Egypt. J. Plant Breed. 28(1):135– 154(2024)

CLASSIFYING NEW MAIZE INBRED LINES INTO HETEROTIC GROUPS USING THREE METHODS

H.E. Mosa, M. A. Abd El-Moula, A.A. Motawei, I.A.I. El-Gazzar, M.S. Abd El-Latif, M. S. Rizk and T. T. El-Mouslhy

Maize Research Dept., Field Crops Research Institute, ARC, Giza, Egypt.

ABSTRACT

Identification of distinct heterotic groups should help development of outstanding hybrids and improve the efficiency of hybrid development program. Twenty-two new yellow maize inbred lines were crossed with two inbred testers using line × tester mating design in 2022 growing season. The resulting 44 F_1's plus one commercial hybrid were evaluated in 2023 growing season at three locations (Sakha, Gemmiza and Mallawi Agricultural Research Stations) in a randomized complete block design with three replications for traits; days to 50% silking, plant height, ear height, ear length and grain yield. The mean squares due to lines (L), testers (T), lines × tester (L×T) and their interactions with locations (Loc) were significant or highly significant for all studied traits except for plant and ear heights of (L×T×Loc) interaction. The additive gene effects were preponderant in the inheritance of all studied traits, except for grain yield, where the non-additive gene effects played more important role. The best inbred line for general combining ability (GCA) effects was L1 for earliness and short plant and ear heights, L7 for longest ear and L20 for high grain yield. The cross (L15×Gz658) significantly out-yielded the commercial check SC168. The three heterotic group methods were differed in identifying the superior hybrids obtained from parents selected from different groups. Heterotic grouping based on combining ability effects (HCAE) method was the best for identifying the superior hybrids followed by heterotic grouping based on specific and general combining ability effects (HSGCA) method; also HCAE identified the lowest number of the superior crosses obtained from parents within the same heterotic group followed HSGCA method. Hence HCAE was the most efficient methods for grouping the inbred lines followed by HSGCA than SCA effects method.

Key words: ***Hybrids, Testers, GCA, SCA, HSGCA, HCAE.***

INTROUDUTION

Obtaining superior maize hybrids depends on the available germplasm, which should possess high genetic variability necessary for establishing new superior inbred lines. Estimating the combining ability of inbred lines in hybrid combinations is very necessary for a successful maize hybrid improvement (Murtadha *et al* 2018, Ali *et al* 2019 and Oluwaseun *et al* 2022). Combining ability effects in maize inbred lines has been extensively studied under different conditions for different sets of new maize inbred lines developed, introduced and adapted to different environments (Girma *et al* 2015, Dufera *et al* 2018, de Faria *et al* 2022 and Mosa *et al* 2023). Information on general combining ability (GCA) plays a significant role in evaluating the inbred lines, meanwhile the specific combining ability (SCA) plays a significant role in obtaining the best crosses in maize hybrid development. Identification of heterotic groups among maize inbred lines is crucial to the success of a maize hybrid program. 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 and Fan *et al* 2016). The purpose of maize heterotic groups classification improve maize breeding efficiency by reducing crosses among intragroup lines and increasing intergroup crosses to increase developing of potential super hybrids. Heterotic groups represent a group 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). Inbred lines within the same group are similar genetically, while between the two groups are dissimilar genetically (Gurung *et al* 2009). The SCA effects, GCA effects, pedigree information, grain yield information, molecular marker techniques are frequently used in maize heterotic groups classification (Fan *et al* 2001, Menkir *et al* 2004, Barate and Carena 2006, Fan *et al* 2009, Delucchi *et al* 2012, Mosa *et al* 2021 and Mosa *et al* 2024). The value of SCA effects reveals the genetic relationship of two parents; high SCA effects indicates far genetic relationship of two parents; while low SCA effects means close genetic relationship between them (Fan *et al* 2003). Many researchers support the use of SCA effects and testcross mean yield as a major criterion for classifying inbred lines into heterotic groups (Menkir *et al* 2004, Librando and Magulana 2008 and Mosa *et al* 2021). If the heterotic grouping improves the identification of viable commercial hybrids, the per-hybrid cost will actually be reduced (Ceccarelli 2015). The efficiency of different methods in classifying inbred lines into heterotic groups have been studied by many researchers (Akinwale *et al* 2014, Badu-Apraku *et al* 2015, Tian *et al* 2015, Oyetunde *et al* 2020 and Mosa *et al* 2024). Efficiency for many inbred lines may be tested by line × tester mating design. Testers can be used to determine the genetic differences of the emerged inbred lines based on the results of the crosses (Pswarayi and Vivek 2008, Fan *et al* 2016 and Murtadha *et al* 2018). Therefore, the objectives of this study were to determine the combining abilities of new maize inbred lines and crosses, classify the inbred lines into heterotic groups using three methods (HSGCA, SCA effects and

HCAE), compare the efficiencies of the three grouping methods and identify the best crosses as compared with a check hybrid.

