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Heterosis and Combining Ability Studies in Indigenous Collection of Pearl Millet Germplasm [*Pennisetum glaucum* (L.) R. Br.]

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A B S T R A C T

The heterosis and combining ability study was conducted in pearl millet involving 60 crosses and 32 parents for 10 quantitative traits to predict the gene action involved in inheritance of yield and yield contributing traits and to identify best general combiners and superior crosses. Among parents, the line ICMA 04999 and testers 2325, 2396, 2306, 2337, 2348 and 2394 were the good general combiners for grain yield and could be used in hybridization programme to exploit their general combining ability. The components of variance due to *gca* and *sca* revealed predominance of non-additive gene action for all the traits. The cross ICMA 04999 × 2309 recorded high significant positive *sca* effect, mid parent, better parent heterotic effect and *per se* performance for grain yield.

Introduction

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is the important staple food crop in arid and semi-arid zones. It occupied sixth place among cereal crops in the world after wheat, rice, maize, barley and sorghum. In India it occupies fourth place in acreage of 7.4 million hectares with a production of 9.2 million tonnes and productivity of 1231kg/ha (Ministry of Agriculture, 2017-2018). Pearl millet is a cross pollinated crop with protogynous nature and also availability of cytoplasmic male sterile lines, helps in exploitation of heterosis for development of hybrids. Selection of better parents is a prerequisite for exploitation of heterosis. Selection of parents based on their phenotypic performance may not give better results when combined with other genotypes. Combining ability analysis provides information about selection of desired parents and nature of gene action involved in the inheritance of different traits. The nature of gene action depends on the genetic architecture of the parents involved in the hybridization programme

(Khandagale *et al.,* 2014). So, combining ability analysis is necessary for selection of parents before conducting any hybrid breeding programme. Among the biometrical procedures, Line × Tester mating design is widely used to study the combining ability of parents chosen for heterosis breeding (Solanki *et al.,* 2017). This design is helpful in evaluation of large number of germplasm lines at a time in terms of combining ability variances and effects (Sprague and Tatum, 1942).

Hence the present investigation was undertaken to study combining ability and heterosis for selection of desired hybrids based on their mid parent heterosis, heterobeltiosis and standard heterosis.

Materials and Methods

The material consists of two male sterile lines (ICMA 04999 and ICMA 97111), 30 testers collected from different parts of the India *i.*e., Tamilnadu, Maharashtra, Madhya Pradesh and Andhra Paradesh, six national checks (GHB 558, GHB 905, RHB 173, HHB 272, MPMH 21, HHB 67 improved) and 60 F_1 hybrids generated by crossing two male sterile lines with 30 testers in Line × Tester mating design (Kempthorne, 1957) at IIMR during *summer,* 2019. All the F_1's along the parents and checks were raised in alpha lattice design (Patterson and Williams, 1976) with three replications during *kharif*, 2019. Each genotype was grown in two rows with two metres row length and spacing of 45cm between rows and 15cm between plants in a row. All agronomic and plant protection measures were followed as per recommendation to raise good and healthy crop. The observations were recorded on five randomly selected competitive plants in each replication for 10 quantitative traits *viz.,* days to 50 per cent flowering, plant height, total number of productive tillers, panicle length, panicle width, 1000-grain weight, fodder yield, grain yield, total biomass and harvest index. Among the six checks, the *per se* performance of RHB- 173 was good and this was taken as standard parent for estimation of standard heterosis. Statistical analysis was executed using Genstat 12 edn and Indostat software packages.

Results and Discussion

The Analysis of variance for combining ability analysis revealed the presence of considerable amount of genetic variability in the experimental material for all the traits except total number of productive tillers per plant indicating significant contribution of these traits towards combining ability. The components of variance for all the characters suggested that the *gca* variance was less than the *sca* variance, the ratio of *gca*/*sca* variance being less than unity indicating the predominance of non- additive gene action in the inheritance of these traits. This indicates that recurrent selection for specific combining ability would be quite effective in improvement of these traits. Similar pattern of results for non-additive gene action were earlier reported by Bharath and Dangaria (2018) for days to 50 per cent flowering, Gavali *et al.,* (2018) for plant height, panicle length and panicle width; Patel *et al.,* (2018) for 1000- grain weight, Krishnan *et al.,* (2019) for number of productive tillers per plant and grain yield; Shinde and Mehetre (2014) for fodder yield; Solanki *et al.,* (2017) for total biomass and harvest index. (Table 1).

The general combining ability estimates provide the information regarding the average performance of a line among different crosses which in turn reflects the breeding value of the line. In the present study, general combining ability effects of parents revealed that none of the line or tester recorded significant gca effect in desirable direction for all the traits. However, among the parents, the tester 2325 was turned to be the good general combiner for grain yield, panicle width in addition to panicle length and 1000-grain weight in desirable direction. The parent 2381 and 2349 recorded highest significant *gca* effect in desirable direction for days to 50 per cent flowering and plant height respectively, which inturn can be used in breeding programmes to develop early and dwarf genotypes. The tester 2368 was good combiner for panicle length along with 1000-grain weight. Similarly the parents 2352 and 2365 were found to be good combiners for 1000-grain weight and harvest index respectively. Athoni *et al.,* (2016) reported significant *gca* effects for days to 50 per cent flowering, plant height, panicle length, panicle width, 1000 grain weight and grain yield; Kumar *et al.,* (2017) for harvest index (Table 2).

