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Research Article

Combining ability and heterotic grouping of inbred lines for kernel yield in maize (*Zea mays* L.)

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Abstract
Development and identification of suitable parents for hybridization is a vital step in hybrid production programmes. Success of hybrid breeding depend on how distantly the parents are related, which can be possible through crossing of parents belongs to different heterotic groups. So, the phenomenon of heterotic grouping and combining ability are imperative in maize breeding programmes. The present investigation was carried to identify lines with good general combining ability (GCA) and crosses with good specific combining ability (SCA). 44 testcrosses were generated by crossing 11 lines with 4 testers using L x T mating design. The testcrosses along with parents and 5 checks were evaluated for kernel yield and its attributing traits in simple lattice design. Analysis of variance for combining ability revealed that the parents *vs* hybrids exhibited significant difference for all the traits indicating the presence of variability in the genetic material. None of the lines exhibited significant GCA in desirable direction for kernel yield. The cross VL15869-14 x LM14 exhibited positive significant SCA effect for kernel yield. Heterotic grouping classified 5 inbred lines L1, L3, L4, L6 and L10 into heterotic group B and 1 inbred line L8 into heterotic group A. Remaining 5 inbred lines L2, L5, L7, L9 and L11 were not categorized into any heterotic groups.

Keywords: GCA, SCA, lines, testers, crosses

INTRODUCTION

Maize (*Zea mays* L.) is one of the world's most significant cereal crops after rice and wheat. Maize is known as the "Queen of Cereals" because it has the highest genetic production potential among all cereals (Kumari *et al*., 2016). It is the only cultivated species in the Maydeae tribe of the Poaceae family with greater economic value, and plays a critical role in global food and nutritional security. Being a C_4 plant, it is physiologically more efficient, yields more grain, and adapts to a wider range of environments. Maize is expected to overtake rice as the world's most important grain by 2030, owing to rising demand for dairy and meat products in developing countries and declining rice production in China and India (Salvi *et al*., 2007).

In India, it is cultivated over an area of 9.89 m ha with a production and productivity of 31.60 million tonnes and 3199 kg ha^{-1} respectively. In Andhra Pradesh, maize is cultivated in an area of 0.3 m ha with a production and productivity of 1.78 million tonnes and 5917 kg ha^{-1} respectively (www.indiaagristat.com, 2020-21). It accounts for over 30% of global cereal output and still its demand continues to soar. Maize contributes to 15% of the world's protein and 19% of the calories derived from the food crops (Kumari *et al*., 2018). Maize, coupled with rice and wheat, supplies at least 30% of the calories consumed by approximately 4.5 billion people in 94 developing countries (Shiferaw *et al*., 2011).

Knowledge of parents breeding behaviour is critical for the design of a breeding programme. The phase of developing and identifying parents that form superior heterotic patterns, though fundamental to hybrid breeding, is the most costly and laborious in a maize hybrid programme. This is because *per se* performance of the parents does not predict the performance of maize hybrids for grain yield (Hallauer and Miranda, 1988; Dao *et al*., 2014 and Katragadda *et al*., 2020). The yield potential is realized in maize mainly due to success in hybrid breeding for exploitation of heterosis in the form of hybrids and synthetics (Sharma *et al*., 2019).

Combining ability of inbred lines provides information about the genetic nature of quantitative traits and facilitates the selection of the best parents for heterosis breeding (Dao *et al*., 2014; Nyaligwa *et al*., 2016 and Katragadda *et al*., 2020). It is one of the most useful techniques for determining the best combiner to engage in crosses, to either exploit heterosis or to accumulate fixable genes. According to Allard (1960), the expected value of any cross is the sum of its two parental lines general combining ability (GCA), whereas the deviation from this expected value is called specific combing ability (SCA). The predominance of GCA allows for better selection efficiency in segregating populations (Bocanski *et al*., 2009). GCA variation describes the degree of additive gene action, whereas SCA variance shows the degree of non-additive gene action. Gene actions, both additive and non-additive, are critical for the genetic expression of yield and related traits. Selection of appropriate breeding programme for maximum genetic improvement is based on relative values of general and specific combining abilities (Griffing, 1956).

Apart from selection of superior lines and analysis of their combining ability, placing them in well-defined heterotic groups is essential to increase the probability of success in heterosis breeding. Heterotic patterns are important as they guide breeders to decide on the germplasm to be used in hybrid production over a long period thus simplifying germplasm management and organization (Nepir *et al*., 2015 and Oppong *et al*., 2019). A heterotic group is a group of related or unrelated genotypes displaying similar combining ability and giving a heterotic response when crossed to opposite or other genetically distinct germplasm group and establishment of the best combination of inbreds among the heterotic groups is crucial to the development of successful maize hybrids (Barata and Carena, 2006 and Fan *et al*., 2009).

