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Research Article

GENERAL AND SPECIFIC COMBINING ABILITY STUDIES ON YIELD AND YIELD RELATED ATTRIBUTES IN MAIZE (*Zea mays.* L)

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Abstract- Combining ability studies were carried out for yield and its related traits by considering 72 hybrids, 12 lines, 6 testers and 3 checks during *kharif*-2012 at college of Agriculture, Dharwad. Parents and crosses showed highly significant differences for yield traits. The traits were further analyzed for general combining ability and specific combining ability effects.Combining ability estimates revealed, line BM254 and testers BM59 and BM258 as good combiners for cob weight. Similarly, for number of rows per cob, line BM5, for 100-grain weight, line BM8 and tester BM59 were considered as good combiners. With respect to grain yield per plant, line BM254 and testers BM59 and BM258 were found to be potential good combiners apart from expressing significant *gca* effects in desirable direction. The derived hybrids, BM24 x RNBL4611 and BM136 x BM1 were considered as early for flowering and silking respectively. For cob weight, cross BM60 x BM59 recorded highest *sca* effects with high mean cob weight. The hybrids BM51 x BM258 and BM24 x BM59 were found to be promising for number of rows per cob and 100-grain weight respectively. The complex/quantitative trait, grain yield per plant of the cross BM51 x BM258 was found to be good combination. Thus, the present study confirms BM254, BM59, BM258, BM5 and BM8 as best general combiners for the yield dependent traits. Therefore, these parental lines could be utilized in improvement of traits directly correlated with grain yield. The cross BM254 x BM285 with high specific combing ability for grain yield proves a best combination of these parents in exploitation of heterosis for grain yield in the form of single cross hybrids.

Keywords- General combining ability, Specific Combining Ability, Maize, Yield

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Introduction

Maize (*Zea mays* L.) is the third most important crop among the cereals grown in India. It has diversified uses like food, feed, fodder and industrial raw material. Maize acreage and production have an increasing tendency with the introduction of hybrids due to its high yield potential and hence it is also called queen of cereals. Yield in maize crop have increased dramatically over the years, as the crop breeders are successful in harnessing the heterosis for yield and its associated traits.

Exploitation of hybrid vigour and selection of parents based on combining ability has been used as an important breeding approach in crop improvement. For developing high yielding hybrids, potential parents and superior cross combinations must be identified. That is, information about combining ability of the parents and the resulting crosses is essential. Study of combining ability effects infers, type and nature of genes and gene interactions controlling the trait of interest and intern breeding value of the traits. Hence, the information on combining ability effects helpful in choosing the parents with high general combining ability (*gca*) and hybrids with high specific combining ability (*sca*).

General combining ability refers to the average performance of the genotype in a series of hybrid combinations and is a measure of additive gene action. Likewise, specific combining ability is the performance of a parent in a specific cross in relation to general combining ability and is a measure of genes showing non-additive effects [1]. A design called, Line× tester developed by [2] provides, reliable information on the general and specific combining ability effects of parents and their hybrid combinations.

Inbred lines considered in the present study were not studied for their combining ability features earlier and these lines were known for high yielding based on last few ys' evaluation studies. Consideration of such inbreds to estimate the combining abilities would be most advisable and therefore these lines could be utilized in development of single cross hybrids, composite and synthetic population. With this brief importance, estimation of combining ability effects of inbred lines and crosses of maize for yield and its associated traits was formed.

Material and Methods

The present investigation was carried out at college of Agriculture, Dharwad. Line x Tester mating design was followed to develop test cross hybrids by considering 12 lines and 6 testers during *Summer*-2012. The 72 test cross hybrids, 18 parents and 3 checks (Arjun, Bio-9681 and Super 900 M) were evaluated for yield and its components in a RBD with two replications during *Kharif*-2012 by following recommended agronomic practices and plant protection measures to raise a good crop.

Quantitative data of characters like, days to fifty per cent flowering, days to fifty per cent silking, plant height (cm), weight (g), length (cm), diameter (cm), kernel rows per, number of kernels per row, 100-grain weight (g), shelling percentage, grain yield per plant, fodder yield (t/ha) and protein content (%) was noted as plot basis for days fifty per cent flowering and silking whereas, for remaining characters plants were selected randomly from each entry and each replication. Mean values of each trait was considered for analysis according to principles and methods of Line x Tester design using the WINDOSTAT v8.1 software.

