Combining ability and heterosis study for yield and it's attributing traits in maize (*Zea Mays* L.)

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Abstract

Combining ability and heterosis was studied in maize for grain yield and its attributing traits using line x tester mating design. Significant general and specific combining ability variances were observed for all the characters studied indicating the importance of both additive and non-additive gene action for the expression of these traits. Among the parents GPM-4, GPM-38, GPM-608, GPM-688, GPM-759, GPM-648 and CI-4 were found to be good general combiners for days to 50% tasseling and days to 50% silking. Similarly, GPM-18, GPM-27, GPM-30 and GPM-606 were good combiners for grain yield. Among the test hybrids GH-1834 and GH-1813 were found to be promising recording significant SCA effects for Number of kernels/ row, cob length and cob girth. whereas, for 100 seed weight GH-1852 and GH-1819 and for grain yield GH-1862, GH-1843,GH-1852 and GH-1829 were found to be promising. Similarly, among the 64 F1 hybrids significant economic heterosis of 21.0 and 6.46 per cent over National and Popular private hybrid check was recorded by both the test hybrids GH-1809 and GH-1829 respectively. GGE biplot technique was used to understand the interrelationship between genotypes, testers and their interaction and it could explain the variation through two components PC1 (55.28 %) and PC2 (44.72 %). The parental line L5 (GPM-27) which falls on the ATC absicca showed the highest GCA effects for grain yield followed by L7 (GPM-30). Likewise, among the two testers CM-111 was able to discriminate more number of genotypes.

Abbreviations

AICRP=All India Coordinated Research programme
ANOVA=Analysis of Variance
ARS=Agricultural Research Station
CC=Commercial Check
CIMMYT= International Maize and Wheat Improvement programme
COMH=Coimbatore Maize Hybrid
GCA=General Combining Ability
GGE= Genetic, Genetic x Environment
IIMR=Indian Institute of Maize Research
SCA=Specific Combining Ability
UAS =University of Agricultural Sciences, Dharwad

Introduction

Globally, maize is amongst the most widely produced and consumed cereal crops with a production of about 1.15 billion MT from an area of 197 million ha across 170 countries and contributing to the extent of 27% of the area and 39% to the global cereal grain production and further it is estimated that by 2030 the farms cultivating maize will increase by 5 % whereas, wheat by 4 % (Erenstein, 2021). During 2019 global consumption of the top three cereals (maize, wheat and rice) stood at 2,365 million MT of which maize held about 48% share. Over the last decade (2009 to 2019) both global production as well as consumption has increased at a CAGR of about 3.4% (Yes bank & FICCI report, 2021). India ranks 4th and 7th in terms of global maize acreage and production and occupying 4.6% of the global maize area and 2.4% of the production respectively. Maize is the 3rd most important cereal crop in Inida (after rice and wheat) and also it is the fastest growing cereal crop in terms of area, production as well as productivity. Over the last decade, maize consumption in India grew at a CAGR of 5.6% while production grew at just about 2.9%. A combination of high market demand as the feed industry is growing at a CGAR of 9 % (FICCI, Maize Vision document,2022) with comparatively low cost of production and higher yield potential of maize crop is encouraging many farmers to take up maize cultivation. The Projected demand for maize production

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

Source of variation	DF	Days to 50 per cent tasselling	Days to 50 per cent silking	Plant height (cm)	Ear height (cm)	Number of kernel rows per cob	Number of kernels per row	Cob girth (cm)	Cob length (cm)	Hundred grain weight (g)	Grain Yield (q/ha)
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 within 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

Significant at 5 % level of probability

by 2050 in India is around 121 mt (Raju *et al.*, 2018). However, the area under maize is 9.26 m.ha and further scope for area expansion is limited and it becomes imperative to explore for yield expansion only. And yield expansion can be achieved through high yielding and heterotic hybrids, through improved crop management practices including production and protection measures. Among these, high yielding heterotic hybrids can be a major contributor to yield expansion because maize productivity in India is at 2.6 t/ha as compared to 5.6 t/ha at Global level. Therefore there is tremendous scope to increase the maize productivity. Since maize is highly cross pollinated crop and crop breeders have successfully demonstrated and exploited heterosis commercially by which the productivity has increased 4 times in India from 1955-56 to 2019-20. The quest for high yielding and heterotic hybrids is a continuous process as new inbred lines /germplasm/genetic material is infused into the breeding programme.

Inbred lines are pre-requisite for hybrid development in maize. Combining ability analysis is of special importance in cross-pollinated crops like maize as it helps in identifying potential parents that can be used for producing hybrids and synthetics (Vasal, 1998). The nature and magnitude of gene action is an important factor in developing an effective breeding program, which can