MATERIALS AND METHODS

Twenty-two new yellow maize inbred lines obtained from maize breeding program at Sakha Research Station were crossed with two inbred lines; Sk11 and Gz658 as testers using line × tester mating design during the growing season of 2022. The resulting 44 F_1 crosses plus one commercial hybrid (SC168) were evaluated at three locations; Sakha, Gemmiza and Mallawi Research Stations in 2023 growing season. A randomized complete block design with three replications was used in each location. Each cross was placed in a one-row plot of 6 m long and 0.80×0.25 m apart between and within row spacing, respectively. The trials were hand planted with two seeds/hill, which later thinned to one plant/hill after 21 days from planting to get a total plant population of 21875plants/feddan (feddan=4200 m^2). All standard cultural practices were followed as per recommendation for the area. The procedure of data collection followed CIMMYT's manual for managing trials and reporting data (CIMMYT's 1985). Data were recorded on days to 50% silking, plant height (cm), ear height (cm), ear length (cm) and grain yield in ardab per feddan (ard/fed), which was adjusted at 15.5% grain moisture (ardab=140Kg). Before data analysis, homogeneity test was performed. Combined analysis was made across three locations following same procedure of Snedecor and Cochran (1989). Calculation of variances analysis was carried out by using computer application of Statistical Analysis System (SAS, 2008). When the differences between crosses were significant, hence line × tester analysis was done according to Kempthorne (1957) and Singh and Chaudhary (1985). Calculation of variances analysis was carried out using the AGD-R Software (Analysis of Genetic Designs in R for windows) version 5.0 Statistical Software (Rodríguez *et al* 2015). The inbred lines were classified into heterotic groups based on three methods; HSGCA method proposed by Fan *et al* (2009), SCA effects mothod according to Vasal *et al* (1992 a, b) and we followed the Vasal *et al* (1992 a, b) and Fan *et al* (2009) criteria with some modifications depending on combining ability effects (HCAE) method.

RESULTS AND DISCUSSION

Analysis of variance

Combined analysis of variance for number of days to 50% silking, plant height, ear height, ear length and grain yield (Table 1), showed significant differences ($P \leq 0.01$); among locations (Loc) due to the difference between them in soil and climate conditions, among crosses (C) and their interaction with locations (C × Loc), indicating that studied crosses have a significant genetic variability, also these crosses behaved differently under different locations which makes selection possible. Several previous studies reported significant differences among genotypes for grain yield and other agronomic traits of maize (Oyekunle and Bedu-Apraku 2013, Dufera *et al* 2018 and Mosa *et al* 2024).

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

SOV	df	Days to 50% silking	Plant height (cm)	Ear height (cm)	Ear length (cm)	Grain yield (ard/fed)
Locations (Loc)	2	365.43**	74100.75**	44177.82**	241.41**	628.96**
Rep/L	6	12.87	885.44	549.11	7.66	30.33
Crosses (C)	44	19.13**	1590.21**	703.85**	5.18**	61.25**
C × Loc	88	4.05**	340.40**	180.57**	3.41**	34.93**
Error	264	1.80	142.11	85.02	1.63	10.69

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

Means performance

Means of 44 crosses and the check hybrid SC168 combined across three locations showed a wide range between the minimum and maximum values for all studied traits (Table 2). The earliest crosses in silking (62 days) were the two crosses (L1×Sk11) and (L12×Sk11), while the later cross (67.33 days) was the cross (L11×Gz658), eight crosses were earlier than the check hybrid SC168, the best crosses from them were (L1×Sk11), (L12×Sk11) and (L19×Sk11). The tallest plant (284.67 cm) was exhibited by the cross (L14×Sk11), while the shortest plant (220.78 cm) was exhibited by the cross (L1×Gz658); additionally, the cross (L1×Gz658) had a shorter plant than the check hybrid SC168. The highest ear height (161.56 cm) was recorded by (L5×Gz658), while the lowest ear height (122.44 cm) was shown by the cross (L2×Sk11), six crosses had significant shorter ear height than SC168, the best crosses form them were (L1×Sk11), (L1×Gz658), (L2×Sk11) and (L2×Gz658). The cross (L4×Gz658) showed the longest ear (22.93 cm), while the cross (L1×Sk11) recorded the shortest ear length (19.18 cm); the cross (L4×Gz658) had significant longer ear length than the check SC168. The highest yielding cross (36.11 ard/fed) was recorded by the cross (L15×Gz658), while the lowest yielding cross (23.22 ard/fed) was recorded by the cross (L11×Sk11). One cross (L15×Gz658) was significantly out-yielded than check hybrid SC168, while 12 crosses were not significantly out-yielded than SC168; the best crosses form them were (L10×Gz658), (L13×Gz658), (L20×Sk11) and (L22×Gz658). This study recommends using the best crosses in a breeding program to develop new hybrids.

Line × tester analysis

Data in Table (3), showed that the mean squares due to lines (L), testers (T) and (L×T) interaction were significant or highly significant for all studied traits, indicating that the inbred lines differed in their behavior with respect to their crosses, also testers were differed from each other in their crosses, while significant (L×T) interaction means that the inbred lines performed differently in crosses depending on type of tester used.

Tabel 2. Mean performance of 44 new crosses along with check hybrid for days to 50% silking, plant height, ear height, ear length and grain yield across three locations.