Results and Discussion

Analysis of variance for combining abilities with respect to yield and its components [Table-1] revealed, a significant mean sum of squares for all the traits except for fodder yield per plant and protein content indicating sufficient variability among the parents and thus, parents chosen were highly significant and similar results were also obtained by [3]. However, males showed significant mean sum of square for protein content.

Similarly, mean sum of squares for female versus male was found to be significant for plant height, cob height, cob length, kernels per row, days to 50 per cent silking, cob weight, plant girth, cob weight, cob diameter, number of rows per cob, 100-seed weight, shelling percentage and grain yield per plant. In the same way, variance due to the interaction effect of parents versus hybrids was also found to be significant for days to 50% tasseling, days to 50% silking, plant height, cob height, cob weight, cob length and protein content. These results agree with reports of [4]. These findingsindicated that, parents chosen were diverse and with a different genetic background and also revealing the presence of average heterosis due to the significant differences in the mean performances of hybrids and parents.

Table-1 *Analysis of variance for combining ability*

Source of variation	df	Days to 50% tasseling	Days to 50% silking	Plant height (cm)	Plant girth (cm)	Cob height (cm)	Cob weight (g)	Cob length (cm)
Replicates	1	23.36***	31.17***	21.62	0.07***	21.62	246.48	2.48
Crosses	71	0.91***	1.58***	451.84***	0.04***	451.84***	2845.51***	5.62***
Females (Lines)	11	1.49	1.80	1224.55***	0.03	1224.55***	4110.53	11.69**
Males (Testers)	5	0.28	3.29*	595.62	0.03	595.62	6392.71*	9.01
Line × Tester	55	0.85***	1.38***	284.23***	0.04***	284.23***	2270.03**	4.10***
Error	71	0.36	0.46	52.13	0.004	52.13	1202.12	1.74

Source of variation	df	Cob diameter (cm)	Number of rows per cob	Number of seeds per row	100-seed weight (g)	Shelling percentage	Grain yield per plant (g)	Fodder yield per plant (g)	Protein content (g)
Replicates	1	0.03	1.82	1.36	0.002	25.80	1974.32	0.004*	3.06
Crosses	71	0.26***	2.84*	21.21**	34.07***	43.86***	2643.34***	0.001*	2.26***
Females (Lines)	11	0.55***	8.96***	33.36	71.22***	60.11	3855.91*	0.001	3.37
Males (Testers)	5	0.91***	2.24	20.81	175.53***	70.65	7772.04**	0.003*	0.96
Line × Tester	55	0.15*	1.68	18.82*	13.78*	38.18***	1934.58***	0.001	2.16***
Error	71	0.09	1.64	11.45	7.81	7.76	587.38	0.001	0.97

* - Significant at 5% level ** - Significant at 1% level *** - Significant at 0.1% level

Combining ability estimates presented in [Table-2] infers that, among the lines, the gca effects for days to 50% flowering (-0.792) and days to 50% silking (-0.757) were significant and in negative direction for BM423, indicating the earliness of the parental line. Whereas, among tester RNBL 4711 (-0.424), was found to be early with significant and negative gca effects for days to 50% silking. For plant girth significant and positive gca effect was observed in four females BM259 (0.036), BM136 (0.049), BM52 (0.039) and BM254 (0.093), while among the tester BM59 (0.057) showed significant positive *gca* effect.

For cob weight, line BM254 (41.203) and testers BM59 (24.712) and BM258 (16.5)showed significant positive *gca* effects. Line BM254 (2.610) and tester BM59 (0.842) exhibited significant positive *gca* effect for Cob length. Similarly, for cob diameter, lines BM51 (0.227), BM254 (0.219) and the tester BM59 (0.326)obtained significant positive values and were found to be good combiners for the trait. While for number of rows per cob, lines BM127 (0.935), BM51 (1.235) and BM254 (1.435) showed significant positive *gca* values and the line BM136 (3.014) showed significant positive *gca* effects for number of kernels per row.

The lines such as BM24 (1.899), BM423 (2.354), BM8 (2.878), BM51 (1.938), BM254 (2.097) and the tester BM59 (5.421) showed significant positive *gca* values for 100-seed weight. For shelling percentage, line BM254 (3.654) and the tester BM59 (1.889) showed significant positive *gca* effects. For the trait grain yield per plant, line BM254 (3.654) exhibited significant positive *gca* value. Two testers such as, BM59 (27.1) and BM258 (18.317) showed significant positive *gca* effects for grain yield per plant. None of the lines were found to be good combiners for fodder yield. These results were mostly in conformity with findings of[5]. Line BM24 (0.814) was the only positive contributor for protein content. Thus the above parental lines were found to be potentially good combiners for the respective trait apart from expressing significant highest *gca* effects.

