

Heterotic grouping in maize using the specific and general combining ability method

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Abstract: Maize being a highly cross-pollinated crop, hybrid breeding is commercially proven due to the high amount of heterosis, and the quantum of heterosis is maximized when lines from opposite heterotic groups are mated. The analysis of variance recorded significant differences among the different quantitative characters. Similarly, ANOVA for combining ability revealed that the mean sum of squares due to lines, testers, and line-tester interaction was significant. Hence, these lines were subjected to heterotic grouping using the HSGCA method. The 32 maize inbred lines were grouped into heterotic groups A (8), B (6), and AB (9). While nine lines were unclassified into any of the groups, The lines grouped under the AB heterotic group recorded the highest *gca* effects for grain yield, viz., GPM-27 (25.5), GPM-18 (20.3), and GPM-606 (17.0). Whereas GPM-114 (4.3) and GPM-702 (4.2) recorded the highest *gca* for grain yield from heterotic groups A and B, respectively. The lines belonging to the AB heterotic group GPM-27 (96.7 q/ha), GPM-18 (91.6 q/ha), GPM-606 (88.3 q/ha), and GPM-30 (83.3 q/ha) also recorded the highest mean grain yield. Similarly, the line (GPM-114) with the highest mean grain yield and *gca* from heterotic group A, when crossed with GPM-706 from heterotic group B, may result in a high-yielding heterotic hybrid. Overall, the two test hybrids GH-1809 (101.93 q/ha) and GH-1829 (101.71 q/ha) recorded significantly higher grain yield as compared to the best-check 900M Gold (95.74 q/ha). Both these hybrids, GH-1809 (GPM-27 × CM-111) and GH-1829

(GPM-606 × CM-111), had female lines from the AB heterotic group with the highest *gca* effects for grain yield and CM-111 as their common tester.

Keywords: Maize · Combining ability · *gca* · *sca* · heterotic grouping · HSGCA

Introduction

Maize is one of the major coarse cereal crops of India, occupying an area of 9.8 million ha and around 15.0 lakh ha in Karnataka (www.iimr.res.in/annual report). Maize is primarily used for poultry (47%) and livestock feed (13%) in India, and its demand has been increasing due to rapid expansion in poultry-based industries both for egg and meat. Maize production in India at present stands at 31.65 million tonnes and a productivity of 3.19 t/ha (ICAR-Indian Institute of Maize Research). However, as per the projections, India has to double its maize production by 2050 to meet future demands (Antony *et al.*, 2023). In this situation, the area expansion of maize cultivation cannot happen at that pace; therefore, the other way is to increase productivity by cultivating high-yielding hybrids, improving agronomic practices, and practicing an integrated disease and pest management approach.

Among these, the focus has to be on having a systematic hybrid breeding program, which involves classifying the available maize inbreds and germplasm lines into different heterotic groups. Heterotic grouping tries to broadly classify maize genotypes with diverse genetic basis that are complementary and result in the expression of heterosis after hybridization (Melchinger and Gumber, 1998). Heterotic grouping is the first and foremost fundamental step for maximum exploitation of

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heterosis for hybrid cultivar development (Vasal *et al.*, 1992; Reif *et al.*, 2003 and Legesse *et al.*, 2009). Similarly, information on genetic diversity is also very important for hybrid breeding and population improvement programs. In hybrid maize breeding, information on genetic diversity and heterotic groups of the inbred lines is very useful in making planned crosses to maximize heterosis. Apart from genetic diversity, the type of gene action prevalent in the set of parents under study is well expressed when additive gene action is preponderant over non-additive gene action (Akinwale, 2021).

Accordingly, Aslam and Zafar (2020), through their review paper, have emphasized the identification of genetically divergent heterotic groups and subsequent heterotic patterns as the need of the hour for maximum exploitation of genetic diversity for sustaining a long-term breeding program in maize. A set of maize inbred lines was available at All India Coordinated Research Program (AICRP) Maize, UAS Dharwad, but the information on which heterotic group they belonged to was not known. Therefore, the present study was planned to classify the available maize inbred lines into different heterotic groups so that they can be used in hybrid breeding.

Materials and methods

Genetic material, hybridization and evaluation

In this experiment, there were 32 maize germplasm lines that were crossed with diverse testers (CM-111 and CM-202) in a line $\times$ tester mating design during the *rabi* season in 2018-19. CM-111 is orange and flint type, while CM-202 is yellow and dent type, and these two testers have been used in the AICRP-Maize to derive inbred lines by crossing with X1 (Y) and X2 (Y) pools (A Compendium of Hybrids and Composites of Maize (1993-2012) www.icar.iimr.gov.in).

