7	Sk12
Sk5002/1	**0.970**	**1.322**
Sk5003/5	**0.258**	**-0.247≠**
Sk5004/7	**1.327**	**-0.117≠**
Sk5007/8	**0.387**	**-0.696≠**
Sk5007/10	**2.300**	**0.231**
Sk5008/11	**0.302**	**0.131**
Sk5008/12	**0.741**	**1.445**
Sk5008/13	**2.178**	**-0.922≠**
Sk5008/14	**0.874**	**-1.249≠**
Sk5008/15	**-0.939≠**	**1.092**
Sk5008/16	**-0.855**	**-1.897≠**
Sk5009/17	**-0.233≠**	**2.105**
Sk5009/18	**-6.020≠**	**0.432**
Sk5009/19	**-0.769**	**-0.971≠**
Sk5010/21	**0.754**	**-0.517≠**
Sk5012/22	**-1.274≠**	**-0.140**

≠ means that this inbred line belongs to tester group.

The results showed the sixteen inbred lines were placed into two heterotic groups. Group-1(tester Sd-7) included the four inbred lines Sk5008/15, Sk5009/17, Sk5009/18 and Sk5012/22 while group-2 (tester Sk-12) included the eight inbred lines Sk5003/5, Sk5004/7, Sk5007/8, Sk5008/13, Sk5008/14, Sk5008/16, Sk5009/19 and Sk5010/21. Meanwhile, the method was unable to categorize the four inbred lines Sk5002/1, Sk5007/10, Sk5008/11 and Sk5008/12. The above results for heterotic grouping could be recommended for breeding programs to select the best parents for developing crosses of high heterosis. Lee (1995), Mosa *et al* (2017), Motawei *et al* (2019) and Ibrahim *et al* (2021) 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 different heterotic group, but not when crossed to other lines of the same heterotic group. Also, Vasal *et al* (1992), Melchinger (1999), Menkir *et al* (2004) and Legesse *et al* (2009) classified inbred lines into heterotic groups for grain yield and reported that the classification of inbred lines into heterotic groups facilitates the exploitation of heterosis in maize, which can contribute to hybrid performance.

The phenotypic correlation coefficients estimated among the six studied characters including grain yield are presented in Table (8). It is worth noting that grain yield showed highly significant and positive correlation with each of ear length, ear diameter, ear height and plant height. This result indicates that selection, considering any of all these characters simultaneously may be useful and effective in improving grain yield, especially if those characters had high heritability estimates. While significant and negative correlation was observed between grain yield and number of days to 50% silking. Mosa (2003) found that simple correlation coefficients between grain yield with plant height, ear height, ear length and ear diameter were significant and positive, while with number of days to 50% silking was significant and negative. Meanwhile correlation between ear length and each of ear diameter, plant height and ear height were highly significant and positive. The correlation between ear diameter and plant height was significant and positive while, the correlation between ear diameter and number of days to 50% silking was highly significant and negative. Also, the correlation between both plant height and ear height with number of days to 50% silking were highly significant and positive. Similar results were reported by Wannows *et al* (2010), Hasyan *et al* (2012), Al-Ahmad *et al* (2014), Aman *et al* (2020) and Matin *et al* (2022).

Table 8. The correlation coefficients between grain yield, ear length, ear diameter, plant height, ear height, and number of number of days to 50% silking of 32 crosses along with two checks across the three locations.

Traits	Grain yield	Ear Length	Ear diameter	Plant height	Ear height
Ear Length	**0.718****				
Ear diameter	**0.647****	**0.697****			
Plant height	**0.460****	**0.613****	**0.217***		
Ear height	**0.414****	**0.552****	**0.170**	**0.891****	
Number of days to 50% silking	**-0.220***	**-0.002**	**-0.337****	**0.364****	**0.354****

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

Path coefficient analysis was performed to identify the important yield attributes by estimating the direct effects of traits contributing to yield and separating the direct from the indirect effects through other related traits by partitioning the correlation coefficient and finding out the relative importance of different characters as selection criteria. The estimates of direct and indirect effects of the four yield related traits viz., ear length and ear diameter, plant height and ear height on grain yield are presented in Table (9). The data reveal that the direct effect of ear length on grain yield was positive and moderate. The indirect effect of ear length *via* ear diameter was positive and moderate. On the other hand, the indirect effects of ear length *via* both plant height and ear height were positive and low. The direct effect of ear diameter on grain yield was positive and relatively moderate. The indirect effects of ear diameter *via* ear length were moderate.