The specific combining ability results [Table-3] revealed that, BM254 x BM258 (-1.292), BM8 x BM32 (-1.250), BM83 x BM1(-1.125) and BM24 x RNBL 4611 (-1.00) displayed significant desirable negative *sca* effect for days to 50 per cent tasseling indicating good combinations for earliness and similar results were also reported by [6]. Significant *sca* effects in desirable direction for silking was exhibited by the hybrids such as, BM136 x BM1 (-1.368), BM254 x BM258 (-1.368), BM254 x BM59 (-1.285), BM136 x RNBL 4611 (-1.243), BM24 x BM59 (-1.201), BM60 x RNBL 4711 (-1.076) and BM259 x RNBL 4711 (-0.993) and these results are on par with the findings of [7].

High magnitude of *sca* effects for cob weight, was evidenced in the crosses BM60 x BM59 (77.521), BM52 x BM258 (59.646) and BM127 x BM32 (59.452) and were found to be best combinations for the trait. This indicates presence of additive x additive type of gene interaction. For cob length, BM259 x BM258 (2.973), BM127 x BM1 (2.332) and BM8 x RNBL 4711 (2.148) expressed maximum *sca* values. Similar results were also reported by [8] But, none of these crosses possessed the parents with high *gca* effects. This must be due to gene complementation between the parents, which has lead to increased cob length.

Maximum significant *sca* effects in positive direction was prevalent in three crosses, *viz.* BM136 x BM32 (0.567), BM254 x BM258 (0.535) and BM52 x BM258 (0.524) for cob diameter. Some parents of these crosses expressed non-significant *gca* effects. This confirmed the prevalence of non-additive gene effects in such crosses. BM51 x BM258 (2.182), BM52 x BM258 (2.082) and BM136 x BM1 (1.865) evidenced significantly positive and highest magnitude of *sca* effects for number of rows per cob. BM259 x BM258 (5.953) and BM8 x BM32 (5.894) expressed significant positive *sca* effects for number of kernels per row. BM259 x BM32 (6.207), BM36 x BM258 (4.498) and BM60 x RNBL 4711 (3.714) registered significant and maximum *sca* effects for the trait hundred seed weight.

Estimates of *sca* effects for shelling percentage revealed that BM52 x BM258 (7.445), BM52 x RNBL 4611 (5.998) and BM24 x BM32 (5.528) registered significant and maximum *sca* effects for the trait. Hybrid combinations BM51 x BM258 (76.35) displayed maximum positive *sca* value followed by BM52 x BM258 (49.417) and BM60 x BM59 (46.333) for grain yield per plant.Similar results were obtained by [9,10]. Crosses had at least one parent with significantly higher *gca* effect for the trait. This indicates presence of additive x dominance type of gene interaction.

For fodder yield per plant, highest magnitude of *sca* effects were evidenced in the crosses, BM24 x BM59 (0.061), BM127 x RNBL 4711 (0.042) and BM259 x BM1 (0.042). While the parents of these crosses expressed non-significant *gca* effects and interestingly there was prevalence of non-additive gene effects in such

Table-3 *Estimates of general combining ability effects of parents for yield and its componential traits*