The resulting 64 F_1 s, along with six checks, were evaluated in an alpha lattice design with 10 blocks and seven entries per block (107) with three replications at AICRP Maize, UAS, Dharwad during the *kharif* season of 2019–20. Each entry was planted in two rows of a 4-meter-long plot. The spacing between rows was 60 cm, and the plant-to-plant distance was 20 cm. One plant per hill was maintained after proper thinning. All the

recommended agronomic practices were followed to raise a healthy crop. Observations for all the quantitative traits (plant height, ear height, cob length, cob girth, number of kernel rows per cob, number of kernels per row, 100-grain weight, shelling percentage, and grain yield per ha) were recorded on five randomly selected plants of each entry in each replication except for days to 50 per cent tasselling, days to 50 per cent silking, and plot weight (kg), where observations were recorded on a plot basis. For calculating grain yield, the plot weight was considered and adjusted at 15 per cent moisture and shelling % as one more factor.

$$\text{Grain yield (q/ha)} = \frac{[(\text{plot wt} * (100 - M) * \text{Shelling \%} * 10000)]}{(100 * 85 * \text{plot area})} / 100$$

Where, M: moisture %, 10000= ha factor

Statistical analysis

Analysis of variance was performed for all the traits using R software, and line $\times$ tester analysis was calculated using the method described by Kempthorne (1957). General combining ability (GCA) and specific combining ability (SCA) effects for grain yield were calculated based on the line-tester model.

Heterotic grouping using specific and general combining ability (HSGCA) methods. For heterotic grouping, in the first step, place all the lines with negative HSGCA effects into the same heterotic group as their tester. In the second step, the germplasm lines exhibiting positive HSGCA effects with both testers were assigned to the heterotic AB group, and in the third step, if a line had a negative HSGCA effect with all the testers, not assigned that line to any heterotic group because the line might belong to altogether a different heterotic group than the testers used. The HSGCA method was proposed by Fan *et al.* (2009) and computed as follows:

$$\text{SCA} = \text{cross mean } (x_{ij}) + \text{line mean } (x_i) + \text{tester mean } (x_j) + \text{overall mean } (x)$$

$$\text{GCA} = \text{line mean } (x_i) - \text{overall mean } (x)$$

$$\text{HSGCA} = \text{Cross mean } (x_{ij}) - \text{Tester mean } (x_j) = \text{GCA} + \text{SCA}$$

Where, x = the mean yield of the cross between the i^{th} line and the j^{th} tester.

1. x_i = mean yield of i^{th}

x_j = mean yield of the j^{th} tester

The computed HSGCA values were subjected to the three classification steps described by Fan *et al.* (2009).

Results and discussion

The analysis of variance (ANOVA) for different traits is represented in Table 1, and the sum of squares due to genotypes showed significant differences for all the quantitative traits studied in the experiment. The results imply that there was sufficient variability for yield and its contributing traits among all the entries. Since significant differences were observed from the ANOVA, an analysis of variance for combining ability effects was performed in Table 2. For combining ability effects, significant differences were also observed by the sum of squares due to lines, testers, crosses, and line-tester interaction for most of the traits except for the cob girth trait, indicating significant variance for the combining ability effects. Among the different traits, for hundred-grain weight and grain yield, lines contributed more to the effects as compared to testers, but for all the other traits testers contributed more to the effects.

The combining ability effects for all the lines for different quantitative traits are presented in Table 3 for

gca effects and Table 4 for *sca* effects. Among the lines, the highest and most significant *gca* effects for grain yield were observed in GPM-27 (25.468**), followed by GPM-18 (20.318**), and GPM-606 (17.033**). This indicates the predominance of additive gene action, and selection is likely to be more effective if there is a sufficient amount of additive variance. Similarly, for hundred seed weight, GPM-606 (7.89**), GPM-629 (5.39**), and GPM-38 (4.64**), for plant height, GPM-606, GPM-56, and GPM-642 were the best general combiners, and for flowering traits, GPM-648, GPM-4, and GPM-759 recorded significant GCA effects in a desirable negative direction and were found to be early.

Likewise, the *sca* effects ranged from -23.19 (GH-1845) to 15.77 (GH-1862), and eight hybrids recorded significant *sca* effects in a desirable positive direction for grain yield, to name some: GH-1812 (GPM-28 CM-202), GH-1843 (GPM-701 × CM-111), GH-1852 (GPM-114 × CM-202), and GH-1819 (GPM-45 × CM-111). Higher *sca* variance for grain yield among these hybrids indicates the predominance of non-additive gene action, which favors hybrid breeding. For other yield-contributing traits like hundred grain weight, GH-1852, GH-1819, GH-1812, GH-1841, and GH-1801 recorded significant *sca* effects;

Table 1. Analysis of variance for different quantitative traits in maize.