Cross	Days to 50% silking	Plant height (cm)	Ear height (cm)	Ear length (cm)	Grain yield (ard/fed)
L1 × Sk11	62.00	234.89	126.33	19.18	23.90
L1 × Gz658	62.56	220.78	122.89	20.73	31.13
L2 × Sk11	62.56	242.33	122.44	19.49	27.86
L2 × Gz658	62.78	237.67	132.56	20.96	29.09
L3 × Sk11	63.33	251.22	133.56	20.73	30.51
L3 × Gz658	63.78	245.67	135.78	20.91	32.29
L4 × Sk11	64.33	267.44	134.89	20.42	30.37
L4 × Gz658	65.00	269.33	151.22	22.93	32.60
L5 × Sk11	63.67	283.56	152.78	21.16	32.60
L5 × Gz658	66.67	275.44	161.56	22.31	31.19
L6 × Sk11	63.78	256.67	130.78	20.84	29.87
L6 × Gz658	66.11	260.44	152.78	20.84	32.22
L7 × Sk11	63.33	280.89	146.67	21.64	30.93
L7 × Gz658	65.44	265.89	152.33	21.89	33.10
L8 × Sk11	63.56	260.89	134.44	20.00	29.94
L8 × Gz658	64.89	254.67	139.56	20.33	33.10
L9 × Sk11	64.11	259.89	139.22	20.20	31.60
L9 × Gz658	66.44	266.00	155.11	21.51	32.67
L10 × Sk11	64.22	271.44	138.78	20.73	30.78
L10 × Gz658	64.67	272.89	152.78	20.80	34.85
L11 × Sk11	65.67	267.67	142.67	20.24	23.22
L11 × Gz658	67.33	258.56	152.33	21.40	32.59
L12 × Sk11	62.00	255.78	141.78	19.96	28.55
L12 × Gz658	63.56	240.33	139.78	20.33	32.05

Tabel 2. Cont.

Cross	Days to 50% silking	Plant height (cm)	Ear height (cm)	Ear length (cm)	Grain yield (ard/fed)
L13 × Sk11	63.89	272.00	147.67	20.82	33.45
L13 × Gz658	66.44	258.89	150.22	20.87	34.88
L14 × Sk11	64.33	284.67	151.78	20.38	34.51
L14 × Gz658	66.44	267.78	155.22	21.29	34.26
L15 × Sk11	63.78	267.22	143.44	19.82	32.83
L15 × Gz658	65.11	265.67	153.44	20.82	36.11
L16 × Sk11	65.56	269.44	144.00	21.22	30.51
L16 × Gz658	66.89	255.11	149.89	20.78	33.36
L17 × Sk11	63.78	263.56	141.89	20.24	33.10
L17 × Gz658	65.44	247.00	141.22	19.84	33.79
L18 × Sk11	63.33	261.11	143.33	19.62	31.73
L18 × Gz658	65.11	249.56	143.44	20.44	31.70
L19 × Sk11	62.33	254.78	142.11	19.56	31.69
L19 × Gz658	63.11	252.00	151.44	20.89	31.70
L20 × Sk11	62.56	262.78	140.67	20.67	35.79
L20 × Gz658	63.33	251.22	141.22	20.20	34.04
L21 × Sk11	64.11	282.44	153.44	19.73	34.32
L21 × Gz658	67.22	256.33	148.00	20.09	33.49
L22 × Sk11	62.78	265.67	145.22	19.96	32.62
L22 × Gz658	65.78	259.78	150.78	19.96	35.79
SC168 (check)	64.56	244.56	143.00	21.58	33.10
LSD 0.05	1.24	11.07	8.56	1.19	3.00

Table 3. Line × tester analysis of variance for days to 50% silking, plant height, ear height, ear length and grain yield across three locations.

SOV	df	Days to 50% silking	Plant height (cm)	Ear height (cm)	Ear length (cm)	Grain yield (ard/fed)
Lines (L)	21	24.46**	2610.38**	1077.45**	6.04**	77.26**
Testers (T)	1	252.16**	7025.82**	3764.75**	37.34**	416.19**
L × T	21	3.61**	284.81**	217.68**	2.64*	30.71**
L × Loc	42	4.30**	554.38**	216.51**	3.62**	50.90**
T × Loc	2	30.83**	717.33**	1605.36**	15.53**	65.90**
L × T × Loc	42	2.57*	120.06	71.51	2.73**	19.11*
Error	258	1.63	137.44	82.70	1.61	10.79

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

Mean squares due to (L×Loc), (T×Loc) and (L×T×Loc) interactions were significant or highly significant for all studied traits, except for (L×T×Loc) of plant and ear heights, meaning that (L), (T) and (L×T) interactions were affected by changing locations for most traits. These results are in agreement with those obtained by Ashish and Singh (2002), El-Shenawy *et al* (2003) and Mosa *et al* (2021).

Genetic components

The ratio between additive gene effects (GCA) and non-additive gene effects (SCA) for the studied traits in Table (4), showed that additive gene effects were more important in the inheritance of days to 50% silking, plant height, ear height and ear length. While, the non-additive gene action played an important role in the inheritance of grain yield. Similar results were reported by Mosa (2003) for days to 50% silking and grain yield, El-Shenawy *et al* (2003) and Keimeso and

Abakemal (2020) for plant and ear heights and Mosa and Motawei (2005) for ear length.