MATERIALS AND METHODS

Genetic materials: The crosses were generated during *kharif* season 2021 by crossing 11 lines with 4 testers (**Table 1**) in line × tester mating design proposed by Kempthorne (1957) at ARS, Peddapuram. The generated hybrids were evaluated along with their parents and five checks during *rabi,* 2021-22 at Agricultural College Farm, Bapatla, Andhra Pradesh, situated at 15^0 55' North latitude and 80^0 30' East longitude and altitude of 5.49 m above Mean Sea Level (MSL).

Trail management: The experimental material was evaluated using simple lattice design. The whole experimental area was divided into two replications. Each replication consisted of eight blocks. In each block eight genotypes were allocated and each genotype was planted in two rows each of three meter in length with a spacing of 60 cm between rows and 20 cm within row. To maintain adequate crop stand all agronomic practices and need based plant protection measures were adopted throughout the crop growth period.

Data collection and Analysis: Data were recorded on various pre and post-harvest parameters like days to 50% tasseling, days to 50% silking, days to maturity on plot basis whereas plant height, ear placement height, ear length, ear girth, No. of kernel row per cob, No. of kernels per row, hundred kernel weight, protein content and kernel yield on plant basis. All of data collected were subjected to statistical analysis using software Windostat Version 9.3 from Indostat Services. General combining ability (GCA) and specific combing ability (SCA) effects were calculated from the mean sum of squares of L x T mating design according to the procedures developed by Kempthorne (1957) and adopted by Singh and Choudhry (1979). Heterotic grouping was determined according to Vasal *et al*. (1992). Depending on the direction of the

Table 1. List of lines and testers used in the present experiment

S. No.	Inbred line	S. No.	Inbred line
L1	VL171488-2	L9	SNL19564-20
L2	VL18828	L10	SNL19582-22
L3	VL19978-6	L11	SNL19588-23
L4	VL19705-8	**Testers**	
L5	VL19255	T1	BML6
L6	VL18142	T2	BML7
L7	CAL1733-13	T3	LM13
L8	VL175869-14	T4	LM14

SCA estimates such that lines displaying positive SCA with tester A were grouped towards the opposite heterotic group, and vice versa, whereas lines exhibiting positive SCA to both testers were grouped under AB heterotic group.

RESULTS AND DISCUSSION

Analysis of variance and mean performance: Variability in a crop species is of utmost importance as it provides the basis for effective selection. Selection of parents based on their phenotypic performance may not be desirable because phenotypically superior lines may not provide good hybrid combinations (Elmyhun *et al*., 2020). So, combining ability of parents as well as crosses is an important measure in the selection of parents (Sprague & Tatum, 1942; Griffing, 1956 and Ahmed *et al*., 2017).

Analysis of variance for combining ability revealed that the parents *vs* hybrids exhibited significant difference for all the traits indicating the presence of variability in the genetic material (**Table 2**). Significant differences among lines and interaction of lines and crosses for plant height, ear placement height, ear length, ear girth, No. of kernels per row, hundred kernel weight and kernel yield per plant indicating sufficient variability among these traits and providing the chance for selection for improvement of yield and yield attributing traits. Similar findings have been reported by several authors. (Pandit *et al*., 2018; Rajesh *et al*., 2018 and Elmyhun *et al*., 2020).

Mean performance of kernel yield per plant which is a primary economic produce of maize ranged from 78.33 g to 182.17 g with mean value of 135.80 g. The cross VL175869-14 x LM14 revealed high kernel yield per plant (182.17 g) followed by SNL19564-20 x BML6 (163.33 g). But none of the crosses exhibited significant heterosis over standard checks DKC8171 and PAC751. Abebe, Wolde and Gebreselassie (2020) investigated combining ability and heterosis of maize inbred lines and stated that none of the crosses performed better than the best standard check in kernel yield.

Combining ability effects: Information on *gca* effects helps a breeder to exploit existing variability in breeding materials to choose genotypes having desirable characters and to distinguish relatedness among the breeding material (Sprague and Tatum, 1942). The *gca* effects of the inbred lines were presented in **table 3**. The line VL18828 exhibited significant *gca* effect in desirable direction for days to 50% tasseling, days to 50% silking (Nyombayire *et al*., 2021 and Olayiwola *et al*., 2021). This line can be further utilized in the development of early duration hybrids.

None of the lines exhibited significant *gca* effects for kernel yield but the line SNL19582-22 possessed significant negative *gca* effect for kernel yield signifying that this line was undesirable combiner for developing high yielding hybrids and synthetic varieties. Andayani *et al*. (2018) and Olayiwola *et al*. (2021) identified inbred lines with significant negative and positive *gca* effects for kernel yield in their studies.