Table 9. Phenotypic path coefficient of grain yield contributing characters of 32 crosses along with two checks across the three locations.

SOV	Path coefficient
Ear Length *vs.* Grain yield	
Direct effect	0.383
Indirect effect *vs.* Ear diameter	0.243
Indirect effect *vs.* Plant height	0.065
Indirect effect *vs.* Ear height	0.027
Total	0.718
Ear diameter *vs.* Grain yield	
Direct effect	0.349
Indirect effect *vs.* Ear Length	0.267
Indirect effect *vs.* Plant height	0.023
Indirect effect *vs.* Ear height	0.008
Total	0.647
Plant height *vs.* Grain yield	
Direct effect	0.106
Indirect effect *vs.* Ear Length	0.235
Indirect effect *vs.* Ear diameter	0.076
Indirect effect *vs.* Ear height	0.043
Total	0.460
Ear height *vs.* Grain yield	
Direct effect	0.048
Indirect effect *vs.* Ear Length	0.211
Indirect effect *vs.* Ear diameter	0.059
Indirect effect *vs.* Plant height	0.095
Total	0.414

The indirect effects of ear diameter *via* both plant height and ear height were low. The direct effect of plant height on grain yield was positive and relatively low, while the indirect effects of plant height *via* ear length were positive and relatively moderate. On the other hand, the indirect effects of plant height *via* both ear diameter and ear height were relatively negligible value. The direct effect of ear height on grain yield was positive and negligible value, while the indirect effects of ear height *via* ear length were positive and relatively moderate. On the other hand, the indirect effects of ear height *via* both ear diameter and plant height were low.

The components of the total grain yield variation determined directly and jointly by each factor are presented in Table (10).

Table 10. Phenotypic components (direct and joint effects) in percent of grain yield variation of 32 crosses along with two checks across the three locations.

SOV	CD	RI %
Ear Length (X_1)	**0.147**	**14.67**
Ear diameter (X_2)	**0.122**	**12.20**
Plant height (X_3)	**0.011**	**1.13**
Ear height (X_4)	**0.002**	**0.23**
(X_1) × (X_2)	**0.186**	**18.64**
(X_1) × (X_3)	**0.050**	**4.98**
(X_1) × (X_4)	**0.020**	**2.05**
(X_2) × (X_3)	**0.016**	**1.61**
(X_2) × (X_4)	**0.006**	**0.57**
(X_3) × (X_4)	**0.009**	**0.92**
Residual	**0.430**	**43.00**
Total	**1**	**100**

CD: Coefficient of determination, RI %: Relative importance.

Main sources of yield variation in order of importance were the joint effect of ear length through ear diameter (18.64%) followed by the direct effect of ear length (14.67%), then by direct effect of ear diameter (12.20%), then by joint effect of ear length through plant height (4.98%), then by joint effect of ear length through ear height (2.05%), then by joint effect of ear diameter through plant height (1.61%), then by direct effect of plant height (1.13%), then by joint effect of plant height through ear height (0.92%), then by joint effect of ear diameter through ear height (0.57%), then by direct effect of ear height (0.23%). Therefore, the direct and simultaneous selection for ear length and ear diameter may be useful for improving maize grain yield. The total contribution of the four traits was 57.00%, while the residual effect assumed to be about 43.00% of the total phenotypic variation of grain yield per plant. Our results coincide with those obtained by Wannows *et al* (2010), Hasyan *et al* (2012) and Al-Ahmad *et al* (2014).