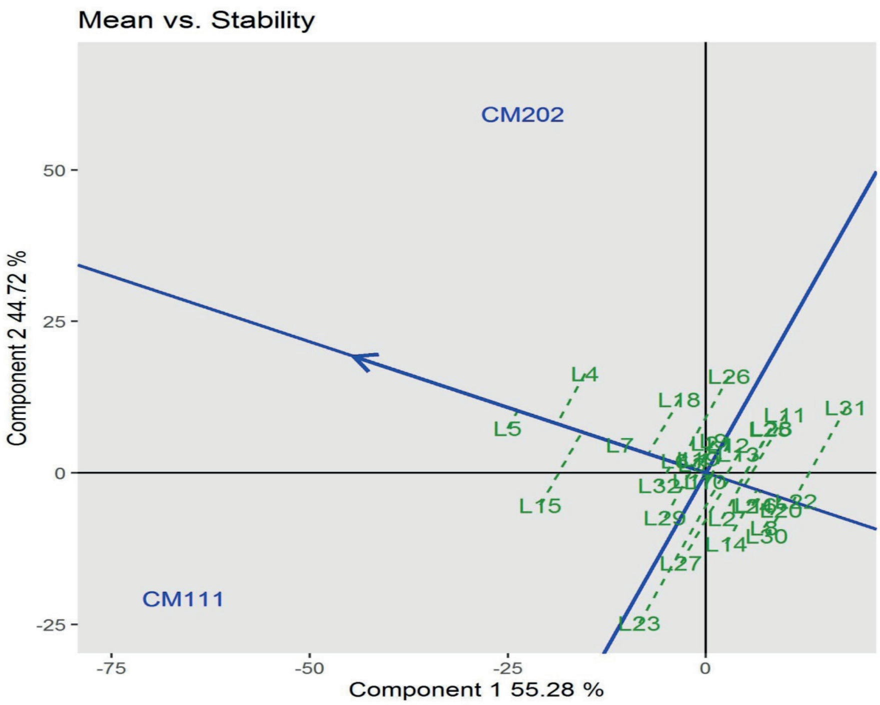

Fig. 1 - GGE biplot showing components 1 and 2 explaining 100 per cent of the total variation (ATC biplot) for grain yield

Table 2 - Analysis of variance for combining ability in maize for grain yield and its component traits

Source of variation	d.f.	Days to 50 per cent tasselling	Days to 50 per cent silking	Plant height (cm)	Ear height (cm)	Number of kernel rows per cob	Number of kernels per row	Cob girth (cm)	Cob length (cm)	Hundred grain weight (g)	Grain Yield (q/ha)
Lines	31	14.95*	9.096*	659.09*	251.87*	1.67*	50.73*	0.44*	9.97*	62.59*	1099.16*
Testers	1	128.76*	113.64*	3254.6*	323.3*	10.13*	159.70*	1.77*	15.79*	21.66*	93.00*
crosses	63	10.369*	6.756*	442.85*	181.87*	1.362*	38.72*	0.284*	8.09*	40.90*	701.26*
Lines x Testers	31	2.111*	1.070*	151.90*	108.58*	0.74*	22.43*	0.077*	5.96*	19.84*	332.03*
Error	111	0.773	0.735	26.45	12.77	0.309	8.66	0.028	1.61	1.936	22.35
Total	237	156.26	131.29	4534.89	878.39	14.211	280.24	2.59	41.42	146.92	2247.80

* - Significant at 5 % level of probability

be understood through combining ability analysis. This information is helpful to plant breeders for formulating hybrid breeding program. Similar the information on Heterosis is essential for developing a good and economically viable maize hybrid. The phenomenon of heterosis has been exploited extensively in crop breeding, leading to significant increase in yield.

Therefore, the present study was undertaken to study the combining ability among the parental lines and heterosis among the newly generated cross combinations using line x tester mating design.

Material and methods

Genetic material

The present study comprised of 32 diverse maize germplasm lines collected from IIMR / CIMMYT and maintained at AICRP on Maize, MARS, UAS, Dharwad. These lines were crossed with two testers (CM-111 and CM-202) in line x tester mating design during the rabi season, 2018-19.

Field evaluation

The 64 F_1 hybrids along with checks [GH-0727 (LC) / CoMH-08-282(NC) /900 M G (PC)] were evaluated in alpha lattice design (10 x7) in the field with three replications at AICRP on Maize, UAS Dharwad during kharif season, 2019-20. Each entry was planted in two rows of 4 m length by following a spacing of 60 cm between rows and 20 cm between plant to plant. All the recommended agronomic package were followed to raise a healthy crop and care was taken to maintain optimum plant population.

In order to understand the genetic difference between the test hybrids and to identify superior hybrid combination, the phenotypic data was collected on twelve quantitative traits. Among them, observations on 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 and for days to 50 per cent tasseling and days to 50 percent silking the obser-

Table 3 - Magnitude of genetic variance for different maize traits

Sl. No.	Characters	σ^2GCA	σ^2 SCA	σ^2GCA/ σ^2SCA	σ^2A	σ^2D	σ^2A/σ^2D
1	DFT	1.48	3.80	0.380	2.9	3.80	0.78
2	DFS	1.13	5.67	0.199	2.27	5.67	0.40
3	PHT	45.67	62.05	0.73	91.34	62.05	1.47
4	EHT	5.97	38.62	0.015	11.94	38.62	0.31
5	NKR	0.15	0.21	0.71	0.29	0.21	1.38
6	KPR	2.66	7.78	0.34	5.32	7.78	0.68
7	CL	0.02	0.022	0.90	0.05	0.022	2.27
8	CG	0.31	2.27	0.13	0.62	2.27	0.27
9	HGW	0.89	8.48	0.10	1.77	8.48	0.02
10	GY	12.53	124.49	0.10	25.06	124.49	0.02