Table 4. Estimates of ratio between additive gene effects (GCA) and non-additive gene effects (SCA) for five studied traits across the three locations.

Genetic component	Days to 50% silking	Plant height	Ear height	Ear length	Grain yield
Additive gene effects (GCA)	**1.264**	**43.339**	**21.652**	**0.186**	**2.185**
Non-additive gene effects (SCA)	**0.202**	**16.375**	**14.998**	**0.114**	**2.213**
GCA/ SCA	**6.257**	**2.647**	**1.444**	**1.632**	**0.987**

General combining ability effects:

General combining ability (GCA) effects of 22 inbred lines and two testers for days to 50% silking, plant height, ear height, ear length and grain yield are presented in Table (5). The GCA effects of inbred lines ranged from -2.11** for L1 to 2.11** for L11 for days to 50% silking, the best inbred lines for earliness were L1, L2, L3, L12, L19 and L20. Meanwhile the best tester for earliness was Sk11. The highest GCA effects for plant height and ear height was L5, while the lowest GCA effects was exhibited by inbred line L1, the desirable GCA effects for both traits were shown by L1, L2 and L3, plus L12 and L19 for plant height and L9 for ear height. Meanwhile the best tester for GCA effects was Gz658 for short plant height and Sk11 for short ear height. The desirable inbred lines for plant and ear heights should be used to reduce plant and ear heights, which is important for development of hybrids resistant to lodging. GCA effects for ear length varied from -0.65** for L1 and L22 to 1.16** for L7, the desirable GCA effects were shown by L4, L5 and L7 for inbred lines and Gz658 for testers.

Tabel 5. General combining ability effects of 22 inbred lines and two testers for days to 50% silking, plant height, ear height, ear length and grain yield across three locations.

Inbred line	Days to 50% silking	Plant height	Ear height	Ear length	Grain yield
L1	-2.11**	-32.33**	-19.29**	-0.65*	-4.45**
L2	-1.72**	-20.17**	-16.40**	-0.39	-3.49**
L3	-0.83**	-11.72**	-9.23**	0.21	-0.56
L4	0.28	8.22**	-0.84	1.07**	-0.48
L5	0.78*	19.33**	13.27**	1.13**	-0.07
L6	0.56	-1.61	-2.12	0.24	-0.92
L7	0.00	13.22**	5.60**	1.16**	0.03
L8	-0.17	-2.39	-6.90**	-0.44	-0.48
L9	0.89**	2.78	3.27	0.25	0.17
L10	0.06	12.00**	1.88	0.16	0.85
L11	2.11**	2.94	3.60	0.21	-4.06**
L12	-1.61**	-12.11**	-3.12	-0.46	-1.66*
L13	0.78*	5.28	5.05*	0.24	2.20**
L14	1.00**	16.06**	9.60**	0.23	2.42**
L15	0.06	6.28*	4.55*	-0.29	2.46**
L16	1.83**	2.11	3.05	0.39	-0.03
L17	0.22	-4.89	-2.34	-0.56	1.47
L18	-0.17	-4.83	-0.51	-0.57	-0.25
L19	-1.67**	-6.78*	2.88	-0.39	-0.27
L20	-1.44**	-3.17	-2.95	-0.17	2.95**
L21	1.28**	9.22*	6.83**	-0.70*	1.94*
L22	-0.11	2.56	4.10	-0.65*	2.24**
LSD $g_{i\ 0.05}$	0.62	5.44	4.22	0.59	1.52
0.01	0.82	7.17	5.56	0.78	2.01
LSD $g_i - g_{j\ 0.05}$	0.89	7.77	6.03	0.84	2.18
0.01	1.18	10.29	7.99	1.11	2.88
Tester (Sk11)	-0.80**	4.21**	-3.08**	-0.31**	-1.03**
Tester (Gz658)	0.80**	-4.21**	3.08**	0.31**	1.03**
LSD $g_{i\ 0.05}$	0.19	1.66	1.28	0.18	0.46
0.01	0.25	2.19	1.70	0.24	0.62
LSD $g_i - g_{j\ 0.05}$	0.27	2.34	1.82	0.25	0.66
0.01	0.35	3.10	2.41	0.34	0.87

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

GCA effects for grain yield varied from -4.45** for L1 to 2.93** for L20, the desirable GCA effects were exhibited by inbred lines L13, L14, L15, L20, L21 and L22 and tester Gz658, indicating the potential advantage of these inbred lines for development of high yielding hybrids and synthetic varieties.

Specific combining ability effects

The desirable hybrids for specific combining ability (SCA) effects were (L2×Gz658), (L5×Sk11), (L21×Sk11) and (L22×Sk11) for earliness, (L4×Sk11), (L6×Sk11), (L9×Sk11) and (L21×Gz658) for short plant and ear heights, (L1×Gz658), (L4×Gz658), (L16×Sk11) and (L20×Sk11) for ear length and (L1×Gz658), (L5×Sk11), (L11×Gz658) and (L20×Sk11) for high grain yield (Table 6).