Parents	Days to 50% flowering	Days to 50% silking	Plant height (cm)	Plant girth (cm)	Cob height (cm)	Cob weight (g)	Cob length (cm)	Cob diameter (cm)	Number of rows per cob	Number of seeds per row	100-seed weight (g)	Shelling percentage	Grain yield per plant (g)	Fodder yield per plant (g)	Protein content (%)
Females (Lines)															
BM259	0.458*	0.576**	-12.676***	0.036*	-12.676***	0.446	0.080	0.042	0.618	0.381	-3.088***	-0.881	-12.608	0.000	-0.761**
BM127	0.375*	0.326	-5.426**	0.016	-5.426**	-3.945	-0.973*	0.161	0.935**	-1.369	-0.525	0.459	9.942	0.003	-0.219
BM136	-0.125	0.160	-16.793***	0.049**	-16.793***	-6.493	0.595	-0.144	-1.065**	3.014**	0.169	-0.430	-2.475	-0.012	0.447
BM24	-0.292	-0.257	10.574***	-0.009	10.574***	11.159	0.082	-0.024	-0.532	0.731	1.899*	1.261	12.092	0.012	0.814**
BM423	-0.792***	-0.757***	8.390***	-0.026	8.390***	7.366	0.115	-0.009	-0.532	0.131	2.354**	0.915	6.808	0.013	0.381
BM8	0.208	0.243	8.907***	-0.058**	8.907***	-6.512	0.323	0.076	-0.265	-0.786	2.878***	0.614	4.492	-0.015	0.206
BM60	0.292	0.160	4.574*	-0.066***	4.574*	7.273	0.085	0.137	0.235	1.147	-0.671	-0.741	-7.008	0.003	0.106
BM51	-0.292	-0.340	-5.926**	-0.014	-5.926**	1.258	-0.812*	0.227*	1.235***	-3.069**	1.938*	1.738	13.858	0.004	-0.719**
BM52	-0.042	-0.424*	-10.926***	0.039*	-10.926***	-40.865***	-0.250	-0.559***	-0.865*	-1.203	-4.948***	-5.820***	-34.808***	-0.015	0.297
BM254	0.208	0.326	13.990***	0.093***	13.990***	41.203***	2.610***	0.219*	1.435***	1.364	2.097**	3.654***	35.592***	0.007	-0.811**
BM36	-0.125	-0.174	1.324	-0.058**	1.324	-7.371	-1.022**	-0.146	-0.799*	1.281	-2.217**	-0.259	-14.242	0.002	0.356
BM83	0.125	0.160	3.990*	-0.003	3.990*	-3.518	-0.833*	0.022	-0.399	-1.619	0.113	-0.511	-11.642	-0.001	-0.094
SEm±	0.1854	0.2025	1.8683	0.0171	1.8683	9.5271	0.3859	0.095	0.3499	0.9623	0.7505	0.956	7.9437	0.0079	0.2688
CD at 5% female	0.370	0.404	3.725	0.034	3.725	18.996	0.770	0.189	0.698	1.919	1.496	1.906	15.839	0.016	0.536
CD at 1% female	0.491	0.536	4.945	0.045	4.945	25.217	1.022	0.251	0.926	2.547	1.987	2.530	21.026	0.021	0.711
Males (Testers)															
BM59	0.000	0.618***	4.865***	0.057***	4.865***	24.712***	0.842**	0.326***	0.035	-1.511*	5.421***	1.889**	27.100***	0.011	-0.036
BM258	0.125	0.201	1.565	0.003	1.565	16.500*	-0.060	0.113	0.418	0.531	-0.128	1.252	18.317**	0.006	0.106
BM32	0.083	-0.007	-8.235***	-0.045***	-8.235***	-6.544	-1.048***	-0.065	0.285	-0.244	-1.455**	-2.829***	-14.650*	-0.001	0.214
RNBL4611	-0.167	-0.257	-3.218*	0.009	-3.218*	-10.331	0.179	-0.091	-0.240	0.681	-1.016	-0.236	-13.800*	-0.022***	-0.253
RNBL 4711	-0.083	-0.424**	0.615	-0.021	0.615	-10.909	-0.078	-0.049	-0.132	-0.469	-1.291*	-0.911	-8.117	0.007	0.181
BM1	0.042	-0.132	4.407**	-0.003	4.407**	-13.427	0.165	-0.234***	-0.365	1.014	-1.532**	0.834	-8.85	-0.001	-0.211
SEm±	0.1311	0.1432	1.3211	0.0121	1.3211	6.7367	0.2729	0.0671	0.2474	0.6805	0.5307	0.676	5.617	0.0056	0.19
CD at 5% male	0.261	0.286	2.634	0.024	2.634	13.432	0.544	0.134	0.493	1.357	1.058	1.348	11.2	0.011	0.379
CD at 1% male	0.347	0.379	3.497	0.032	3.497	17.831	0.722	0.178	0.655	1.801	1.405	1.789	14.867	0.015	0.503

* - Significant at 5% level ** - Significant at 1% level *** - Significant at 0.1% level

Table-4 *Estimates of specific combining ability effects of experimental single cross hybrids in respect of yield and its componential traits*