DFT= Days to 50 per cent tasseling, DFS= Days to 50 per cent silking, PHT= Plant height (cm), EHT=earheight (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 4 - General combining ability (GCA) effects for different characters in maize

Parents	Days to 50 per cent tasselling	Days to 50 per cent silking	Plant height (cm)	Ear height (cm)	Number of kernel rows per cob	Number of kernels per row	Cob girth (cm)	Cob length (cm)	Hundred grain weight (g)	Grain Yield (q/ha)
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	-0.20	-0.52	-14.89**	-8.29 **	-0.34	-0.11	-0.68 **	-2.04	0.89 **	-10.05 **
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**	0.30	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**	-0.30**	-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	-0.70	-0.69*	-3.92**	-0.69	0.60	0.02	0.319	0.76	0.64 **	8.335*
GPM-642	1.79**	1.81**	17.4**	4.84**	0.50	0.18*	0.62 **	-0.39	1.14**	2.542
GPM-666	-0.54	-0.35	1.65*	-2.42*	-2.9 **	-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	-12.9**	-10.9 *	0.20	-0.04	-0.08	-0.24	-1.35 **	-10.92 **
GPM-706	1.29 **	1.15 **	5.48**	-0.26	-1.3**	0.41**	0.92 **	-4.84 **	1.14 **	-1.248
GPM-748	0.30	-0.02	-1.49*	-0.13	-1.8 **	-0.04	0.92 **	-1.74	-2.35 **	-6.362*
GPM-759	-2.37**	-2.52 **	-9.75**	-4.49 **	-1.5**	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 **	4.270
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	-3.22**	-3.96 *	1.85 **	0.30**	-0.08	2.66 *	1.39 **	-3.622
GPM-648	-4.20**	-2.8 **	-20.9**	-10.3*	-2.9 **	-0.58**	-0.28	-3.79**	-7.11 **	2.528
KDMI-16	-1.370**	-0.354	-5.02**	-5.39**	-0.850	0.06	0.62**	-4.19 **	1.89**	-9.842 **
CI-4	-1.37*	-1.1 **	-12.5**	-8.82**	0.128	-0.36**	0.12	-0.239	0.89 **	-10.60 **
GPM-56	2.13**	1.64 **	20.4**	8.84 **	0.68	0.002	0.92**	1.66	-0.27	5.15
S.Em. +	0.387	0.335	0.737	1.207	0.432	0.057	0.184	1.030	0.226	3.295
C.D. at 5 %	0.766	0.662	1.459	2.389	0.856	0.112	0.364	2.039	0.446	6.5206
C.D. at 1 %	1.012	0.8750	1.9282	3.1579	1.133	0.1485	0.4809	2.6949	0.5900	8.6176

vations were recorded on plot basis.

Statistical analysis

The data was compiled and the replicated data was used for Analysis of variance using R software program. Combining ability analysis was carried out according to the model suggested by Kempthorne (1957) using Windostat software and percent heterosis was calculated by using the following formula.

Heterosis over check (standard heterosis) = $(F_1\text{-CC/CC}) \text{ x}100$

Where, F_1 = Mean performance of F_1, CC = Mean performance of the best commercial check

In the present study, the biplot data was generated using GGEBiplot package of R Software version 3.6.2

Results and Discussion

Analysis of variance

The mean sum of squares (Table 1) showed that the genotypes recorded significant variance for all the quantitative traits under study indicating that their existed good amount of genetic differences among the genotypes and this a pre-requist for any crop improvement study. Among the different quantitative traits the difference between the genotypes was highest for grain yield followed by plant height whereas, it was very low for number of kernel rows per cob.

Table 5 - Specific combining ability (SCA) effects for different characters in maize

Hybrids	Days to 50 per cent tasselling	Days to 50 per cent silking	Plant height (cm)	Ear height (cm)	Number of kernel rows per cob	Number of kernels per row	Cob girth (cm)	Cob length (cm)	Hundred grain 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
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 *

Table 5 - Specific combining ability (SCA) effects for different characters in maize

Hybrids	Days to 50 per cent tasselling	Days to 50 per cent silking	Plant height (cm)	Ear height (cm)	Number of kernel rows per cob	Number of kernels per row	Cob girth (cm)	Cob length (cm)	Hundred grain weight (g)	Grain Yield (q/ha)
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
S.Em. +	0.548	0.473	1.043	1.707	0.612	0.08	0.26	1.457	0.319	3.237
S.E (gi-gj)	0.775	0.669	1.474	2.415	0.865	0.114	0.368	2.061	0.451	4.164
C.D. at 5 %	1.084	0.936	2.063	3.379	1.211	0.159	0.515	2.884	0.631	9.222

GCA and SCA variance

The existence of significant genetic variance in the experimental material under evaluation, encouraged to go for the combining ability analysis, which enables the partitioning of genotypic variation among the hybrids into variation due to lines, testers and lines x tester interaction (Table 2). ANOVA for combining ability indicated that the lines, testers, crosses and lines x tester interactions differed significantly for all the traits. However, it was lines which contributed significantly more towards the total variance for the traits grain yield and 100 seed weight. Whereas, for other yield contributing traits of number of kernels/row, number of kernels/row, cob length and cob girth the contribution of testers was more. Overall the contribution of crosses and line x tester interaction to the total variation was low for all the traits except for grain yield.