Source of variation	DF	DFT	DFS	PHT	EHT	CLT	CGT	NKR	KPR	HGW	GY
Replication	2	0.871	1.55	72.19	30.87	1.21	0.066	0.005	3.70	6.04	25.56
Genotypes	69	13.53**	8.64**	508.79**	199.71**	9.74**	0.31*	1.433*	42.09**	51.20**	893.04**
Blocks with in replication	27	3.54*	2.09*	27.43	10.83	1.69	0.035	0.412	11.00	2.53	17.02
Error	111	0.773	0.73	26.46	12.77	1.61	0.028	0.309	8.67	1.93	22.35
Total	209	18.71	13.01	634.87	254.18	14.25	0.439	2.16	65.46	61.7	957.97

* and ** indicates significance at 5% and 1% level respectively

DF = degrees of freedom, DFT = Days to 50 per cent tasseling, DFS = Days to 50% silking, PHT = Plant height (cm), EHT = Ear height (cm), CLT = Cob length (cm), CGT = Cob girth (cm), NKR = Number of kernel rows per cob, KPR = Number of kernels per row, HGW = 100 grain weight (g), GYP = Grain yield per hectare (q/ha)

Table 2. Analysis of variance for combining ability effects for grain yield and its component traits

Source of variation	DF	DFT	DFS	PHT	EHT	CLT	CGT	NKR	KPR	HGW	GY
Lines	31	14.95*	9.09*	659.09*	251.87*	9.97*	0.44	1.67*	50.73*	62.59*	1099.16*
Testers	1	128.76*	113.64*	3254.60*	323.30*	15.79*	1.77	10.13*	159.70*	21.66*	93.0*
Crosses	63	10.37*	6.76*	442.85*	181.87*	8.09*	0.28	1.36*	38.72*	40.90*	701.26*
Line X testers	31	2.11*	1.07*	151.90*	108.58*	5.96*	0.08	0.74*	22.43*	19.84*	332.03*
Error	111	0.77	0.73	26.45	12.77	1.61	0.028	0.31	8.66	1.936	22.35
Total	237	156.26	131.29	4534.89	878.39	41.42	2.59	14.21	280.24	146.92	2247.80

* and ** indicates significance at 5% and 1% level respectively

DFT = Days to 50 per cent tasseling, DFS = Days to 50 per cent silking, PHT = Plant height (cm), EHT = ear height (cm), CLT = Cob length (cm), CGT = Cob girth (cm), NKR = Number of kernel rows per cob, KPR = Number of kernels per row, HGW = 100 grain weight (g), GYP = Grain yield per hectare (q/ha)

Table 3. Estimates of general combining ability effects of lines and testers for grain yield and its component traits in maize (*Zea mays* L.)