The *sca* effects help breeders to determine heterotic patterns among populations or inbred lines to identify promising single crosses and assign them into heterotic groups (Lahane *et al*., 2014). Significant high *sca* effects in desirable direction was recorded by the cross VL19255 x BML7 for days to 50% tasseling, days to 50% silking (Amiruzzaman *et al*., 2013). The cross VL15869-14 x LM14 possessed significant positive *sca* effect whereas the cross VL175869-14 x LM13 exhibited significant negative *sca* effect for kernel yield per plant (**Table 4**). Similar reports of both positive and negative significant *sca* effects for kernel yield was reported by Natol *et al*. (2017); Abebe *et al*. (2020) and Elmyhun *et al*. (2020).

The ratio of GCA to SCA variance determines the gene action involved in the inheritance of those traits. If ratio that is less than unity represents predominance of non-additive gene action, more than unity represents predominance of additive gene action (Kumawat *et al*., 2021).

The component of variance due to SCA was higher than GCA in all the studied traits except for kernel rows per ear and protein content indicating the predominance of non-additive gene action in the inheritance of these traits, whereas GCA variance was higher than SCA variance for the remaining traits indicating the predominance of additive gene action and are presented in **Table 5**. Similar findings were reported by Italia *et al*. (2022); Wani *et al*. (2017); Niyonzima *et al*. (2015); Chandel and Guleria, (2019); Ibrahim *et al*. (2021); Patil *et al*.(2021).

Heterotic grouping: “Lines displaying positive SCA effects with a tester were grouped towards the opposite heterotic group, whereas lines exhibiting positive SCA effects to both testers were grouped towards both groups, and lines that expressed negative SCA effects with the two testers could be discarded” (Vasal *et al*., 1992 and Elmyhun *et al*., 2020). The combining ability effects of the inbred lines when crossed to 2 testers. Testers exhibiting better performance were considered during heterotic grouping (LM13, LM14). Among the 11 inbred lines, 5 inbred lines L1, L3, L4, L6 and L10 having positive SCA effect with tester LM13 were placed in heterotic group B and the line L8 having positive SCA with tester LM14 was placed in heterotic group A. The 5 inbred lines L2, L5, L7, L9 and L11 possessing negative SCA with both the testers were discarded (**Table 6**).

Combining ability analysis is an important tool in estimating GCA of the parents and SCA of the crosses in selecting desirable parents for hybridization as well as in identification

Table 2. Analysis of variance for combining ability (including parents) for kernel yield and its contributing traits in maize (*Zea mays* L.)

Source of variation	d.f	Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height (cm)	Ear placement height (cm)	Ear length (cm)	Ear girth (cm)	Kernel rows per ear	No of kernels per row	100 kernel weight (g)	Protein content (%)	Kernel yield per plant (g)
Replications	1	1.660	0.008	0.034	25.542	10.74	5.079	0.846	0.918	5.773	0.066	2.100	274.454
Treatments	58	46.692 **	42.684 **	46.313 **	757.272 **	367.63 **	7.646 **	1.795 **	1.929**	31.08 **	41.60**	1.709 *	724.96 **
Parents	14	6.705	6.748	9.248	459.310 **	231.80**	10.380 **	1.608 **	1.375	32.187**	69.70**	1.700	605.65 **
Lines	10	8.227	8.109	9.536	574.197 **	117.55 **	10.369 **	1.850 **	1.384	44.47**	47.714 *	1.600	645.83 **
Testers	3	2.125	3.000	11.125	229.378	84.787	8.253 *	1.330	1.778	1.934	165.78**	2.500	577.197
Lines vs. Testers	1	5.219	4.376	0.728	0.240	1815.38**	16.878 **	0.025	0.079	0.054	1.307	0.100	289.28
Parent vs. Crosses	1	2251.88**	2017.86**	2133.10**	31005.02**	9010.27**	130.99**	10.84**	1.691	358.89**	251.25**	7.306 *	13825.44**
Crosses	43	8.428	8.450	9.851	150.847	210.86**	3.887 *	1.645 **	2.114**	23.10 **	27.580	1.600	459.15**
Line effect	10	4.127	5.586	6.295	173.102	208.836	3.375	2.169	4.494**	47.39**	22.902	0.900	365.813
Tester effect	3	2.981	0.515	6.314	144.387	518.48	12.789 *	5.552 **	5.122**	21.841	169.48 **	6.305 **	381.395
Line x Tester effect	30	10.406	10.198 *	11.389	144.075	180.78**	3.167	1.080 *	1.021	15.133	14.949	1.300	498.03 **
Error	58	7.851	5.922	11.224	132.26	42.658	2.307	0.647	0.86	10.285	19.021	1.000	221.124
Total	117	27.053	24.096	28.523	441.183	203.485	4.977	1.218	1.39	20.557	30.054	1.400	471.348

*Significant at 5% level; ** Significant at 1% level

Table 3. Estimates of general combining (*gca*) effects of lines and testers for kernel yield and its contributing traits in maize (*Zea mays* L.)