The magnitude of genetic variance (Table 3) revealed that the SCA variance was higher than GCA variance for all the characters. Apart from that the magnitude of SCA variance was high for grain yield, hundred seed weight and ear height when compared to the corresponding GCA variance indicating higher proportion of non-additive genetic variance was responsible for controlling these traits in the test hybrids. The results obtained in the present study are in confirmation with the results obtained in maize by Kanagarasu *et al.*, 2010 and Abrha *et al.*, 2013. The ratio of GCA/ SCA variance was less than unity for all the traits confirming the preponderance of non-additive gene action governing these traits. Further, the estimates of dominance variance and ratio of additive / dominance variance for grain yield, hundred seed weight and number of kernels/ row also indicated that hybrid breeding approach would be useful in exploitation of these traits in yield enhancement.

General combining ability (GCA) effects

The combining ability effects among the parental lines (Table 4) revealed that for maturity traits, GPM-4, GPM-38, GPM-608, GPM-688, GPM-759 and GPM-648 recorded significant GCA effects in desirable negative direction and were found to good combiners for earliness. These lines form the source to develop early maturing hybrids or may be intercrossed to develop a base population to derive early maturing inbred lines. Similarly, for plant growth traits the parental lines GPM-606, GPM-27, GPM-43, GPM-61, GPM-642, GPM-61 and GPM-56 recorded significant GCA effects in desirable positive direction (Fig:3) and for major yield contributing traits the parental lines GPM-61, GPM-30, GPM-606 and GPM-753 were found to good general combiners. For grain yield GPM-18, GPM-27, GPM-30 and GPM-606 recorded significantly highest GCA effects in desirable positive direction indicating that these lines have favourable alleles for yield, hence these lines can be used in further either as parents in hybrid crossing programme or in population improvement programme by creating a heterotic pool of genotypes with favourable alleles for grain yield. Among these promising lines for yield, GPM-27 recorded highest gca effects for grain yield, whereas, GPM-606 recorded highest gca