Parents	Days to 50% tasseling	Days to 50% silking	Plant height (cm)	Ear height (cm)	Cob length (cm)	Cob girth (cm)	Kernel rows per cob	Kernels per row	100-grains weight (g)	Grain yield (q/ha)
<i>Lines</i>										
GPM-4	-2.87**	-1.85**	-1.22	-1.62	0.34	-0.518**	-0.48**	0.36	-6.60**	2.645
GPM-13	-0.53	-0.68*	-4.19**	-4.23**	0.33	0.26**	1.02**	3.01**	-2.60**	-3.808
GPM-16	1.13**	0.64	0.71	4.44**	-0.007	0.002	-0.081	2.41*	-0.36	2.872
GPM-18	0.96*	0.81*	11.51**	9.57**	0.09	0.16**	0.319	-0.29	1.14**	20.318**
GPM-27	1.29**	0.98**	9.65**	6.57**	1.95**	0.17**	0.019	2.76**	0.64**	25.468**
GPM-28	-0.2	-0.52	-14.89**	-8.29**	-0.34	-0.11	-0.68**	-2.04	0.89**	-10.005**
GPM-30	0.79*	0.47	5.51**	4.37**	2.55**	0.05	-0.38*	2.21*	4.64**	12.042**
GPM-38	-1.87**	-1.68**	-14.73**	-7.03**	-0.49	-0.068	-0.48**	-0.59	0.89**	-9.043**
GPM-43	2.63**	2.15**	14.84**	12.54**	-0.02	0.360**	0.22	0.47	1.31**	1.955
GPM-45	2.63**	2.15**	6.15**	-2.02	-0.14	-0.063	0.012	1.51	-4.35**	-9.673**
GPM-61	0.63	0.31	15.35**	8.54**	1.80**	0.167**	0.42*	3.06**	1.64**	-4.265
GPM-492	-0.37	-0.85*	-9.19**	0.3	0.59	0.167**	-0.481**	4.11**	0.81**	0.118
GPM-496	-1.53**	-0.35	6.61**	6.74**	0.12	0.002	-0.481**	-1.24	1.64**	-1.615
GPM-583	-0.53	-0.35	-14.18**	-10.49*	-1.64**	-0.303**	-0.38*	-1.04	-4.10**	-5.855
GPM-606	1.96**	1.48**	21.84**	15.87*	1.45**	0.30**	-0.58**	2.81**	7.89**	17.033**
GPM-608	-1.53**	-1.01**	-6.88**	-1.83	-0.95*	-0.64**	-0.38*	-3.14**	-7.11**	-6.677*
GPM-629	1.63**	1.31**	5.38**	2.67*	0.45	0.30**	-0.181	-1.59	5.39**	1.658*
GPM-640	-0.7	-0.69*	-3.92**	-0.69	0.6	0.02	0.319	0.76	0.64**	8.335*
GPM-642	1.79**	1.81**	17.38**	4.84**	0.5	0.18*	0.62**	-0.39	1.14**	2.542
GPM-666	-0.54	-0.35	1.65*	-2.42*	-2.99**	-0.31**	-0.38*	-3.79**	-3.60**	-9.785**
GPM-688	-1.53**	-1.19**	2.41**	2.04	0.53	0.22**	-0.18	2.76**	2.6**	1.992
GPM-701	0.63	0.31	-12.92**	-10.96*	0.2	-0.04	-0.08	-0.24	-1.35**	-10.92**
GPM-706	1.29**	1.15**	5.48**	-0.26	-1.29**	0.41**	0.92**	-4.84**	1.14**	-1.248
GPM-748	0.3	-0.02	-1.49*	-0.13	-1.87**	-0.04	0.92**	-1.74	-2.35**	-6.362*
GPM-759	-2.37**	-2.52**	-9.75**	-4.49**	-1.49**	0.332**	0.52**	-6.74**	2.39**	-3.562
GPM-114	-1.04**	-0.52	-7.82**	1.27	0.05	-0.02	-0.18	-1.24	1.89**	4.27
CAL-1426	2.30**	1.65**	-2.08**	-5.69**	0.88*	-0.36**	-1.18**	6.56**	-1.10**	-2.052
GPM-753	0.46	0.15	-3.220**	-3.96*	1.85**	0.30**	-0.08	2.66*	1.39**	-3.622
GPM-648	-4.203**	-2.8**	-20.92**	-10.29*	-2.99**	-0.58**	-0.28	-3.79**	-7.11**	2.528
KDMI-16	-1.370**	-0.354	-5.02**	-5.39**	-0.85	0.06	0.62**	-4.19**	1.89**	-9.842**
CI-4	-1.37*	-1.1**	-12.45**	-8.82**	0.128	-0.36**	0.12	-0.239	0.89**	-10.60**
GPM-56	2.13**	1.64**	20.41**	8.84**	0.68	0.002	0.92**	1.66	-0.27	5.15
S.Em. $\pm$	0.387	0.335	0.737	1.207	0.432	0.057	0.184	1.03	0.226	3.295
S.E (gi-gi)	0.548	0.473	1.043	1.707	0.611	0.08	0.26	1.457	0.319	4.6598
CD at 5%	0.766	0.662	1.459	2.389	0.856	0.112	0.364	2.039	0.446	6.5206
CD at 1%	1.012	0.875	1.9282	3.1579	1.133	0.1485	0.4809	2.6949	0.59	8.6176
<i>Testers</i>										
CM-111	-0.92**	-0.86**	-4.52**	-1.33**	-0.35**	-0.10**	-0.27**	-1.10**	0.34**	0.252
CM-202	0.92**	0.86**	4.52**	1.33**	0.35**	0.10**	0.27**	1.10**	-0.34**	-0.252
SEm $\pm$	0.097	0.084	0.184	0.302	0.108	0.014	0.046	0.257	0.056	0.8237
SE (gi-gi)	0.137	0.118	0.261	0.427	0.153	0.02	0.065	0.364	0.0798	1.1649
CD at 5%	0.192	0.166	0.365	0.597	0.214	0.028	0.091	0.51	0.112	1.6301
CD at 1%	0.2532	0.2188	0.4821	0.7895	0.2828	0.0371	0.1202	0.6737	0.1475	2.1544

Table 4. Estimates of specific combining ability effects of single cross hybrids for yield and yield related traits in maize (*Zea mays* L.)