Parents	Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height (cm)	Ear placement height (cm)	Ear length (cm)	Ear girth (cm)	Kernel rows ear^{-1}	Number of kernels row^{-1}	100 kernel weight (g)	Protein content (%)	Kernel yield plant^{-1} (g)
LINES												
VL171488-2	0.216	-0.261	-0.727	0.497	7.507 **	0.585	0.510	1.183 **	0.439	0.094	0.090	-1.377
VL18828	-1.984*	-1.761 *	-1.352	-3.178	-1.318	0.118	0.632 *	0.474	-1.352	-0.837	-0.485	0.540
VL19978-6	0.216	1.364	0.523	-7.753	-4.893 *	-0.303	-0.698 *	-0.695 *	-0.520	0.150	-0.073	-6.290
VL19705-8	-0.784	-0.136	-1.352	0.247	9.107 **	0.389	0.268	0.556	3.523 **	-2.126	0.190	5.126
VL19255	-0.034	0.614	0.898	5.222	1.669	0.532	0.585 *	0.641	0.107	0.919	0.065	7.458
VL18142	-0.409	-0.261	-0.352	0.772	-5.068 *	-0.666	0.150	0.724 *	-2.393 *	2.240	0.265	2.167
CAL1733-13	-0.159	-0.386	0.398	-0.803	-2.506	0.237	-0.516	-0.693 *	4.272**	-3.377 *	-0.21	3.917
VL175869-14	0.716	0.614	0.648	2.947	4.557 *	-0.022	-0.720**	-1.026**	0.233	-0.329	0.127	0.375
SNL19564-20	1.341	0.864	1.273	-4.441	-1.243	0.364	0.397	-0.026	-0.728	0.304	0.002	4.418
SNL19582-22	0.466	-0.261	0.398	-2.578	-5.968 **	-1.602**	-0.291	-0.360	-4.393**	0.609	0.602	-17.125 **
SNL19588-23	-0.284	-0.386	-0.352	9.072 *	-1.843	0.369	-0.318	-0.778 *	0.814	2.353	-0.573	0.792
SE	0.960	0.786	1.165	3.924	1.972	0.507	0.265	0.336	1.182	1.548	0.361	5.559
CD at 5%	1.937	1.586	2.349	7.915	3.978	1.023	0.536	0.677	2.384	3.124	0.729	11.212
CD at 1%	2.588	2.119	3.140	10.577	5.316	1.366	0.716	0.905	3.187	4.174	0.974	14.983
TESTERS												
BML6	-0.534	-0.182	-0.648	-2.144	1.186	-0.461	0.541 **	0.336	-0.799	2.260 *	-0.717**	3.723
BML7	0.284	0.182	0.580	-2.290	-6.464 **	-0.272	0.258	0.035	-0.087	-1.216	0.501 *	3.481
LM13	0.193	0.045	0.261	2.310	0.032	1.138 **	-0.598 **	-0.693**	1.428	2.305 *	-0.081	-3.398
LM14	0.057	-0.045	-0.193	2.124	5.245 **	-0.405	-0.201	0.322	-0.541	-3.349**	0.297	-3.806
SE	0.579	0.474	0.702	2.366	1.189	0.305	0.160	0.202	0.713	0.934	0.218	3.352
CD at 5%	1.168	0.957	1.417	4.773	2.399	0.617	0.323	0.409	1.438	1.884	0.440	6.761
CD at 1%	1.561	1.278	1.893	6.378	3.206	0.842	0.431	0.546	1.921	2.517	0.587	9.035

Table 4. Estimates of specific combining ability (*sca*) effects of crosses for kernel yield and its contributing traits in maize (*Zea mays* L.)