Table 6 - Mean performance of hybrids for different characters in maize

Hybrids	Days to 50 per cent tasseling	Days to 50 per cent silking	Plant height (cm)	Ear height (cm)	Number of kernel rows per cob	Number of kernels per row	Cob girth (cm)	Cob length (cm)	Hundred grain weight (g)	Grain yield (q/ha)
GH-1801	56.67	60.00	136.47	58.6	12.6	30.8	4.04	15.02	31.00	73.05
GH-1802	60.00	62.00	165.40	72.2	12.8	38.5	4.01	18.25	24.00	74.80
GH-1803	59.67	61.00	154.13	65.8	13.8	39.9	4.60	17.75	31.00	72.96
GH-1804	61.67	63.33	141.80	59.8	14.6	34.7	5.01	15.5	32.00	61.97
GH-1805	62.00	63.00	152.00	66.8	12.6	37.9	4.60	17.28	37.50	74.17
GH-1806	62.67	64.00	153.73	76.1	13.6	35.5	4.49	15.3	30.00	74.13
GH-1807	61.67	63.33	157.00	75.7	13	31.5	4.71	15.8	36.50	85.54
GH-1808	62.67	64.00	170.33	77.5	14	36.5	4.71	16.97	39.00	97.65
GH-1809	62.33	63.67	165.07	74.9	13.6	36.8	4.51	19.05	40.00	101.93
GH-1810	62.67	64.00	158.53	72.3	12.8	37.3	4.91	17.45	38.00	91.56
GH-1811	60.33	61.67	127.73	54.1	12.4	30.1	4.30	14.65	32.00	46.77
GH-1812	61.67	63.00	146.80	63.4	12.6	34.4	4.57	17.25	38.00	75.76
GH-1813	60.67	62.33	150.00	67.3	12.6	35.8	4.46	18.4	37.50	84.62
GH-1814	63.33	64.33	165.33	75.5	13	37.2	4.73	19.3	40.00	82.02
GH-1815	57.67	60.00	129.04	62.6	12.4	32.6	4.51	15.05	37.00	66.66
GH-1816	61.00	62.33	145.80	57.4	13	34.8	4.44	16.55	33.00	57.81
GH-1817	63.33	64.67	160.47	75.9	13	30.6	4.70	14.8	36.00	69.07
GH-1818	64.33	65.33	173.53	83.2	13.8	38.9	5.11	17.75	34.83	77.40
GH-1819	63.33	64.67	151.53	64.5	13	35.5	4.57	16.75	34.50	73.19
GH-1820	64.33	65.33	165.07	65.5	13.4	36.1	4.39	15.55	25.00	50.01
GH-1821	61.00	62.33	166.40	74.9	12.8	34.6	4.59	16.1	35.50	55.68
GH-1822	62.67	64.00	168.60	76.3	14.4	40.1	4.83	20.1	36.00	78.34
GH-1823	60.33	61.33	134.20	62.6	12.6	36.1	4.51	15	34.00	67.04
GH-1824	61.33	62.67	151.73	72.1	12.8	40.7	4.91	18.75	35.83	75.75
GH-1825	59.67	61.67	155.73	75.7	12.6	31.5	4.47	16.6	35.50	65.89
GH-1826	59.67	63.33	161.80	71.9	12.8	34.6	4.62	16.23	36.00	73.43
GH-1827	60.67	62.33	138.33	56.3	12.4	32	4.11	13.77	29.00	73.97
GH-1828	60.67	62.67	137.60	56.7	13.2	34.5	4.37	15.55	31.00	56.88
GH-1829	62.33	63.33	175.07	86.9	13	37.1	4.62	16.9	41.00	101.71
GH-1830	64.00	65.33	172.93	78.9	12.2	37.1	5.07	18.6	38.00	74.91
GH-1831	58.67	60.67	141.00	61.5	12.6	31.7	3.89	15.75	30.00	66.50
GH-1832	60.67	63.00	149.53	68.9	13	30.6	3.91	14.95	24.00	62.69
GH-1833	62.00	63.33	156.93	72.3	12	27	4.48	14.85	40.00	75.04
GH-1834	63.67	65.00	158.13	67.1	14	38.4	5.21	18.65	39.00	70.83
GH-1835	60.00	61.67	136.53	59.2	13.4	36.2	4.46	17.9	32.50	71.94
GH-1836	61.00	62.67	159.93	73.5	13.6	33.9	4.67	15.9	37.00	87.28
GH-1837	62.33	64.00	156.47	62.7	13.2	31.2	4.50	15.75	37.00	72.81
GH-1838	63.67	65.33	182.60	81.1	14.4	36.6	4.82	17.85	33.50	74.83
GH-1839	58.67	60.67	148.80	60.9	12.4	31.8	4.24	13.1	29.00	62.72
GH-1840	62.67	64.33	158.80	68.3	13.2	29.2	4.23	13.5	32.00	60.26
GH-1841	58.33	60.33	139.00	56.7	12.6	34.4	4.58	16.85	36.00	69.53
GH-1842	61.00	63.00	170.13	81.5	13.4	39.7	4.95	16.8	37.50	77.01
GH-1843	60.67	62.00	135.27	54.6	13	31.8	4.57	17.25	34.50	59.67
GH-1844	63.00	64.33	143.20	57.5	13.2	36.3	4.43	15.75	31.00	61.06
GH-1845	61.67	63.67	160.47	74.7	14.6	35.00	4.84	15.6	39.00	93.48
GH-1846	63.33	64.33	154.80	58.9	13.6	29.6	5.06	14.41	34.00	46.58
GH-1847	60.67	62.00	144.00	65.7	13.4	34.1	4.36	14.75	32.50	67.14
GH-1848	62.33	63.67	157.33	68.1	14.8	31	4.65	14.1	31.00	62.69
GH-1849	57.33	59.00	135.27	60.5	13	24.6	4.81	13.5	36.00	59.04
GH-1850	60.33	61.67	149.53	64.6	14.4	30.5	4.94	16.1	37.00	76.39
GH-1851	59.67	61.67	135.20	62.3	13.2	27.8	4.38	13.5	30.00	62.17

Table 6 - Mean performance of hybrids for different characters in maize

Hybrids	Days to 50 per cent tasseling	Days to 50 per cent silking	Plant height (cm)	Ear height (cm)	Number of kernel rows per cob	Number of kernels per row	Cob girth (cm)	Cob length (cm)	Hundred grain weight (g)	Grain yield (q/ha)
GH-1852	60.67	63.00	153.47	74.3	12.8	38.3	4.66	19.2	42.00	88.93
GH-1853	63.00	64.00	150.60	67.2	11.2	41.7	4.11	17.65	34.00	82.68
GH-1854	64.00	65.00	149.53	55.5	12.8	40	4.26	16.7	32.00	55.77
GH-1855	59.00	60.67	142.00	62.8	13.4	35.1	4.82	17.2	36.00	58.80
GH-1856	64.33	65.33	155.87	63.3	12.8	38.8	4.87	19.1	35.00	76.51
GH-1857	54.00	57.67	133.07	57.2	12.4	29.9	3.88	12.5	27.00	82.22
GH-1858	60.00	62.33	129.40	56.3	13.4	31.1	4.05	14.1	27.00	65.38
GH-1859	58.67	61.67	147.00	66.7	14	28	4.60	14.55	36.00	66.78
GH-1860	61.00	63.33	147.27	56.6	13.6	32.2	4.61	16.35	36.00	56.09
GH-1861	59.33	61.33	131.93	54.7	12.8	34.2	3.74	17.35	37.00	45.20
GH-1862	60.33	62.00	147.47	61.7	13.8	33.9	4.63	15.5	33.00	76.15
GH-1863	63.33	64.00	177.53	80.1	13.6	40.4	4.56	19.2	34.00	80.98
GH-1864	63.33	65.00	167.60	71.6	14.6	31.5	4.53	14.75	33.00	71.88
COMH- 0282	61.67	62.67	160.80	67.1	13.8	33.9	4.97	18.65	37.00	84.89
GH-0727	55.67	58.67	150.80	69.7	12.8	29.4	4.33	13.35	35.00	55.01
900-MG	62.33	63.33	144.73	67.4	13.8	34.5	5.09	15.2	37.00	95.74
MEAN	61.2	62.8	152.6	67.3	16.3	34.3	4.6	13.2	34.5	72.1
S.Em. +	0.3	0.2	1.0	0.3	0.2	0.0	0.1	0.4	0.5	1.6
CD at 5%	0.7	0.6	2.7	0.9	0.6	0.1	0.2	1.2	1.4	4.5
CV	3.5	2.7	12.1	2.6	11.0	7.1	5.2	10.8	11.7	18.8