Hybrids	Days to 50% tasseling	Days to 50% silking	Plant height (cm)	Ear height (cm)	Cob length (cm)	Cob girth (cm)	Kernel rows per cob	Kernels per row	100-grains weight (g)	Grain yield (q/ha)
GH-1801	-0.745	-0.135	-9.94*	-5.47*	- 1.26*	0.117	0.169	-2.748	3.164**	-1.131
GH-1802	0.745	0.135	9.945**	5.47*	1.261*	-0.117	-0.169	2.748	-3.164**	1.131
GH-1803	-0.078	-0.302	10.68**	4.330*	1.479*	-0.103	-0.131	3.702*	-0.836*	5.243
GH-1804	0.078	0.302	-10.68**	-4.330*	-1.479*	0.103	0.131	-3.70*	0.836**	-5.243
GH-1805	0.589	0.365	3.65**	-3.336	1.344*	0.157	-0.231	2.302	3.414*	-0.234
GH-1806	-0.589	-0.365	-3.65**	3.336	1.344*	-0.157	0.231	-2.302	-3.414**	0.234
GH-1807	0.422	0.531	-2.145*	0.464	0.231	0.102	-0.231	-1.398	0.914**	-6.307
GH-1808	-0.422	-0.531	2.145*	-0.464	0.231	-0.102	0.231	1.398	-0.914**	6.307
GH-1809	0.755	0.698	7.788**	2.664	1.154	-0.098	0.66*	0.852	0.414	4.929
GH-1810	-0.755	-0.698	-7.788**	-2.664	-1.154	0.098	-0.66*	-0.852	-0.414	-4.929
GH-1811	0.255	0.198	-5.01**	-3.336	-0.946	-0.033	0.169	-1.048	-3.336**	-14.76**
GH-1812	-0.255	-0.198	5.012**	3.336	0.946	0.033	-0.169	1.048	3.336**	14.75**
GH-1813	-0.411	-0.135	-3.145*	-2.736	-0.096	-0.033	0.069	0.402	-1.586**	1.049
GH-1814	0.411	0.135	3.145*	2.736	0.096	0.033	-0.069	-0.402	1.586**	-1.049
GH-1815	-0.745	-0.302	-3.86**	3.930*	-0.396	0.137	-0.031	0.002	1.664**	4.171
GH-1816	0.745	0.302	3.86**	-3.930*	0.396	-0.137	0.031	-0.002	-1.664**	-4.171
GH-1817	0.422	0.531	-2.012	-2.303	-1.121	-0.104	-0.131	-3.04*	0.247	-4.414
GH-1818	-0.422	-0.531	2.012	2.303	1.121	0.104	0.131	3.04*	-0.247	4.414
GH-1819	0.422	0.531	-2.245*	0.864	0.954	0.192*	0.069	0.802	4.41**	11.34*
GH-1820	-0.422	-0.531	2.245*	-0.864	-0.954	-0.19*	-0.069	-0.802	-4.41**	-11.338*
GH-1821	0.089	0.031	3.421**	0.63	-1.646*	-0.018	-0.53*	-1.648	-0.586	-11.58*
GH-1822	-0.089	-0.031	-3.421*	-0.63	1.646*	0.018	0.53*	1.648	0.586	11.584*
GH-1823	0.422	0.198	-4.245*	-3.403*	-1.52*	-0.098	0.169	-1.198	-1.25**	-4.607
GH-1824	-0.422	-0.198	4.245**	3.403*	1.521*	0.098	-0.169	1.198	1.25**	4.607
GH-1825	0.922	0.031	1.488	3.23	0.539	0.027	0.169	-0.448	-0.586	-4.024
GH-1826	-0.922	-0.031	-1.488	-3.23	-0.539	-0.027	-0.169	0.448	0.586	4.024
GH-1827	0.922	0.698	4.888*	1.13	-0.536	-0.028	-0.131	-0.148	-1.336**	8.289
GH-1828	-0.922	-0.698	-4.88**	-1.13	0.536	0.028	0.131	0.148	1.336**	-8.289
GH-1829	0.089	-0.135	5.58**	5.27**	-0.496	-0.123	0.67*	1.102	-1.336**	13.15**
GH-1830	-0.089	0.135	-5.58**	-5.29**	0.496	0.123	-0.67*	-1.102	1.336**	-13.14**
GH-1831	0.922	0.365	9.488**	5.59*	2.579**	0.117	-0.231	5.55**	0.497	4.296
GH-1832	0.078	0.302	-0.255	2.336	-0.754	-0.092	-0.069	-1.652	-2.664**	-1.654
GH-1833	0.745	0.135	9.945**	5.47*	1.261*	-0.117	-0.169	2.748	-3.164**	1.131
GH-1834	-0.089	-0.031	-3.921**	-3.897*	1.55*	0.263**	0.731*	4.598*	-0.164	-1.849
GH-1835	0.078	0.302	-10.68**	-4.330*	-1.479*	0.103	0.131	-3.70*	0.836**	-5.243
GH-1836	-0.422	-0.365	7.179**	5.80*	-1.35*	0.003	-0.169	-2.252	2.586**	7.921
GH-1837	-0.589	-0.365	-3.65**	3.336	1.344*	-0.157	0.231	-2.302	-3.414**	0.234
GH-1838	-0.255	-0.198	8.545**	7.87**	0.696.	0.058	0.331	1.598	-1.414**	1.261
GH-1839	-0.422	-0.531	2.145*	-0.464	0.231	-0.102	0.231	1.398	-0.914**	6.307
GH-1840	1.078	0.96*	0.479	2.33	-0.154	-0.107	0.131	-2.402	1.836**	-0.979
GH-1841	-0.755	-0.698	-7.788**	-2.664	-1.154	0.098	-0.66*	-0.852	-0.414	-4.93
GH-1842	0.411	0.469	11.04**	11**	-0.379	0.083	0.131	1.548	1.086**	3.994

Table 4 contd...