S. No.	Crosses	Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height (cm)	Ear placement height (cm)	Ear length (cm)	Ear girth (cm)	Kernel rows ear^{-1}	No of kernels row^{-1}	100 kernel weight (g)	Protein content (%)	Kernel yield plant^{-1} (g)
1	VL171488-2 x BML6	2.284	2.307	-0.227	-0.006	22.939 **	-0.323	-1.146*	-1.210	-0.242	0.747	0.592	-7.313
2	VL171488-2 x BML7	-2.534	-2.557	-1.955	9.04	-6.411	0.488	-0.743	0.422	-0.789	-0.156	-1.026	1.939
3	VL171488-2 x LM13	-1.443	-1.420	-0.636	-7.16	-3.607	-0.971	2.043**	0.819	1.366	-1.357	0.706	6.483
4	VL171488-2 x LM14	1.693	1.670	2.818	-1.874	-12.920 **	0.806	-0.154	-0.031	-0.335	0.766	-0.272	-1.109
5	VL18828 x BML6	0.784	0.307	0.898	-6.731	-0.336	1.394	0.768	-0.171	1.879	1.379	0.417	2.776
6	VL18828 x BML7	0.966	0.943	0.670	6.615	-3.086	-0.709	-0.169	-0.2	2.002	-2.055	0.599	1.353
7	VL18828 x LM13	-0.943	-0.420	-1.011	5.115	5.218	0.861	-0.409	-0.142	0.157	1.929	0.081	-0.269
8	VL18828 x LM14	-0.807	-0.830	-0.557	-4.999	-1.795	-1.546	-0.19	0.513	-4.039	-1.253	-1.097	-3.86
9	VL19978-6 x BML6	-1.716	-3.818 *	-1.977	-0.356	-7.961 *	1.516	0.063	-0.338	-1.618	-0.404	1.255	-3.389
10	VL19978-6 x BML7	0.466	1.318	-0.205	-7.31	0.689	-0.143	-0.004	-0.036	2.505	4.418	-0.864	-5.147
11	VL19978-6 x LM13	-0.443	0.455	0.614	-2.11	-6.207	-0.997	0.201	0.362	0.655	-0.138	0.318	16.396
12	VL19978-6 x LM14	1.693	2.045	1.568	9.776	13.480 **	-0.375	-0.26	0.012	-1.541	-3.875	-0.709	-7.86
13	VL19705-8 x BML6	-1.216	0.182	-0.602	-4.356	3.839	-1.242	-0.703	-0.254	-1.491	2.032	1.042	-3.475
14	VL19705-8 x BML7	0.466	-0.182	0.670	-4.11	-11.511 **	-0.200	1.149 *	0.383	-4.038	0.744	-1.226	-3.899
15	VL19705-8 x LM13	-0.443	-1.045	-0.011	8.190	5.493	1.875	-0.150	0.111	4.112	0.673	-0.244	8.315
16	VL19705-8 x LM14	1.193	1.045	-0.057	0.276	2.180	-0.433	-0.296	-0.239	1.416	-3.449	0.428	-0.941
17	VL19255 x BML6	1.034	1.932	0.148	6.669	-8.524 *	-0.669	0.749	0.326	-0.074	1.377	-0.883	8.527
18	VL19255 x BML7	-4.284 *	-4.432 **	-4.58	-6.685	7.626	0.377	-0.573	-0.367	0.878	0.729	0.949	7.769
19	VL19255 x LM13	0.807	0.705	-0.261	2.015	-2.069	1.303	0.168	0.361	-0.472	0.923	-0.219	-11.352
20	VL19255 x LM14	2.443	1.795	4.693	-1.999	2.967	-1.010	-0.344	-0.319	-0.333	-3.029	0.153	-4.944
21	VL18142 x BML6	1.409	0.807	1.898	10.519	13.214 **	-0.707	0.314	-0.086	0.591	-0.439	-0.233	6.653
22	VL18142 x BML7	1.091	1.443	0.67	6.365	-14.836 **	-0.645	-0.373	-0.785	-0.787	-1.653	0.599	-20.275
23	VL18142 x LM13	-0.818	-0.420	-1.011	-12.335	2.168	0.130	-0.232	0.943	0.863	0.327	-0.619	13.939

Table 4. Continued..