CONCLUSION

It is concluded that the best parental line for GCA effects was Sk5007/10 for grain yield and Sk5008/13 possess desirable GCA effects for earliness, long ear and large ear diameter. The two crosses Sk5007/10× Sd7 and Sk5009/17×Sk12 had desirable SCA effects and high mean performance for grain yield compared to standard check SC10. The inbred lines for grain yield, based on heterotic group specific and general combining ability (HSGCA) method, were classified into two heterotic groups as follows: group-1 (Sd-7) included Sk5008/15, Sk5009/17, Sk5009/18 and Sk5012/22. While, group-2 (Sk12) included Sk5003/5, Sk5004/7, Sk5007/8, Sk5008/13, Sk5008/14, Sk5008/16, Sk5009/19 and Sk5010/21. It worthy to note that the effect of ear length and ear diameter proved to be the most effective selection criteria in maize breeding programs aiming for high grain yield capacity.

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القدرة على الإئتلاف والمجاميع الهجينية والتلازم المظهرى ومعامل المرور فى الذرة الشامية

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

تم إختبار ستة عشر سلالة جديدة من الذرة الشامية بيضاء الحبوب للقدرة على التآلف بإستخدام تحليل السلالة × الكشاف حيث تم تهجينها مع سلالتين من سلالات الذرة الشامية كمختبرين خلال موسم ٢٠٢٠ في محطة البحوث الزراعية بسخا. تم تقييم الهجن الناتجة (٣٢ هجيناً) مع اثنين من الهجن التجارية كهجن مقارنة فى ثلاثة مواقع خلال موسم ٢٠٢١ أوضحت النتائج أن التباين الراجع للمواقع كان عالى المعنوية لجميع الصفات المدروسة. وكانت التباينات الراجعة للهجن ومجزئاتها (السلالات والكشافات وتفاعل السلالة × الكشاف) عالية المعنوية لجميع الصفات المدروسة باستثناء تباين الكشاف لصفة إرتفاع الكوز، تباين تفاعل السلالة × الكشاف لصفة إرتفاع النبات. أظهرت السلالات: Sk5002/1، Sk5004/7، Sk5007/10، Sk5008/13، Sk5008/14، Sk5009/17 **قدرة عامة على الإئتلاف معنوية ومرغوبة لمحصول الحبوب وأظهرت السلالة** Sk5008/13 **قدرة مرغوبة للتبكير، لطول الكوز ولقطر كوز كبير. أوضحت النتائج أن الهجينان:** Sk5007/10×Sd7، Sk5009/17×Sk12 **قد أظهرا قدرة خاصة على الإئتلاف معنوية ومرغوبة لمحصول الحبوب ومتوسطات عالية لصفة محصول الحبوب بالمقارنة بأعلى هجين مقارنة** (SC10)**. هذين الهجينين سوف يخضعان لمزيد من التقييم على نطاق واسع فى مصر. تبين أن الفعل الجينى المضيف له الدور الأهم والرئيسى فى وراثة عدد الأيام اللازمة حتى خروج ٥٠% من حرائر النورات المؤنثة وإرتفاع النبات وقطر الكوز بينما كان للفعل الجينى غير المضيف الدور الأهم فى وراثة إرتفاع الكوز وطول الكوز ومحصول الحبوب. تم تصنيف السلالات لمحصول الحبوب بناء على طريقة** (HSGCA) **إلى مجموعتين هجينيتين على النحو التالى: تضم المجموعة الأولى** (Sd-7) **السلالات** Sk5008/15، Sk5009/17، Sk5009/18، Sk5012/22 **بينما تضم المجموعة الثانية** (Sk12) **السلالات** Sk5003/5، Sk5004/7، Sk5007/8، Sk5008/13، Sk5008/14، Sk5008/16، Sk5009/19، Sk5010/21 **ويمكن استخدام هذه المجموعات فى برامج التربية لإنتخاب أفضل الآباء لتكوين هجن جديدة ذات قوة هجين عالية. أظهر محصول الحبوب إرتباطات موجبة معنوية عالية مع كل من طول الكوز وقطر الكوز وإرتفاع النبات وإرتفاع الكوز. ومن الجدير بالذكر أن تأثير طول الكوز وقطر الكوز أثبت أنهم أكثر معايير الإنتخاب فعالية فى برامج تربية الذرة الشامية وذلك للحصول على إنتاجية عالية من الحبوب.**

المجلة المصرية لتربية النبات ٢٧(٢): ٢٠٣ – ٢٢٣ (٢٠٢٣)