Hybrids	Days to 50% tasseling	Days to 50% silking	Plant height (cm)	Ear height (cm)	Cob length (cm)	Cob girth (cm)	Kernel rows per cob	Kernels per row	100-grains weight (g)	Grain yield (q/ha)
GH-1843	-0.255	-0.198	5.012**	3.336	0.946	0.033	-0.169	1.048	3.336**	14.76**
GH-1844	0.245	0.302	-0.555	0.136	-1.104	-0.172*	-0.169	1.148	-1.414**	0.949
GH-1845	0.411	0.135	3.145*	2.736	0.096	0.033	-0.069	-0.402	1.586**	-1.049
GH-1846	-0.089	-0.531	-7.35**	-9.23*	-0.949	0.008	-0.769*	-0.952	-0.914**	-23.19**
GH-1847	0.745	0.302	3.86**	-3.930*	0.396	-0.137	0.031	-0.002	-1.664**	-4.171
GH-1848	-0.089	-0.031	2.145*	-0.097	-0.679	0.043	0.431	-2.652	-0.414	-1.969
GH-1849	-0.422	-0.531	2.012	2.303	1.121	0.104	0.131	3.04*	-0.247	4.414
GH-1850	0.578	0.469	2.612*	0.736	0.946	-0.037	0.431	1.848	0.836**	8.927
GH-1851	-0.422	-0.531	2.245*	-0.864	-0.954	-0.19*	-0.069	-0.802	-4.41**	-11.34*
GH-1852	-0.422	-0.198	4.612**	4.70**	2.49**	0.038	-0.469	4.148**	6.336**	13.62**
GH-1853	-0.089	-0.031	-3.421*	-0.63	1.646*	0.018	0.53*	1.648	0.586	11.58*
GH-1854	-0.422	-0.365	-5.055**	-7.19**	-0.829	-0.026	0.531*	-1.952	-0.664*	-13.19**
GH-1855	-0.422	-0.198	4.245**	3.403*	1.521*	0.098	-0.169	1.198	1.25**	4.607
GH-1856	1.745**	1.469**	2.412*	-1.064	0.596	-0.077	-0.569*	0.748	-0.164	9.107
GH-1857	-0.922	-0.031	-1.488	-3.23	-0.539	-0.027	-0.169	0.448	0.586	4.024
GH-1858	2.078**	1.469**	-6.355**	-1.797	0.446	-0.017	0.231	-0.502	0.336	-8.169
GH-1859	-0.922	-0.698	-4.88**	-1.13	0.536	0.028	0.131	0.148	1.336**	-8.289
GH-1860	0.245	-0.031	-4.388**	-6.36*	0.546	-0.097	-0.469	0.998	0.336	-5.094
GH-1861	-0.089	0.135	-5.58**	-5.29**	0.496	0.123	-0.67*	-1.102	1.336**	-13.15**
GH-1862	-0.422	-0.531	3.245**	2.203	-1.279*	0.344**	0.231	-1.252	-1.664**	15.77**
GH-1863	0.922	0.365	9.488**	5.59*	2.579**	0.117	-0.231	5.55**	0.497	4.296
GH-1864	-0.922	-0.365	-9.488**	-5.59*	-2.579**	-0.117	0.231	-5.55**	-0.497	-4.296
SEm $\pm$	0.548	0.473	1.043	1.707	0.612	0.08	0.26	1.457	0.319	3.237
SE ($g_i - g_j$)	0.775	0.669	1.474	2.415	0.865	0.114	0.368	2.061	0.451	4.164
CD at 5%	1.084	0.936	2.063	3.379	1.211	0.159	0.515	2.884	0.631	9.222

for plant growth traits, i.e., plant height, GH-1842, followed by GH-1803, GH-1831, GH-1833, and GH-1863, showed significant *gca* values. For flowering traits, GH-1801, GH-1810, and GH-1824 were the earliest. GH-1858 and GH-1856 recorded significant *sca* effects but in an undesirable positive direction, which indicated they were very late for flowering. These findings are in parallel with the findings of Pavan *et al.* (2011); Kage *et al.* (2013); Katragadda *et al.* (2015); Matin *et al.* (2016) and Anilkumar *et al.* (2018).

Grouping of maize inbred lines into heterotic groups

The criteria suggested by Fan *et al.* (2009) were followed in grouping germplasm lines into different heterotic groups. The general combining ability effects and specific combining ability effects of the maize inbred lines and

crosses were used as the basis for classifying the lines into heterotic groups. The inbred lines showing negative HSGCA effects with the CM-111 tester (A) but having positive HSGCA effects with the CM-202 tester (B) were placed into the heterotic A group (Table 5). Similarly, the lines displaying a negative HSGCA effect with tester B but having positive HSGCA effects with tester A were put into the heterotic B group. Germplasm lines exhibiting positive HSGCA effects with both testers were assigned to the heterotic AB group. Also, lines exhibiting negative HSGCA effects with both testers were unclassified.