Tabel 6. The best crosses for specific combining ability effects for days to 50% silking, plant height, ear height, ear length, ear diameter and grain yield across three locations.

Days to 50% silking	Plant height	Ear height	Ear length	Grain yield
L2×Gz658	L4×Sk11	L4×Sk11	L1×Gz658	L1×Gz658
L5×Sk11	L6×Sk11	L6×Sk11	L4×Gz658	L5×Sk11
L21×Sk11	L9×Sk11	L9×Sk11	L16×Sk11	L11×Gz658
L22×Sk11	L21×Gz658	L21×Gz658	L20×Sk11	L20×Sk11

Heterotic groups for ibred lines

It is important for breeders to classify inbred lines into heterotic groups in order to determine the potential utility of parental lines for developing high-yielding hybrids. The grouping of 22 new maize inbred lines based on; HSGCA, SCA-effects and HCAE methods was made for grain yield in this study as follows (Table 7), according to HSGCA method of Fan *et al* (2009).

Table 7. Classification of 22 inbred lines into different heterotic groups based on HSGCA, SCA effects and HCAE methods for grain yield across the three locations.

Inbred line	GCA effects	SCA effects		Heterotic group method		
		Sk11 (A)	Gz658 (B)	HSGCA	SCA effects	HCAE
L1	-4.45	-2.59	2.59	A	A	A
L2	-3.49	0.41	-0.41	B	B	B
L3	-0.56	0.14	-0.14	B	B	B
L4	-0.48	-0.09	0.09	A	A	A
L5	-0.07	1.73	-1.73	B	B	B
L6	-0.92	-0.15	0.15	A	A	A
L7	0.03	-0.05	0.05	A	A	-
L8	-0.48	-0.52	0.52	A	A	A
L9	0.17	0.49	-0.49	B	B	-
L10	0.85	-1.01	1.01	A	A	-
L11	-4.06	-3.66	3.66	A	A	A
L12	-1.66	-0.72	0.72	A	A	A
L13	2.20	0.31	-0.31	-	B	-
L14	2.42	1.15	-1.15	-	B	-
L15	2.46	-0.57	0.57	-	A	-
L16	-0.03	-0.40	0.40	A	A	A
L17	1.47	0.67	-0.67	-	B	-
L18	-0.25	1.04	-1.04	B	B	B
L19	-0.27	1.02	-1.02	B	B	B
L20	2.95	1.90	-1.90	-	B	-
L21	1.94	1.44	-1.44	-	B	-
L22	2.24	-0.56	0.56	-	A	-

The results showed that the inbred lines were divided into groups depending on their SCA effects plus their GCA effects with each tester (SCA+GCA). All inbred lines placed into each tester heterotic group, keeping the inbred lines with the heterotic group where its HSGCA had negative or largest negative value, but if the inbred line had positive HSGCA effects with both testers, hence this inbred line is not placed in any group. So the group A (tester Sk11) included the inbred lines L1, L4, L6, L7, L8, L10, L11, L12 and L16. The group B (tester Gz658) contained the inbred lines L2, L3, L5, L9, L18 and L19 while, this method was not able to classify the inbred lines L13, L14, L15, L17, L20, L21 and L22. According to SCA-effects method of Vasal *et al* (1992 a, b), positive SCA effects indicating that lines are in opposing heterotic groups, while negative SCA effects indicate that lines are in the same heterotic group. Therefore, the inbred lines, which had negative SCA effects with tester Sk11 were assigned to heterotic group A while, the inbred lines which had negative SCA effects with tester Gz658 were assigned to heterotic group B. Hence, all inbred lines under this study were assigned to two heterotic groups. Among 22 inbred lines, eleven inbred lines (L1, L4, L6, L7, L8, L10, L11, L12, L15, L16 and L22) were grouped into heterotic group A, also eleven inbred lines (L2, L3, L5, L9, L13, L14, L17, L18, L19, L20 and L21) were grouped into heterotic group B. According to HCAE method, we followed the Vasal *et al* (1992 a, b) and Fan *et al* (2009) criteria with some modifications as follow, any inbred line showing negative SCA effects with the first tester (A) but had positive SCA with the second tester (B) and had negative GCA effects is placed into the heterotic group A. Similarly, any inbred line displayed negative SCA effects with the second tester (B) but had positive SCA effects with the first tester (A) and had negative GCA effects is placed into the heterotic group B. Meanwhile, if the inbred line had positive GCA effects, this line is not placed in any group. Hence, the group A (tester Sk11) includes the inbred lines L1, L4, L6, L8, L11, L12 and L16. The group B (tester Gz658) contained the inbred lines L2, L3, L5, L18 and L19. While this method was not able to classify the inbred lines L7, L9, L10, L13, L14, L15, L17, L20, L21 and L22. From above results the group A included seven inbred lines according HCAE method, nine inbred lines (same seven above mentioned inbred lines plus two other inbred lines) according to HSGCA method, and eleven inbred lines (same nine above mentioned inbred lines plus two other inbred lines) according to SCA effects method. The group B included five inbred lines according to HCAE method, six inbred lines (the same as the previous five inbred lines and one other inbred line) according to HSGCA method, and eleven inbred lines (the same as the previous six inbred lines and five other inbred lines) according to SCA effects method, indicating that there were differences between the three methods in the number of inbred lines in each group. Heterotic groups have been studied extensively by many researchers (Bhatnagar *et al* 2004, Barata and Carena 2006, Fan *et al* 2009, Badu-Apraku *et al* 2013, Tian *et al* 2015, Ejigu *et al* 2017 and Mosa *et al* 2024).