Experimental hybrids			Days to 50% tasseling	Days to 50% silking	Plant height (cm)	Plant girth (cm)	Cob height (cm)	Cob weight (g)	Cob length (cm)	Cob diameter (cm)	Number of rows per cob	Number of seeds per row	100-seed weight (g)	Shelling percentage	Grain yield per plant (g)	Fodder yield per plant (g)	Protein content (g)
BM259	×	BM59	-0.417	-0.035	-5.865	-0.172***	-5.865	-35.06	0.101	0.079	0.382	0.094	-4.179*	-7.663**	-61.967**	-0.040*	-1.697*
BM259	×	BM258	0.458	0.382	12.435**	-0.008	12.435**	-1.740	2.973**	-0.328	-0.801	5.953*	-0.299	1.066	20.617	0.012	1.461*
BM259	×	BM32	-0.500	-0.410	-8.265	0.040	-8.265	36.954	-0.388	0.310	0.332	-2.272	6.207**	2.695	12.983	-0.004	-0.697
BM259	×	RNBL 4611	0.250	0.340	6.718	0.036	6.718	-18.106	-1.196	-0.284	-0.043	-2.097	-0.696	0.172	0.633	-0.021	-1.231
BM259	×	RNBL 4711	-0.833	-0.993*	0.885	0.166***	0.885	12.033	-2.208*	0.444	0.549	-2.447	-0.018	3.869	36.25	0.012	1.136
BM259	×	BM1	1.042*	0.715	-5.907	-0.062	-5.907	5.920	0.718	-0.221	-0.418	0.769	-1.016	-0.140	-8.517	0.042*	1.028
BM127	×	BM59	0.667	0.715	-6.115	0.178***	-6.115	-38.786	-2.135*	-0.060	0.265	-3.456	0.391	0.343	-24.717	-0.006	-0.439
BM127	×	BM258	-0.458	-0.368	-13.315**	0.022	-13.315**	-83.791***	-1.203	0.254	-0.918	-0.497	-2.600	-3.352	-15.233	-0.019	-1.131
BM127	×	BM32	-0.417	-0.660	6.985	-0.060	6.985	59.452*	0.345	-0.098	1.215	2.878	1.753	2.889	23.933	-0.010	-0.489
BM127	×	RNBL 4611	-0.167	-0.410	12.468**	-0.144***	12.468**	-5.847	-1.033	-0.022	-0.060	-2.347	0.445	-0.586	-18.017	0.013	0.228
BM127	×	RNBL 4711	0.250	1.257*	1.135	-0.014	1.135	48.963*	1.695	0.155	0.232	1.803	0.209	0.943	37.600	0.042*	1.594*
BM127	×	BM1	0.125	-0.535	-1.157	0.018	-1.157	20.009	2.332*	-0.229	-0.735	1.619	-0.197	-0.237	-3.567	-0.020	0.236
BM136	×	BM59	0.667	0.882	1.751	0.105*	1.751	-13.515	0.846	-0.025	-0.535	1.761	-2.169	-3.482	-17.800	0.003	0.044
BM136	×	BM258	0.042	1.799***	-6.449	-0.192***	-6.449	-47.601*	-1.232	-0.381	-2.118*	-4.881*	-3.017	-6.376**	-60.817**	0.006	-0.147
BM136	×	BM32	0.583	0.007	-22.849***	-0.043	-22.849***	1.737	1.687	0.567*	0.615	3.994	3.375	5.206*	45.750*	-0.019	1.094
BM136	×	RNBL 4611	-0.667	-1.243*	-17.165***	-0.028	-17.165***	20.938	0.569	-0.057	0.740	-1.031	0.658	0.712	-6.900	-0.003	-1.139
BM136	×	RNBL 4711	0.250	-0.076	26.001***	-0.128**	26.001***	13.535	-1.433	-0.16	-0.568	0.419	1.067	3.873	35.217	0.005	0.428
BM136	×	BM1	-0.875	-1.368**	18.710***	0.285***	18.710***	24.906	-0.437	0.056	1.865*	-0.264	0.086	0.067	4.550	0.009	-0.281
BM24	×	BM59	-0.667	-1.201*	4.885	0.113**	4.885	11.234	0.470	0.005	-0.468	-0.656	3.562	2.981	37.633	0.061**	0.428
BM24	×	BM258	0.208	0.215	11.685*	-0.043	11.685*	17.362	0.342	-0.021	0.149	3.703	-0.570	1.629	7.317	0.021	0.286
BM24	×	BM32	1.250**	1.424**	16.985***	-0.035	16.985***	27.518	0.360	0.367	1.482	1.678	0.018	5.528*	32.083	0.019	0.078
BM24	×	RNBL 4611	-1.000*	0.174	-4.032	0.151***	-4.032	-6.401	0.402	0.033	-0.793	-2.047	3.215	-3.284	-2.467	-0.008	0.944
BM24	×	RNBL 4711	-0.083	-0.160	-7.365	-0.139**	-7.365	5.710	-0.030	-0.440	-0.701	1.203	-4.625*	-3.203	-43.050*	-0.052**	-0.789
BM24	×	BM1	0.292	-0.451	-22.157***	-0.047	-22.157***	-55.423*	-1.543	0.056	0.332	-3.881	-1.601	-3.651	-31.517	-0.040*	-0.947