effects for test weight and cob length and GPM-30 for number of kernel rows/cob. Amiruzzaman *et al.* (2010), Kage *et al*. (2013) and Ofori *et al.* (2015) have also identified promising inbred lines with significant gca effects for different traits from their study in maize.

Specific combining ability (SCA) effects

The specific combining ability effects (SCA) among the hybrids (Table 5) revealed that none of the hybrids recorded significant SCA effects for maturity traits (days to 50% tasselling and days to 50% silking) indicating the role of both additive and non-additive genes in expression of the traits. For plant aspect traits i.e., plant height and ear height out of the 64 test hybrids 12 of them recorded significant SCA effects in desirable positive direction and among them GH-1833 recorded highest SCA effects for plant height and was also the tallest as evident from the mean plant height of 182.0 cm (Table 6) as compared to the best hybrid check at 160.0 cm. For yield contributing traits GH-1834 and GH-1813 were found to be promising recording significant SCA effects for Number of kernels/ row, cob length and cob girth for test weight GH-1852 and GH-1819. Likewise for grain yield GH-1862, GH-1843,GH-1852 and GH-1829 recorded significantly highest sca effects in desirable positive direction and were found promising. However, it was only GH-1829 which also recorded highest mean grain yield of 101.71 q/ha and was significantly superior to National check hybrid CoMH-08-282 (84.89 q/ha). Among all the test hybrids, GH-1852 recorded significant sca effects for majority of the traits. However, the results from the present study differ from the results of Arifin *et al.*,2018 who opined that the crosses with highest SCA for grain yield also recorded high mean grain yield and along with significant SCA effects for most of the yield contributing characters. But according to Fashat *et al.*, 2016 parental choice on the basis of SCA effect has limited value in breeding programs. Therefore, SCA effect should be used in combination with a high *per se* performance of the hybrid. Significant SCA estimates involving at least one parent with high GCA is desirable and in this study, GH-1829 had female parent (GPM-606) with GCA effect (17.03) for grain yield.

GGE Biplot

GGE biplot is a graphical representation of genotype main effect and genotype by environment interaction by two-way data. This can also be used to graphically view both the entries and the testers of two-way data and to understand the interrelationship between genotypes, testers and the interaction between entries and testers (Yan and Hunt, 2002).For a comprehensive assessment of GCA and SCA effects, line x tester cross analysis is the most popular method developed by Kempthorne (1957). Yan and Hunt (2002) suggested the use of the GGE biplot technique and principal component for the line x tester data for assessing GCA and

Table 7 - Standard heterosis of experimental hybrids in respect of different quantitative characters in maize

No.	Characters	Over CoMH-08-282		Over GH-0727		Over 900-MG		Best Hybrid based on significant heterosis with mean value
		Range	No. of hybrids in desirable direction	Range	No. of hybrids in desirable direction	Range	No. of hybrids in desirable direction	
1	Days to 50 % tasseling	-12.44 to 4.32	16	-3.0 to 15.56	01	-12.90 to 3.76	20	GH-1857 (54.0)
2	Days to 50 % silking	-5.86 to 4.25	09	-1.59 to 11.48	01	-8.94 to 3.16	21	GH-1857 (58.0)
3	Plant height (cm)	-20.56 to 13.56	13	-15.30 to 21.09	29	-11.74 to 26.17	39	GH-1838 (182.60)
4	Ear height (cm)	-19.42 to 29.46	21	-22.43 to 24.63	14	-18.99 to 28.88	18	GH-1829 (86.9)
5	Number of kernel rows per cob	-18.84 to 7.25	04	-12.50 to 15.63	18	-18.84 to 7.25	03	GH-1848 (14.8)
6	Number of kernels per row	-27.4 to 23	11	-16.3 to 41.8	39	-28.70 to 20.90	08	GH-1853 (41.7)
7	Cob girth (cm)	-24.8 to -4.80	00	-13.70 to 20.3	32	-26.6 to -4.9	0	GH-1834 (5.21)
8	Cob length(cm)	-32.98 to -9.38	00	12.36 to 50.56	46	-17.76 to 32.74	17	GH-1852, GH-1863 (19.2)
9	Hundred grain yield (g)	-35.14to 10.81	3	-31.43 to 22.86	25	-35.14 to 16.22	07	GH-1852 (42.0)
10	Grain yield (q/ha)	-46.19 to 21.34	02	28.79 to 85.32	34	-52.79 to 6.46	0	GH-1809 (101.93) GH-1829 (101.71)

SCA on two-dimensional plain.