Comparison of the efficiency for three heterotic group methods

Comparing the effectiveness of the three methods for making heterotic groups is shown in Table 8. The best grouping method is one that allowed inter-group crosses to produce superior hybrids than within- group crosses (Fan *et al* 2009). The HSGCA method identified 23, SCA effects method identified 16 and HCAE method identified 24 high yielding crosses for yield group-1(≥ grand mean). From the above results, the three heterotic group methods were differed in identifying superior hybrids (≥ grand mean). The HCAE followed HSGCA methods recorded higher mean of crosses obtained from parents selected from different groups. On the other hand, SCA effects method revealed nine higher mean of crosses obtained from parents within the same heterotic group, followed by HSGCA method (two crosses) and HCAE method (one cross) for yield group-1. Hence the two methods HCAE followed HSGCA were the best methods for classification of inbred lines into heterotic groups than SCA effects method. Heterotic groups have been extensively studied in maize. Fan *et al* (2009) stated 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.

Table 8. Number of crosses classified by the mean grain yield (ard/fed) for three heterotic group classification methods across the three locations.

Yield group	Cross type	Heterotic group method		
		HSGCA	SCA effects	HCAE
Group-1 31.97-36.11 (ard/fed)	Inter group	23	16	24
	Within group	2	9	1
Group-2 31.96-23.22 (ard/fed)	Inter group	6	6	8
	Within group	13	13	11

Also, they reported that the HSGCA method was better than SCA and SSR methods for assigning an unknown maize line to a known maize heterotic group. Akinwale *et al* (2014) found that SSR marker-based genetic distance (GD) method was not as effective as the HSGCA method in classifying the early maturing inbred lines under both striga infested and striga free environments. Meanwhile Badu-Apraku *et al* (2015) found that the SNP markers method proved more effective than HSGCA method. Oyetunde *et al* (2020) compared the efficiencies of the four grouping methods for classifying the inbred lines. They found that the HSGCA and SCA methods were the most efficient for grouping in all test conditions than heterotic grouping based on general combining ability effects of multiple traits (HGCAMT) and SNP-based genetic distance (GD) methods. Mosa *et al* (2024) found 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.

REFERENCES

Akinwale, R.O, B. Badu-Apraku, M.A.B. Fakorede and I. Vroh-Bi (2014). Heterotic grouping of tropical early-maturing maize inbred lines based on combining ability in striga-infested and striga-free environments and the use of SSR markers for genotyping. Field Crops Research 156:48-62.

Ali, M., Kuswanto and H. Kustanto (2019). Phenomenon of inbreeding depression on maize in perspective of the quran. Agrivita J. Agric. Sci. 41: 385-393.

Ashish, S. and I.S. Singh (2002). Evaluation and classification of exotic inbreds over locations based on line × tester analysis in maize (*Zea mays* L.). Crop improvement 29:184-189.

Badu-Apraku, B., B. Annor, M. Oyekunle, R.O. Akinwale, M.A.B. Fakorede, A.O. Talabi, I.C. Akaogu, G. Melaku and Y. Fasanmade (2015). Grouping of early maturing quality protein maize inbreds based on SNP markers and combining ability under multiple environments. Field crops Research 183: 169-183.

Badu-Apraku, B., M. Oyekunle, M.A.B. Fakorede, I. Vroh, R.O. Akinwale and M. Aderounmu (2013). Combining ability, heterotic patterns and genetic diversity of extra-early yellow inbreds under contrasting environments. Euphytica 192: 413-433.

Barata, C. and M.J. Carena (2006). Classification of North Dakota maize inbred lines into heterotic groups based on molecular and testcross data. Euphytica 151: 339-349.

Bhatnagar, S., F.J. Betran and L.W. Rooney (2004). Combining ability of quality protein maize inbrds. Crop Sci. 44: 1997-2005.

Ceccarelli, S. (2015). Efficiency of plant breeding. Crop Sci. 55: 87-97.

CIMMYT (1985) Managing trials and reporting data for CIMMYT's International Maize Testing Programme. CIMMYT, El Batan, Mexico.

de Faria, S.V., L.T. Zuffo, W.M. Rezende, D.G. Caixeta, H.D. Pereira, C.F. Azevedo and R.O. Delima (2022). Phenotypic and molecular characterization of a set of tropical maize inbred lines from a public breeding program in Brazil. BMC Genomics 23: 1-17.

Delucchi, C., H.E. Guillermo, D.L. Roberto, A.P. Daniel, E. O. María, and G.L. César (2012). Classification of argentine maize landraces in heterotic groups. Maydica 57: 26-33.

Dufera, T., T. Bulti and A. Girum (2018). Heterosis and combining ability analysis of quality protein maize (*Zea mays* L.) inbred lines adapted to mid-altitude sub-humid agro-ecology of Ethiopia. Afr. J. Plant Sci. 12: 47-57.