Experimental hybrids	Days to 50% tasseling	Days to 50% silking	Plant height (cm)	Plant girth (cm)	Cob height (cm)	Cob weight (g)	Cob length (cm)	Cob diameter (cm)	Number of rows per cob	Number of seeds per row	100-seed weight (g)	Shelling percentage	Grain yield per plant (g)	Fodder yield per plant (g)	Protein content (g)
BM423 × BM59	-0.667	0.799	0.568	-0.01	0.568	4.671	-0.094	-0.270	-0.668	1.544	0.521	0.934	0.317	-0.004	1.011
BM423 × BM258	0.208	-0.785	-0.232	0.063	-0.232	-20.948	-1.312	-0.096	-0.051	-0.697	-1.775	-2.151	-17.800	-0.028	-1.031
BM423 × BM32	0.750	0.424	5.668	0.022	5.668	14.854	-0.483	0.032	0.082	-2.622	0.374	1.123	-0.333	0.018	0.961
BM423 × RNBL 4611	0.000	-0.326	-7.349	0.088*	-7.349	-10.196	1.849	0.198	1.007	2.753	-2.397	-0.956	13.017	0.024	-0.722
BM423 × RNBL 4711	-0.583	-0.660	-2.182	0.168***	-2.182	-1.025	0.857	-0.015	0.099	0.103	1.078	1.036	2.033	-0.025	-0.556
BM423 × BM1	0.292	0.549	3.526	-0.330***	3.526	12.644	-0.817	0.151	-0.468	-1.081	2.199	0.014	2.767	0.015	0.336
BM8 × BM59	-0.167	-0.701	-4.949	0.112**	-4.949	-16.837	-0.962	-0.195	-0.535	-1.239	-0.088	-1.688	-15.867	0.004	0.286
BM8 × BM258	0.208	-0.285	7.351	-0.125**	7.351	-27.595	-2.410*	0.029	-0.518	-5.281*	-0.014	-3.725	-41.183*	-0.003	0.894
BM8 × BM32	-1.250**	-0.576	1.151	-0.067	1.151	13.571	0.718	0.167	-0.385	5.894*	-0.181	4.212	34.483	-0.008	0.236
BM8 × RNBL 4611	0.500	0.674	13.635**	-0.101*	13.635**	27.068	-0.019	-0.147	0.140	-1.131	0.870	-0.316	11.233	-0.015	-0.047
BM8 × RNBL 4711	0.417	-0.160	-10.199*	0.029	-10.199*	-20.890	2.148*	0.040	0.632	-1.381	-1.915	1.155	-4.050	0.014	-1.481*
BM8 × BM1	0.292	1.049*	-6.990	0.152***	-6.990	24.684	0.525	0.106	0.665	3.136	1.327	0.362	15.383	0.008	0.111
BM60 × BM59	-0.250	-0.618	-16.615***	0.050	-16.615***	77.521**	0.886	0.064	0.365	1.028	1.252	1.867	46.333*	-0.030	0.486
BM60 × BM258	0.625	0.799	-0.315	0.003	-0.315	-36.620	0.458	-0.383	-1.218	0.786	-2.802	-1.253	-24.683	-0.009	-0.506
BM60 × BM32	0.167	0.507	13.485**	-0.038	13.485**	-0.781	-0.173	0.035	-0.285	-0.039	1.765	-1.525	-6.717	0.007	-0.164
BM60 × RNBL 4611	-0.083	0.257	-8.532	-0.113**	-8.532	-27.241	-1.861	0.051	0.240	-0.664	-2.513	1.771	5.133	-0.006	-0.597
BM60 × RNBL 4711	-0.167	-1.076*	1.135	0.038	1.135	2.475	1.937*	0.269	0.332	1.986	3.714*	-2.458	-16.950	0.025	1.519*
BM60 × BM1	-0.292	0.132	10.843*	0.060	10.843*	-15.353	-1.247	-0.036	0.565	-3.097	-1.415	1.598	-3.117	0.012	-0.739
BM51 × BM59	-0.167	0.882	13.385**	-0.142**	13.385**	13.268	-0.391	0.014	0.565	-0.556	0.214	-0.491	0.667	0.023	1.111
BM51 × BM258	1.208**	0.799	-1.815	0.112**	-1.815	37.607	-0.504	0.137	2.182*	-0.697	1.554	3.884	76.350***	0.038	0.219
BM51 × BM32	-0.750	-0.493	-17.015***	0.120**	-17.015***	-17.747	-0.726	0.135	-0.485	-0.722	-0.165	0.062	-29.783	-0.020	-0.589
BM51 × RNBL 4611	-0.500	-0.743	-7.532	0.166***	-7.532	14.095	0.297	0.051	-0.360	-0.447	0.108	-0.874	-22.133	-0.013	0.528
BM51 × RNBL 4711	0.417	-0.076	3.635	0.006	3.635	-38.13	0.474	-0.071	-0.468	0.403	-1.348	-0.434	-14.117	0.002	-0.656
BM51 × BM1	-0.208	-0.368	9.343*	-0.262***	9.343*	-9.093	0.851	-0.266	-1.435	2.019	-0.363	-2.147	-10.983	-0.03	-0.614
BM52 × BM59	1.083*	0.965	11.385*	0.025	11.385*	-30.597	1.041	0.150	0.065	1.278	1.895	3.712	-4.167	-0.001	-1.256
BM52 × BM258	-0.542	-0.618	10.185*	0.228***	10.185*	59.646*	2.143*	0.524*	2.082*	4.536	2.774	7.445**	49.417*	0.000	-0.347