S. No.	Crosses	Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height (cm)	Ear placement height (cm)	Ear length (cm)	Ear girth (cm)	Kernel rows ear^{-1}	No of kernels row^{-1}	100 kernel weight (g)	Protein content (%)	Kernel yield plant^{-1} (g)
24	VL18142 x LM14	1.682	-1.830	-1.557	-4.549	-0.545	1.222	0.291	-0.072	-0.668	1.765	0.253	-0.318
25	CAL1733-13 x BML6	-3.841	-3.068	-1.852	-9.706	-9.649 *	-0.139	0.245	2.330 **	-1.244	0.774	-0.458	8.568
26	CAL1733-13 x BML7	6.341 **	6.068 **	5.420 *	-4.660	-1.849	0.172	0.098	-0.698	0.713	-4.160	0.574	-3.690
27	CAL1733-13 x LM13	-1.568	-1.795	-2.261	15.24	7.806	-0.137	-0.396	-0.976	0.198	0.004	-0.944	-0.146
28	CAL1733-13 x LM14	-0.932	-1.205	-1.307	-0.874	3.692	0.105	0.053	-0.656	0.333	3.382	0.828	-4.733
29	VL175869-14 x BML6	1.784	1.432	1.898	-9.556	-10.511 *	0.869	-0.366	-0.336	1.464	-2.300	-0.495	-19.219
30	VL175869-14 x BML7	-1.034	-0.932	-1.330	-0.710	11.239 **	0.531	-0.018	-0.035	2.087	0.891	0.236	16.518
31	VL175869-14 x LM13	3.057	2.705	2.989	-3.910	-7.557	-3.894**	-1.062	-0.307	-7.593 **	-2.795	-0.332	-41.64**
32	VL175869-14 x LM14	-3.807	-3.205 *	-3.557	14.176	6.830	2.494 *	1.446**	0.678	4.041	4.204	0.591	44.305 **
33	SNL19564-20 x BML6	0.659	1.182	0.773	5.932	0.389	-0.187	0.453	-0.001	3.761	0.127	-0.820	13.902
34	SNL19564-20 x BML7	-1.659	-1.682	-1.955	-1.223	0.339	0.345	0.116	-0.035	-0.287	0.519	0.811	10.309
35	SNL19564-20 x LM13	0.432	0.455	0.364	1.877	1.643	0.300	-0.379	-0.307	0.028	0.263	0.243	-8.977
36	SNL19564-20 x LM14	0.568	0.045	0.818	-6.586	-2.370	-0.458	-0.190	0.343	-3.503	-0.909	-0.234	-15.234
37	SNL19582-22 x BML6	0.034	-0.193	0.148	-4.731	-7.186	-0.736	-0.945	-0.338	-3.409	0.692	-0.220	-17.889
38	SNL19582-22 x BML7	-0.784	-0.557	-1.080	-3.085	8.864 *	-0.189	0.453	0.634	1.378	-1.961	0.311	2.353
39	SNL19582-22 x LM13	0.807	0.580	0.739	-0.585	5.468	0.866	0.509	0.027	0.363	3.508	-0.457	19.231
40	SNL19582-22 x LM14	-0.057	0.170	0.193	8.401	-7.145	0.059	-0.017	-0.323	1.668	-2.239	0.366	-3.695
41	SNL19588-23 x BML6	-1.216	-1.068	-1.102	12.319	3.789	0.223	0.568	0.080	0.383	-3.986	-0.195	10.858
42	SNL19588-23 x BML7	0.966	0.568	3.670	5.765	8.939 *	-0.025	0.066	0.717	-3.664	2.685	-0.964	-7.230
43	SNL19588-23 x LM13	0.557	0.205	0.489	-6.335	-8.357 *	0.665	-0.294	-0.891	0.321	-3.336	1.468 *	-2.016
44	SNL19588-23 x LM14	-0.307	0.295	-3.057	-11.749	-4.370	-0.863	-0.34	0.094	2.960	4.637	-0.309	-1.612
	SE	1.921	1.573	2.330	7.849	3.945	1.014	0.531	0.672	2.365	3.097	0.723	11.119
	CD at 5%	3.874	3.172	4.699	15.829	7.956	2.045	1.072	1.355	4.769	6.247	1.458	22.423
	CD at 1%	5.177	4.239	6.280	21.154	10.633	2.733	1.432	1.811	6.374	8.348	1.949	29.967

Table 5. Estimates of genetic components of variance for kernel yield and its contributing traits in maize (*Zea mays* L.)

	Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height (cm)	Ear placement height (cm)	Ear length (cm)	Ear girth (cm)	Kernel rows ear^{-1}	Number of kernels row^{-1}	100 kernel weight (g)	Protein content (%)	Kernel yield plant $^{-1}$ (g)
σ^2gca	-0.456	-0.476	-0.339	0.977	12.191	0.327*	0.185	0.252	1.298*	5.410**	0.150	-8.290
σ^2sca	1.512	2.624*	0.265	10.425	74.825**	0.554	0.257*	0.058	1.973	-2.120	0.140	125.38*
σ^2gca/ σ^2sca	-0.302	-0.181	-1.279	0.094	0.163	0.590	0.720	4.345	0.658	-2.552	1.071	-0.066

σ^2gca – general combining ability variance

σ^2sca – specific combining ability variance

Table 6. Classification of inbred lines into heterotic groups

S. No	Inbred line	Tester LM13 (HB)		Tester LM14 (HA)		
		KYPP (g)	SCA	KYPP (g)	SCA	Heterotic group
L1	VL171488-2	143.00	6.483	135.00	-1.109	B
L2	VL18828	138.17	-0.269	134.17	-3.86	-
L3	VL19978-6	148.00	16.396	123.33	-7.86	B
L4	VL19705-8	151.33	8.315	141.67	-0.941	B
L5	VL19255	134.00	-11.352	140.00	-4.944	-
L6	VL18142	154.00	13.939	139.33	-0.318	B
L7	CAL1733-13	141.67	-0.146	136.67	-4.733	-
L8	VL175869-14	96.67	-41.604**	182.17	44.305 **	A
L9	SNL19564-20	133.33	-8.977	126.67	-15.234	-
L10	SNL19582-22	140.00	19.231	116.67	-3.695	B
L11	SNL19588-23	136.67	-2.016	136.67	-1.612	-

of superior cross combinations. Analysis of variance for combining ability revealed that the parents *vs* hybrids exhibited significant difference for all the traits indicating the presence of variability in the genetic material. The cross VL175869-14 x LM14 (182.17 g) followed by SNL19564-20 x BML6 (163.33 g) revealed high kernel yield per plant.

GCA analysis identified the line VL18828 as a good general combiner for days to 50% tasseling and days to 50% silking. Most of the lines and testers exhibited positive *gca* effect but are non-significant. The cross VL15869-14 x LM14 was identified as good specific combiner for the trait kernel yield. Heterotic grouping classified 5 inbred lines L1, L3, L4, L6 and L10 into heterotic group B and 1 inbred line L8 into heterotic group A. Remaining 5 inbred lines L2, L5, L7, L9 and L11 were not categorized into any heterotic groups. So, superior hybrid combinations can be developed by mating with opposite heterotic groups which saves the time for breeder in identifying distant parents for hybridization.