Ejigu, Y.G., P.B. Tongoona and B.E. Ifie (2017). Classification of selected white tropical maize inbred lines into heterotic groups using yield combining ability effects. Afr. J. Agric. Res. 12: 1674-1677.

El-Shenawy, A.A., E.A. Amer and H.E. Mosa (2003). Estimation of combining ability of newly developed inbred lines of maize by (line × tester) analysis. J. Agric. Res. Tanta Univ. 29: 50-63.

Fan, X.M., J. Tan, B.H. Huang and F. Liu (2001). Analysis of combining ability and heterotic patterns of quality protein maize inbreds. (In Chinese, with english abstract.) Acta, Agron. Sci. 27: 986-992.

Fan, X.M., J. Tan, H.M. Chen and Y.J. Yang (2003). Heterotic grouping for tropical and temperature maize inbreds by analyzing combining ability and SSR markers. Maydica 48: 251-257.

Fan, X.M., X.F. Yin, Y. D. Zhang, Y.Q. Bi, L.L. Liu, H.M. Chen and M.S. Kang. (2016). Combining ability estimation for grain yield of maize exotic germplasm using testers from three heterotic groups. Crop Sci. 56:2527–2537.

Fan, X.M., Y.M. Zhang, L. Liu, H.M. Chen, W.H. Yao, M.S. Kang and J.Y. Yang (2010). Improving grain yield and yield components of temperate maize using tropical germplasm. J. New Seeds 11: 28-39.

Fan, X.M., Y.M. Zhang, W.H. Yao, H.M. Chen, J. Tan, C.X. Xu, X.L. Han, L.M. Luo and M.S. Kang (2009). Classification maize inbred lines into heterotic groups using a factorial mating design. Agron. J. 101: 106-112.

Girma, C., A. Sentayehu, T. Berhanu and M. Temesgen (2015). Test cross performance and combining ability of maize (*Zea mays* L.) inbred lines at Bako, Western Ethiopia. Global Journal of Science Frontier Resarch 15: 1-24.

Gurung, D.B., M.L.C. George and Q.D. Delacruz (2009). Determination of heterotic groups in Nepalese yellow maize populations. Nepal J. Sci. Tech. 10: 1-8.

Hallauer, A.R. and M.J. Carena (2009). Maize Breeding. In: Carena M.J. (Ed.) Handbook of Plant Breeding: Cereals. Springer, New York pp.3-98.

Keimeso, Z., and D. Abakemal (2020). Combining ability of highland adapted maize (*Zea mays* L.) inbred lines for desirable agronomic traits under optimum and low nitrogen conditions. Journal of Science and Sustainable Development 8: 1-13.

Kempthorne, O. (1957). An introduction to genetic statistics. John Wiley and Sons Inc., New York, USA.

Liberando, R.P. and E.E. Magulana (2008). Classification on white inbred lines into heterotic group using yield combining ablitiy effects. USM R & D J 16: 99-103.

Menkir, A., A. Melake-Berhan, A.C. The, I. Ingelbrecht and A. Adepoju (2004). Grouping of tropical mid-altitude maize inbred lines on the basis of yield data and molecular markers**.** Theor. Appl. Genet. 108:1582-1590.

Mosa, H.E. (2003). Heterosis and combining ability in maize (*Zea mays* L.). Minufiya J. Agric. Res. 28: 1375-1386.

Mosa, H.E. and A.A. Motawei (2005). Combining ability of resistance to late wilt disease and grain yield and their relationships under artificial and natural infections in maize. J. Agric. Sci. Mansoura Univ. 30: 731-742.

Mosa, H.E., I.A.I. El-Gazzar, M.A.A. Hassan, S.M. Abo El-Haress, M.A.A. Abd-Elaziz and R.H.A. Alsebaey (2021). Heterotic grouping for some white maize inbred lines *via* combining ability effects and hybrids grain yield. Egypt. J. Plant Breed. 25: 47-57**.**

Mosa, H.E., M.A. A. Hassan, Yosra, A. Galal, M.S. Rizk and T.T. El-Mouslly (2023). Combining ability of elite maize inbred lines for grain yield, resistance to both late wilt and northern leaf blight disease under different environments. Egypt. J. Plant Breed. 27: 269-287.

Mosa, H.E., M.A. Abd El-Moula, A.M.M. Abd El-Aal, I.A.I. El-Gazzar, M.A.A. Hassan, S.M. Abo El-Haress, M.S. Abd El-Latif and M.A.A. Abd-Elaziz (2024). Combining ability and relationships among heterotic grouping classification methods for nine maize inbred lines. Egypt. J. Plant Breed. 28: 1-20**.**

Murtadha, M. A., O.J. Ariyo and S.S. Alghamdi (2018). Analysis of combining ability over environments in diallel crosses of maize (*Zea mays* L.). Journal of the Saudi Society of Agricultural Sciences 17: 69-78.

Oluwaseun, O., B. Badu-Apraku, M. Adebayo and A.M. Abubakar (2022). Combining ability and performance of extra-early maturing provitamin a maize inbreds and derived hybrids in multiple environments. Plants 11: 964 (1-20).