Experimental hybrids	Days to 50% tasseling	Days to 50% silking	Plant height (cm)	Plant girth (cm)	Cob height (cm)	Cob weight (g)	Cob length (cm)	Cob diameter (cm)	Number of rows per cob	Number of seeds per row	100-seed weight (g)	Shelling percentage	Grain yield per plant (g)	Fodder yield per plant (g)	Protein content (g)
BM52 × BM32 RNBL	-0.500	0.090	-20.015***	-0.203***	-20.015***	-42.718	-2.898**	-0.798**	-0.385	-5.689*	-9.276***	-21.810***	-74.117***	-0.001	-0.256
BM52 × 4611 RNBL	0.250	-0.160	-1.532	0.052	-1.532	-0.731	1.754	0.108	-0.860	3.286	1.966	5.998*	19.533	0.018	1.311
BM52 × 4711	-0.333	-0.493	-3.365	-0.188***	-3.365	2.206	-2.078*	-0.055	-0.568	-3.464	0.410	-0.610	-21.05	-0.02	-0.522
BM52 × BM1	0.042	0.215	3.343	0.085*	3.343	12.193	0.038	0.071	-0.335	0.053	2.231	5.265*	30.383	0.003	1.069
BM254 × BM59	0.333	-1.285*	6.968	-0.048	6.968	16.173	-0.699	0.122	-0.235	-3.389	2.024	0.579	20.433	0.003	-0.347
BM254 × BM258	-1.292**	-1.368**	-7.732	0.025	-7.732	41.904	1.733	0.535*	1.582	2.469	0.539	1.766	35.017	0.01	0.561
BM254 × BM32 RNBL	0.750	0.340	1.568	-0.037	1.568	-16.212	2.062*	-0.376	-1.285	-0.156	-0.158	1.207	-8.617	0.004	-0.847
BM254 × 4611 RNBL	0.000	1.090*	-7.449	-0.221***	-7.449	-25.679	-1.256	-0.091	-0.160	0.219	-3.052	-3.264	-24.567	0.021	0.219
BM254 × 4711	-0.083	0.257	3.218	0.239***	3.218	20.511	-0.908	0.077	1.132	3.069	2.767	1.968	6.650	-0.024	1.336*
BM254 × BM1	0.292	0.965	3.426	0.042	3.426	-36.698	-0.932	-0.267	-1.035	-2.214	-2.121	-2.256	-28.917	-0.014	-0.922
BM36 × BM59	-0.333	-0.285	1.635	-0.148***	1.635	13.791	1.153	0.057	0.799	3.194	-1.224	1.108	17.667	-0.002	0.286
BM36 × BM258	0.042	0.132	-14.065**	-0.015	-14.065**	46.057	-1.335	-0.160	0.215	-6.647**	4.498*	-0.202	-25.850	0.002	-1.956**
BM36 × BM32 RNBL	-0.417	-0.660	5.235	0.063	5.235	-47.373*	-1.117	-0.141	-0.251	-4.272	-2.152	-1.534	-24.783	-0.006	0.836
BM36 × 4611 RNBL	0.333	0.090	1.218	0.069	1.218	-4.538	-0.074	-0.106	-0.526	1.803	-0.702	-0.297	-1.333	-0.014	-0.197
BM36 × 4711	0.250	0.757	0.385	-0.001	0.385	-3.050	0.693	-0.058	-0.435	3.353	-0.179	0.388	9.683	0.029	0.919
BM36 × BM1	0.125	-0.035	5.593	0.032	5.593	-4.887	0.680	0.408	0.199	2.569	-0.240	0.538	24.617	-0.009	0.111
BM83 × BM59	-0.083	-0.118	-7.032	-0.063	-7.032	-1.862	-0.215	0.059	-0.001	0.394	-2.198	1.799	1.467	-0.011	0.086
BM83 × BM258	-0.708	-0.701	2.268	-0.070	2.268	15.718	0.347	-0.108	-0.585	1.253	1.714	1.271	-3.150	-0.029	1.694*
BM83 × BM32 RNBL	0.333	0.007	17.068***	0.238***	17.068***	-29.255	0.615	-0.200	-0.651	1.328	-1.559	1.947	-4.883	0.020	-0.164
BM83 × 4611 RNBL	1.083*	0.257	19.551***	0.044	19.551***	36.637	0.567	0.266	0.674	1.703	2.097	0.923	25.867	0.004	0.703
BM83 × 4711	0.500	1.424**	-13.282**	-0.176***	-13.282**	-42.337	-1.145	-0.186	-0.235	-5.047*	-1.162	-6.528**	-28.217	-0.009	-2.931***
BM83 × BM1	-1.125*	-0.868	-18.574***	0.027	-18.574***	21.099	-0.168	0.169	0.799	0.369	1.109	0.588	8.917	0.024	0.611
SEm±	0.454	0.496	4.576	0.042	4.576	23.336	0.9453	0.233	0.857	2.357	1.838	2.342	19.458	0.019	0.658
CD at 5%	0.905	0.989	9.125	0.083	9.125	46.531	1.885	0.464	1.709	4.700	3.666	4.669	38.798	0.039	1.313
CD at 1%	1.202	1.313	12.113	0.111	12.113	61.768	2.502	0.616	2.269	6.239	4.866	6.198	51.502	0.051	1.743