GGE biplot explains 100 % of the variation through two components PC1 and PC2, and in this analysis where PC1 explained about 55.28 % and PC2 about 44.72 % (Fig. 1). An average tester coordinate (ATC) was established to analyze the GCA result of the lines and SCA of crosses for grain yield. According to Yan and Kang (2003), the line passing through the biplot origin and the average tester, with an arrow pointing to the average tester, is called the average tester axis or ATC abscissa and the line that passes through the origin and is perpendicular to the average tester axis is called average tester ordinate or ATC ordinate and the projections of the entries onto the ATC ordinate must approximate their SCA effects, which represents the tendency of the entries to produce superior hybrids with specific tester. The GCA effects of the entries were

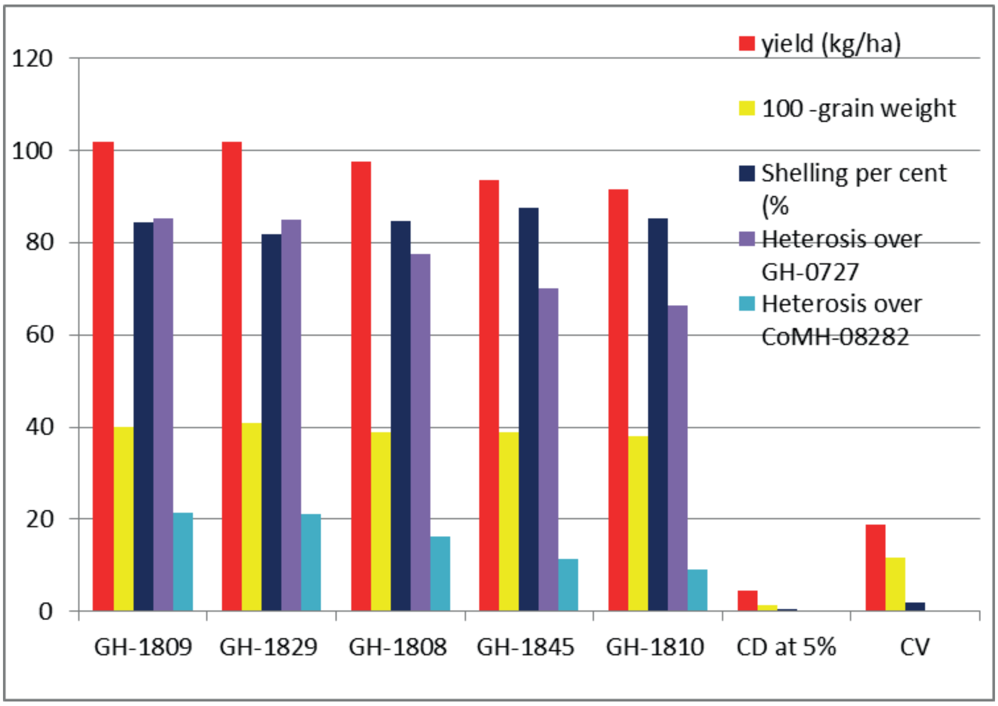

Fig. 2 - Top five hybrids based on mean performance of their grain yield , 100-grain weight, shelling percentage and heterosis over GH-0727 and Co MH -08282

Table 8 - Top ten hybrids based on mean performance of their grain yield along with other quantitative traits

Sl. No.	Genotypes	Grain yield (q/ha)	Days to 50 per cent Tasseling	Days to 50 per cent silking	Plant height (cm)	Ear height (cm)	Number of kernel rows per cob	Number of kernels per row	Cob girth (cm)	Cob length (cm)	Hundred grain weight (g)
1	GH-1809 (GPM-27×CM-111)	101.93*	62.33	63.67	165.07*	74.9*	13.6	36.8*	4.51	19.05*	40.00*
2	GH-1829 (GPM-606×CM-111)	101.71*	62.33	63.33	175.07*	86.9**	13.0	37.1*	4.62	16.9	41.00*
3	GH-1808 (GPM-18×CM-202)	97.65	62.67	64.00	170.33*	77.5	14.0	36.5*	4.71	16.97	39.00*
4	GH-1845 (GPM-706×CM-111)	93.48	61.67	63.67	160.47	74.7	14.6*	35.5*	4.84	15.6	39.00*
5	GH-1810 (GPM-27×CM-202)	91.56	62.67	64.00	158.53	72.3	12.8	37.3*	4.91	17.45	38.00
6	GH-1852 (GPM-114×CM-202)	88.93	60.67	63.00	153.47	74.3	12.8	38.3*	4.66	19.2*	42.00*
7	GH-1836 (GPM-640×CM-202)	87.28	61.00	62.67	159.93	73.5	13.6	33.9	4.67	15.9	37.00
8	GH-1807 (GPM-18×CM-111)	85.54	61.67	63.33	157.00	75.7	13.0	31.5	4.71	15.8	36.50
9	GH-1813 (GPM-30×CM-111)	84.62	60.67	62.33	150.00	67.3	12.6	35.8*	4.46	18.4	37.50
10	GH-1853 (CAL-1462×CM-111)	82.67	63.00	64.00	150.60	67.2	11.2	41.7*	4.11	17.65	34.00
1	COMH-08-282	84.90	61.67	62.67	160.80	67.1	13.8	33.9	4.97	18.65	37.00
2	GH-07227	55.01	55.67	58.67	150.80	69.7	12.8	29.4	4.33	13.35	35.00
3	900-MG (Private check)	95.74	62.33	63.33	144.73	67.4	13.8	34.5	5.09	15.2	37.00
	S.Em. +	1.6	0.3	0.2	1.0	0.3	0.2	0.0	0.1	0.4	0.5
	CD at 0.5 %	4.5	0.7	0.6	2.7	0.9	0.6	0.1	0.2	1.2	1.4
	CV %	18.8	3.5	2.7	12.1	2.6	11.0	7.1	5.2	10.8	11.7