Oyekunle, M., and B. Badu-Apraku (2013). Genetic analysis of grain yield and other traits of early- maturing maize inbreds under drought and well-watered conditions. J. Agron. Crop Sci. 200: 92-107.

Oyetunde, O.A., B. Badu-Apraku, O.J. Ariyo and C.O. Alake (2020). Efficiencies of heterotic grouping methods for classifying early maturing maize inbred lines. Agronomy 10: 1198(1-27).

Pswarayi, A. and B.S. Vivek (2008). Combining ability amongst CIMMYT's early maturing maize (*Zea mays* L.) germplasm under stress and non-stress conditions and identifications of testers. Euphytica 162: 353-362.

Rodríguez, F., G. Alvarado, A. Pacheco, J. Burgueño and J. Crossa (2015). AGD-R (Analysis of genetic designs with R for windows) version 5.0 Vol. 14 (Elbatan, Mexico: CIMMYT Research Data & Software Repository Network).

SAS Institute (2008). Statistical Analysis System (SAS/STAT program, version. 9.1). SAS Inst. Cary NC.

Singh, R.K. and B.D. Chaudhary (1985). Biometrical Method in Quantitative Genetics Analysis (2nd ed). Kalyani Publishers, New Delhi India.

Snedecor, G.W. and W.G. Cochran (1989). Statistical Methods. 8th ed. Iowa State Univ. Press. Ames. Iowa, USA.

Tian, H.Y., S.A. Channa and S.W. Hu (2015). Heterotic grouping and the heterotic pattern among Chinese rapeseed (*Brassica napsu* L.) accessions. Agron. J. 107: 1321-1330.

Vasal, S.K., G. Srinivasan, G.C. Han and F.C. Gonzalez (1992b). Heterotic patterns of eighty-eight white subtropical CIMMYT maize lines. Maydica 37:319-327.

Vasal, S.K., G. Srinivasan, S. Pandey, H.S. Cordova, G.C. Han and F.C. Gonzalez (1992a). Heterotic patterns of ninety-two white tropical CIMMYT maize lines. Maydica 37: 259-270.

تقسيم سلالات جديدة من الذرة الشامية إلى مجاميع هجينية

بإستخدام ثلاث طرق

حاتم الحمادى موسى، مجدى أحمد عبدالمولى, عاصم عبده مطاوع, إبراهيم عبد النبى

إبراهيم الجزار، محمود شوقى عبد اللطيف، موسى سيد رزق و تامر طلعت المصلحى

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

من المهم لمربى النبات تقسيم سلالات الذرة إلى مجاميع هجينية ليستفيد منها فى إنتاج هجن عالية المحصول. تم تهجين ٢٢ سلالة صفراء جديدة مع إثنين من الكشافات فى نظام تزاوج السلالة × الكشاف لإنتاج ٤٤ هجين فى موسم ٢٠٢٢. فى موسم ٢٠٢٣ قيمت الهجن الناتجة بالإضافة لهجين تجارى فى تصميم القطاعات الكاملة العشوائية فى ثلاث مكررات فى ثلاث مواقع (محطات البحوث الزراعية بسخا والجميزة وملوى) لصفات عدد الأيام حتى خروج حرائر ٥٠٪ من النباتات ، إرتفاع النبات، إرتفاع الكوز، طول الكوز، محصول الحبوب. كان التباين الراجع للسلالات والكشافات والسلالة × الكشاف وتفاعلهم مع المواقع معنوى أوعالى المعنوية لجميع الصفات ماعدا التفاعل الراجع بين السلالة × الكشاف × المواقع لصفتى إرتفاع النبات وإرتفاع الكوز. كانت السلالات المرغوبة فى تأثيرات القدرة العامة على الإئتلاف هى السلالة (L1) لصفات التبكير وقصر إرتفاع النبات والكوز، والسلالة (L7) لطول الكوز، والسلالة (L20) لمحصول الحبوب العالى. أظهر الهجين (L15 × Gz658) تفوقاً معنوياً مقارنةً بالهجين التجارى (SC168). إختلفت الطرق الثلاثة لتقسيم السلالات إلى مجاميع هجينية فى تحديد عدد الهجن المتفوقة (أعلى من المتوسط) والناتجة من التهجين بين سلالات من مجاميع مختلفة. كانت طريقة تقسيم السلالات إلى مجاميع هجينية بإستخدام تأثيرات القدرة على الإئتلاف (HCAE) هى الأعلى تليها طريقة تقسيم السلالات إلى مجاميع هجينية بإستخدام تأثيرات القدرة الخاصة والعامة على الإئتلاف (HSGCA)، كذلك أظهرت طريقة (HCAE) أقل عدد من الهجن المتفوقة الناتجة من التهجين بين سلالات من نفس المجموعة الهجينية وتليها طريقة (HSGCA). لذلك تعتبر طريقة (HCAE) هى الأكثر فاعلية تليها طريقة (HSGCA) فى تقسيم السلالات إلى مجاميع هجينية بالمقارنة بطريقة تأثيرات القدرة الخاصة على الإئتلاف (SCA effects).

المجلة المصرية لتربية النبات ٢٨(١): ١٣٥– ١٥٤ (٢٠٢٤)