* - Significant at 5% level ** - Significant at 1% level *** - Significant at 0.1% level

crosses for the trait. Potentially good combinations for protein content were BM83 x BM258 (1.694), BM127 x RNBL 4711 (1.594), BM60 x RNBL 4711 (1.519), BM259 x BM258 (1.461) and BM254 x RNBL 4711 (1.336).

It is evident that the best three crosses exhibiting desirable *sca* effects for grain yield were showed the involvement of parents with high x high *gca* effects. Thus three crosses namely, BM60 x BM59,BM51 x BM258 and BM52 x BM258 which have shown high *sca* effects for grain yield involving parents of positive and significant gca effects can be exploited for the development of single cross hybrids since non additive gene action for most of the traits was observed. Further, they can also be used for population improvement programme through reciprocal recurrent selection.

Conclusion

The study on general and specific combining ability effects for yield and yield related traits conducted using twelve lines, six testers and seventy two test cross hybrids along with three checks concludes as follows. The best general combiner lines and testers for the traits ear weight and grain yield per plant are BM254 and BM59, BM258 respectively. Since, ear weight and grain yield inter correlates with each other, selection of parents with high general combining ability for it would decently lead to grain yield improvement. Our study also identified two better heterotic combinations (BM254 x RNBL4611 and BM136 x BM1) for short duration, a most required feature of hybrids to escape terminal droughts or moisture stress prevailing due to recent climatic change phenomenon. Therefore, these crosses may further tested for their stability at various agro-climates if found stable, they may recommend for multi location trails. A another cross, BM51 x BM258 which showed highest and significant sca effect (76.35**) was found to be heterotic combination for grain yield per plant and this cross also be recommended for stability analysis and the parents can be considered as superior inbreds for grain yield.

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Author Contributions

1. Miss. Chandana BC, MSc (Agri), who has conducted the research work during MSc Agri degree programme.
2. Dr. Deshpande SK, Professor and Head, Department of Genetics and Plant Breeding, UAS, Dharwad, who is the chairman for the advisory committee of research programme

Abbreviations

cm- Centimetre
g-Gram
t/ha- Ton per Hectare
%- Per cent age
L - Linneous
v - Version
MSc - Masters of Science
PhD - Doctors of Philosophy

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.

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