REFERENCES

Abebe, A., Wolde, L. and Gebreselassie, W. 2020. Standard heterosis and trait association of maize inbred lines using line x tester mating design in Ethiopia. *African Journal of Plant Science*, **14** (4): 192-204. [Cross Ref]

Ahmed, D. Z., Ahmed, L. A., Hussain, W. S., Bashir, A., Ishfaq, A., Gowhar, A. and Altaf, W. M. 2017. Analysis of combining ability in maize (*Zea mays* L.) under temperate conditions. *International Journal of Agriculture Sciences,* **9** (2): 3647–3649.

Allard, R. W. 1960, Principles of Plant Breeding, John Wiley and Sons Inc., New York, p. 463.

Amiruzzaman, M., Islam, M.A., Hasan, L., Kadir, M. and Rohman, M.M. 2013. Heterosis and combining ability in a diallel among elite inbred lines of maize (*Zea mays* L.). *Emirates Journal of Food and Agriculture*, 132-137. [Cross Ref]

Andayani, N.N., Aqil, M., Efendi, R. and Azrai, M. 2018. Line × tester analysis across equatorial environments to study combining ability of indonesian maize inbred. *Asian Journal of Agriculture & Biology,* **6** (2): 213–220.

Barata, C. and Carena, M.J. 2006. Classification of North Dakota maize inbred lines into heterotic groups based on molecular and testcross data. *Euphytica,* **151** (3): 339-349. [Cross Ref]

Bocanski, J., Sreckov, Z. and Nastic, A. 2009. Genetic and phenotypic relationship between grain yield and components of grain yield of maize (*Zea mays* L.). *Genetika*, **41** (2): 145 -154. [Cross Ref]

Chandel, U., Kumar, D. and Guleria, S. K. 2019. Combining ability effects and heterotic grouping in newly developed early maturing yellow maize (*Zea mays* L.) inbreds under sub-tropical conditions. *Electronic Journal of Plant Breeding*, **10** (3): 1049-1059. [Cross Ref]

Dao, A., Sanou, J., Gracen, V. and Danquanh, E.Y., 2014. Heterotic relationship between INERA, CIMMYT and IITA maize inbred lines under drought and well-watered conditions. *Maydica*, **59** (3): 201-210.

Elmyhun, M., Liyew, C., Shita, A. and Andualem, M. 2020. Combining ability performance and heterotic grouping of maize (*Zea mays*) inbred lines in testcross formation in Western Amhara, North West Ethiopia. *Cogent Food & Agriculture,* **6** (1): 1727625. [Cross Ref]

Fan, X.M., Zhang, Y.M., Yao, W.H., Chen, H.M., Tan, J., Xu, C.X., Han, X.L., Luo, L.M and Kang, M.S. 2009. Classifying maize inbred lines into heterotic groups using a factorial mating design. *Agronomy journal,* **101** (1): 106-112. [Cross Ref]

Griffing, B. 1956. Concept of general and specific combining ability in relation to diallel crossing systems. *Australian Journal of Biological Sciences,* **9**: 463-493. [Cross Ref]

Hallauer, A.R. and Miranda, J.B. 1988. Quantitative genetics in maize breeding (2nd ed.). Ames: Iowa State University Press.

Ibrahim, K.A., Said, A.A and Kamara, M.M. 2021. Evaluation and classification of yellow maize inbred lines using line x tester analysis across two locations. *Journal of Plant Production,* **12** (6): 605-613. [Cross Ref]

Italia, P.B., Izge, A.U., Sabo, M.U., Buba, U.M and Fagam, A.S. 2022. Genetic analysis among elite nigerian open-pollinated varieties and inbred lines of maize (*Zea mays* L.) for grain yield and other yield components. *Direct Research Journal of Agriculture and Food Science*, **10** (1): 11-21.

Katragadda, S., Tekale, P. and Dinasarapu, S., 2020. Identification of potential parental lines for single, three-way and double crosses in maize (*Zea mays* L.). *Maydica*, **65** (2): 9.

Kempthorne, O. 1957. *An Introduction to Genetical Statistics*. John Willey and Sons Inc., New York. 323-331.

Kumari, R., Singh, A.K. and Sharma, V.K. 2016. Heterosis and genetic divergence correlation studies for yield and its related traits in maize (*Zea mays* L.). *The Bioscan*, **11** (3): 1849-1854.

Kumari, R., Singh, A.K. and Sharma, V.K. 2018. Genetic divergence studies for morpho-agronomical traits in maize (*Zea mays* L.) inbreds. *International Journal of Current Microbiology and Applied Sciences*, **7**: 3589-3594.

Kumawat, R., Dadheech, A. and Barupal, H.L. 2021. Combining ability and genetic architecture studies in maize. *The Pharma Innovation Journal*, **10** (12): 2307-2313.