approximated by their projections onto the ATC abscissa. The parallel lines perpendicular to the ATC abscissa help rank entries relative to GCA effects. Inbred lines near the arrow will be able to combine well with all the testers. In the graph, the entry L5 (GPM-27) showed the highest GCA effects for grain yield followed by L7 (GPM-30) and L6 (GPM-28). However, L20 (GPM-666) and L22 (GPM-701) showed lowest GCA. Tester CM-111 was nearer to the ATC axis and it was found to be the better one among the two testers as it could discriminate more number of entries than CM-202 and this is also evident from the L × T analysis. The line L26 (GPM-114) with the largest projections on to the ATC ordinate is said to combine well with CM-202 tester and produce highest SCA effects. Whereas, L23 when crossed with CM-111 would result in lowest SCA effect. The previous workers like Yan and Hunt (2002), Ruswandi *et al.* (2015) and Singode *et al.* (2017) have tried to analyse the gca and sca effects through biplot approach to have a better understanding of the individual genotypes.

Heterosis

The range of standard / economic heterosis expressed by the F1 hybrids over the Local check (GH-0727), National check (CoMH-08-282) and popular commercial check (900 M Gold) for different quantitative traits along with number of hybrids in desirable direction is represented in Table 7. For maturity traits (days to 50 % tasseling and silking) only one hybrid GH-1857 recorded significant heterosis in desirable negative direction and was found to be earliest over all the three check hybrids, however over national check and commercial check hybrids there were 9 and 21 hybrids respectively which recorded significant heterosis in desirable direction and were early. Similarly, for plant growth parameters (plant height and ear height) a total of 13 and 21 hybrids recorded significant heterosis in positive direction over the best check CoMH-08-282 and among them the test hybrids GH-1838(182.60 cm) for

Fig. 3 - Combining ability (GCA) effects for hundred grain weight and grain yield

plant height and GH-1829 (86.9cm) for ear height were identified as the best genotypes. Among the yield contributing traits the range of heterosis was highest for grain yield over all the three check hybrids followed by number of kernels per row. Whereas, the range of heterosis was low for cob girth trait. For number of kernels/row trait there were reasonably good number of test hybrids which recorded significant heterosis over all the three check hybrids. While for cob girth there none of the hybrids which recorded sifgniciant heterosis over national and private hybrid check. Finally, for grain yield 900 M Gold was the best check, and two test hybrids GH-1809 and GH-1829 recorded significant standard heterosis of more than six per cent and over National check hybrid they recorded significant heterosis of more than 21.0 % in desirable positive direction (fig:2).The other test hybrids GH-1808, GH-1845 and GH-1852 also recorded numerically superior heterosis over National check hybrid. Overall, 7.8 % of the test hybrids recorded heterosis over the National check hybrid which is considered as the bench mark for promotion of the new test hybrids. Similarly, over local check, GH-0727 a total of 39 hybrids recorded significant standard heterosis in desirable positive direction. These results were in line with the findings of Matin *et al.* (2016) and Reddy *et al.* (2018). The highest grain yield was recorded in the test hybrid GH-1809 (101.9 q/ha) and this hybrid differed significantly over the best check for hundred seed weight, cob length and number of kernels per row trait (Table 8). For majority of the top ten hybrids the higher grain yield was manifested through number of kernels per row and hundred seed weight. Similarly, GH-1845 had higher number of kernel rows and GH-1852 higher cob length as compared to the best checks for the respective traits. For cob girth all of the top ten hybrids were statistically on par with the best check hybrid.

Conclusions

The significant outcome from the present study is that the germplasm lines GPM-18, GPM-27, GPM-30 and GPM-606 recorded significant gca effects for grain yield and were found to be promising parental lines in hybrid breeding or through population improvement programme for amassing the favourable alleles for grain yield. Likewise among the 64 F1 test hybrids, GH-1852 recorded significant sca effects for majority of the traits. However for grain yield GH-1809 and GH-1829 recorded significant heterosis over all the three checks. It was found that significant SCA estimates involving at least one of parent with high GCA is desirable in the resent study. Further, GGE biplot technique was able to identify GPM-27 as the best germplasm line w.r.t. grain yield and CM-111as the best tester.

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