Like this, out of the 32 maize inbred lines used in the present study, eight lines showed negative HSGCA effects with tester CM-111 and were placed into the heterotic group A. Likewise, six germplasm lines were placed into heterotic group-B since they had negative HSGCA effects with tester CM-202 (Figure 1). Further, nine inbred lines

Table 5. Heterotic grouping using HSGCA method

Lines	GCA	Tester CM-111		Tester CM-202		HSGCA		Heterotic group
		GY (q/ha)	SCA	GY (q/ha)	SCA	CM-111	CM-202	
GPM-4	2.65	73.05	3.56	74.8	-3.56	6.20	-0.91	B
GPM-13	-3.81	72.96	4.93	61.97	-4.93	1.12	-8.74	B
GPM-16	2.87	74.17	-0.55	74.13	0.55	2.33	3.42	AB
GPM-18	20.32	85.54	-6.62	97.65	6.62	13.70	26.94	AB
GPM-27	25.47	101.93	4.62	91.56	-4.61	30.09	20.86	AB
GPM-28	-10.01	46.77	-5.06	75.76	5.06	-15.07	-4.95	-
GPM-30	12.04	84.62	0.74	82.02	-0.74	12.78	11.31	AB
GPM-38	-9.04	66.66	3.86	57.81	-3.86	-5.19	-12.90	-
GPM-43	1.96	69.07	-4.77	77.4	4.77	-2.82	6.73	A
GPM-45	-9.67	73.19	1.03	50.01	-1.03	-8.65	-10.70	-
GPM-61	-4.27	55.68	-11.89	78.34	11.89	-16.16	7.63	A
GPM-492	0.12	67.04	-4.92	75.75	4.92	-4.80	5.04	A
GPM-496	-1.62	65.89	-4.34	73.43	4.34	-5.95	2.72	A
GPM-583	-5.86	73.97	-7.02	56.88	7.02	-12.88	1.17	A
GPM-606	17.03	101.71	12.84	74.91	-12.84	29.87	4.20	AB
GPM-608	-6.68	66.5	16.34	62.69	-16.34	9.67	-23.02	B
GPM-629	1.66	75.04	1.54	70.83	-1.54	3.20	0.12	AB
GPM-640	8.34	71.94	-8.23	87.28	8.23	0.10	16.57	AB
GPM-642	2.54	72.81	-1.57	74.83	1.57	0.97	4.12	AB
GPM-666	-9.79	62.72	0.67	60.26	-0.67	-9.12	-10.45	-
GPM-688	1.99	69.53	-4.31	77.01	4.31	-2.32	6.30	A
GPM-701	-10.91	59.67	7.07	61.06	-7.07	-3.84	-17.98	-
GPM-706	-1.25	93.48	22.88	46.58	-22.88	21.64	-24.13	B
GPM-748	-6.36	67.14	-5.01	62.69	5.01	-11.37	-1.35	-
GPM-759	-3.56	59.04	-9.24	76.39	9.24	-12.80	5.68	A
GPM-114	4.27	62.17	-13.95	88.93	13.94	-9.68	18.21	A
CAL-1426	-2.05	82.68	7.89	55.77	-7.89	5.84	-9.94	B
GPM-753	-3.62	58.8	-2.75	76.51	2.75	-6.38	-0.87	-
GPM-648	2.53	82.22	2.86	65.38	-2.86	5.39	-0.33	B
KDMI-16	-9.84	66.78	4.78	56.09	-4.78	-5.06	-14.62	-
CI-4	-10.60	45.2	-9.37	76.15	9.37	-19.98	-1.23	-
GPM-56	5.15	80.98	3.98	71.88	-3.98	9.14	1.17	AB

were assigned to the AB group since they had positive HSGCA effects with both testers. While nine lines were unclassified since they had negative HSGCA effects with both testers, A similar method was adopted by Menkir *et al.* (2004); Akinwale *et al.* (2014); Oyetunde *et al.* (2020) and Nandan *et al.* (2021) for heterotic grouping.

Among the lines, 16 lines recorded a positive *gca* effect for grain yield based on their interaction with the testers CM-111 and CM-202 and were grouped into different heterotic groups like A, B, and AB (Table 6). Within heterotic

group 'A', GPM-114 recorded the highest *gca* of 4.27 and a mean grain yield of 75.54 q/ha, followed by GPM-48 and GPM-688, which were on par with respect to *gca* and mean grain yield. Similarly, in heterotic group 'B', GPM-706 recorded the highest *gca* of 4.16 with a mean grain yield of 70.02 q/ha. However, GPM-04 and GPM-648 were on par with GC status and mean grain yield. As opined by Elmyhun *et al.* (2020), desirable hybrids can be generated by crossing lines from opposite heterotic groups, in this case GPM-114 and GPM-706, and for population