Lahane, G. R., Chauhan, R. M and Patel, M. 2014. Combining ability and heterosis for yield and quality traits in quality protein maize. *Journal of Agriculture,* **1** (3): 135-138.

Ministry of Agriculture, Government of India. Indiastat. 2020-21. https://www.indiastat.com.

Natol, B. 2017. Combining ability and heterotic grouping in maize (*Zea mays* L.) inbred lines for yield and yield related traits. *World Journal of Agricultural Sciences*, **13** (6): 212–219.

Nepir, G., Wegary, D. and Zeleke, H. 2015. Heterosis and combining ability of highland quality protein maize inbred lines. *Maydica*, **60**: 1–12.

Niyonzima, J.P., Nagaraja, T.E., Lohithaswa, H.C., Uma, M.S., Pavan, R., Niyitanga, F. and Kabayiza, A. 2015. Combining ability study for grain yield and its contributing characters in maize (*Zea mays* L.). *International Journal of Agronomy and Agricultural Research,* **7** (1): 61-69.

Nyaligwa, L., Hussein, S., Amelework, B. and Ghebrehiwot, H. 2016. Genetic diversity analysis of elite maize inbred lines of diverse sources using SSR markers. *Maydica,* **60** (3): 1-8.

Nyombayire, A., Derera, J., Sibiya, J. and Ngaboyisonga, C. 2021. Combining ability analysis and heterotic grouping for grain yield among maize inbred lines selected for the mid-altitude and highland zones of Rwanda. *Maydica*, **66** (1): 10. [Cross Ref]

Olayiwola, M.O., Ajala, S.O., Ariyo, O.J., Ojo, D.K. and Gedil, M. 2021. Heterotic grouping of tropical maize inbred lines and their hybrid performance under stem borer infestation and low soil nitrogen condition in West and Central Africa. *Euphytica*, **217** (1): 1-22. [Cross Ref]

Oppong, A., Kubi, D.A., Ifie, B.E., Abrokwah, L.A., Ofori, K., Offei, S.K., Dappah, H.A., Mochiah, M.B. and Warburton, M.L. 2020. Analyzing combining abilities and heterotic groups among Ghanaian maize landraces for yield and resistance/tolerance to Maize Streak Virus Disease. *Maydica,* **64** (3): 10.

Pandit, M., Sah, R.P., Chakraborty, M., Prasad, K., Chakraborty, M.K., Tudu, V., Narayan, S.C., Kumar, A., Manjunatha, N., Kumar, A. and Rana, M., 2018. Gene action and combining ability for dual purpose traits in maize (*Zea mays* L.) under water deficit stress prevailing in eastern India. *Range Management. & Agroforestry,* **39** (1): 29-37.

Patil, N.L., Kachapur, R.M. and Nair, S.K. 2021. Genetic evaluation for understanding combining ability effects and heterotic grouping in maize (*Zea mays* L.). *Maydica,* **66** (1): 13.

Rajesh, V., Sudheer Kumar, S., Narsimha Reddy, V. and Siva Sankar, A. 2018. Combining ability and genetic action studies for yield and its related traits in maize (*Zea mays* L.). *International Journal of Current Microbiology and Applied Sciences*, **7** (6):2645-2652. [Cross Ref]

Salvi, S., Sponza, G. and Morgante, M. 2007. Conserved noncoding genomic sequences associated with a flowering-time quantitative trait locus in maize. *Proceedings of the National Academy of Sciences of the United States of America,* **104**: 11376- 11381. [Cross Ref]

Sharma, P., Kamboj, M. C. and Punia, M. S. 2019. Assessment of combining ability effects using quality protein maize donors as testers for yield and yield traits in maize. *Electronic Journal of Plant Breeding*, **10** (4): 1367-1375. [Cross Ref]

Shiferaw, B., Prasanna, B.M., Hellin, J. and Banziger, M. 2011. Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. *Food Security,* **3** (3): 307-327. [Cross Ref]

Singh, R.K. and Chaudhary, B.D. 1977. *Biometrical Methods in Quantitative Genetic Analysis*. Kalyani Publishers, Ludhiana, New Delhi. 54-57.

Sprague, G. F. and Tatum, L. A. 1942. General *vs*. Specific combining ability in single crosses of corn. *Agronomy Journal,* **34**: 923-932. [Cross Ref]

Vasal, S. K., Srinivasan, G., Han, G. C. and Gonzales, C. F. 1992. Heterotic patterns of eighty-eight white subtropical cimmyt maize lines. *Maydica*, **37:** 319–327.

Wani, M.M.A., Wani, S.A., Dar, Z.A., Lone, A.A., Abedi, I. and Gazal, A. 2017. Combining ability analysis in early maturing maize inbred lines under temperate conditions. *International Journal of Pure and Applied Biosciences,* **5** (2): 456-466. [Cross Ref]