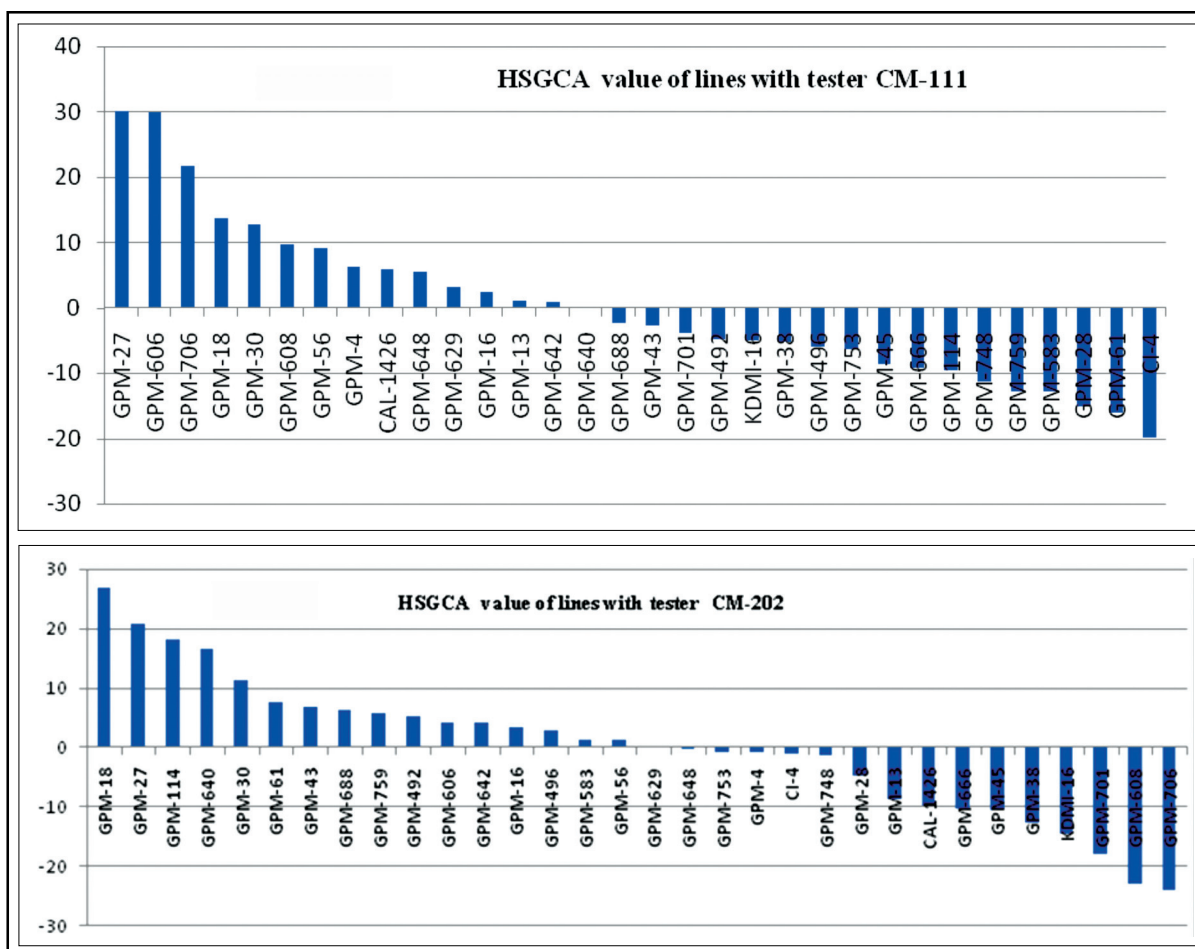


Figure 1. HSGCA value of lines with tester 1 (CM-111) (heterotic group “B”) and tester-2 (CM-202) (heterotic group “A”)

Table 6. Top performing lines for general combining ability (*gca*) in each heterotic group

Lines	Heterotic group	<i>gca</i> status of lines for grain yield	Mean grain yield (q/ha) in cross combination with two testers
GPM-27	AB	25.5	96.7
GPM-18	AB	20.3	91.6
GPM-606	AB	17.0	88.3
GPM-30	AB	12.0	83.3
GPM-640	AB	8.3	79.6
GPM-56	AB	5.2	76.4
GPM-114	A	4.3	75.5
GPM-706	B	4.2	70.0
GPM-16	AB	2.9	74.1
GPM-04	B	2.6	73.9
GPM-648	B	2.5	73.8
GPM-642	AB	2.5	73.8
GPM-43	A	2.0	73.2
GPM-688	A	2.0	73.3
GPM-629	AB	1.7	72.9
GPM-492	A	0.1	71.4

improvement and development of synthetics, the lines with high *gca* within the heterotic can be intercrossed, viz., GPM-114, GPM-43, GPM-688 and GPM-492.

Conclusion

Significant general and specific combining ability effects were found among the selected maize inbred lines. Line GPM-27 (25.468) was identified as a good general combiner among the 32 inbred lines. Whereas, the two crosses, viz., GPM-706 X CM-111 and GPM-606 X CM-111, recorded good specific combining ability effects. Heterotic grouping of 32 maize inbred lines based on the HSGCA method revealed that 11 germplasm lines were grouped into heterotic group A, 12 lines were grouped into heterotic group B, and nine of them were grouped into heterotic group AB. Based on this information, line GPM-114 from heterotic group A can be crossed with line GPM-706 from heterotic group B to get a heterotic hybrid combination.

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