Consideration of *per se* performance of parents along with *gca* effects will give better results in selection of parents for hybrid breeding programme (Rao, 1972 and Bhadalia *et al.,* 2014). In the present study the parents 2348, 2325, 2306 and 2394 recorded significant *gca* effects for grain yield in desirable direction along with better *per se* performance. The results are in accordance with earlier reports of Bhardwaj *et al.,* (2015) for grain yield. Therefore, the crosses involving 2325, 2381 and 2349 would result in development of good hybrids with favourable gene combinations for grain yield, days to 50 per cent flowering and plant height respectively.

The specific combining ability effects determine the specific cross combination for a particular trait or group of traits. A perusal of *sca* effects (Table 3) revealed that the cross ICMA 97111 × 2386 was best specific combiner for days to 50 per cent flowering. This cross may be further used in breeding programs for improvement of this trait and for the production of short duration hybrids. ICMA 04999 × 2382 and ICMA 97111 × 2311 recorded high significant and positive *sca* effects for the traits *viz.,* plant height and panicle length. The crosses ICMA 04999 × 2311 and ICMA 97111 × 2382 recorded significant negative *sca* effects as these were best for improvement of short genotypes with lodging resistance. The cross ICMA 04999 × 2309 was best specific combiner for grain yield and fodder yield. The crosses ICMA 04999 × 2348 and ICMA 97111 × 2348 recorded highest significant *sca* effect with a common tester for total biomass and harvest index respectively. The crosses ICMA 04999 × 2310 and ICMA 97111 × 2310 were best for days to 50 per cent flowering and fodder yield with a common tester respectively. It indicates that, even though the two crosses have same tester, the two traits were not best in one cross. Similar results for significant *sca* effects in desirable direction were earlier reported by Singh and Sharma (2014) for plant height, panicle length and panicle width; Saini *et al.,* (2018) for days to 50 per cent flowering, total biomass, harvest index and grain yield.

The crosses with high *sca* effects resulting from low × low *gca* parental combinations was observed in ICMA 97111 × 2386 for days to 50 per cent flowering, ICMA 97111 × 2311 for plant height, ICMA 04999 × 2382 for panicle length, ICMA 97111 × 2310 for fodder yield, ICMA 04999 × 2309 for grain yield indicating the involvement of complimentary gene action in the inheritance of these traits. The crosses from high × low or low × high *gca* parental combinations with high *sca* effects were noticed in ICMA 97111 × 2333 for 1000-grain weight; ICMA 04999 × 2348 for total biomass and ICMA 97111 × 2348 for harvest index indicating that the involvement of one low combiner will result in high *sca* effects.

Table.1 Analysis of variances for combining ability for yield and its component characters in Pearl millet [*Pennisetum glaucum* (L.) R. Br.]

Source of variations	d.f.	Days to 50 per cent flowering	Plant height (cm)	Total number of productive tillers per plant	Panicle length (cm)	Panicle width (cm)	1000 grain weight (g)	Fodder yield (t/ha)	Total biomass (t/ha)	Harvest index	Grain yield (t/ha)
Replications	2	54.551*	2158.097**	0.630	5.946	0.055	0.999	156.327*	105.576**	0.061**	2.011
Treatments	59	33.465**	665.422**	0.593	18.232**	0.197**	4.913**	86.406**	37.280**	0.008**	1.541**
Line effect	1	14.735	40.850	0.118	13.484	0.017	1.842	35.506	126.085	0.012	1.140
Tester effect	29	18.524	487.630	0.714	22.648	0.243	5.651	83.875	37.396	0.007	1.854
Lines × Tester effect	29	49.051**	864.751**	0.489	13.979**	0.158**	4.281**	90.693**	34.103**	0.008	1.242*
Error	118	7.560	298.979	0.659	3.785	0.070	1.026	37.085	15.042	0.004	0.761
σ^2 gca		0.1890	-0.7237	-0.0051	0.2975*	0.0012	0.0567	0.471	1.3895*	0.0001	0.0153
σ^2 sca		13.8303**	188.5907**	-0.0569	3.3982**	0.0293**	1.0850**	17.8694**	6.3534**	0.0014**	0.1602*
σ^2 gca / σ^2 sca		0.0137	-0.004	0.0896	0.0875	0.0409	0.0522	0.0263	0.218	0.0714	0.0955

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

Table.2 General combining ability for quantitative traits in pearl millet

Parents	Days to 50 per cent flowering	Plant height (cm)	Total number of productive tillers per plant	Panicle length (cm)	Panicle width (cm)	1000 grain weight (g)	Fodder yield (t/ha)	Total biomass (t/ha)	Harvest index	Grain yield (t/ha)
Lines										
ICMA 04999	-0.286**	0.476	-0.026**	0.274*	0.010**	-0.101**	0.444	0.837*	-0.008**	0.080**
ICMA 97111	0.286	-0.476**	0.026	-0.274**	-0.010**	0.101**	-0.444**	-0.837**	0.008**	-0.080**

SE	0.289	1.822	0.085	0.205	0.027	0.106	0.641	0.4088	0.0071	0.092
C D at 5%	0.573	3.609	0.169	0.406	0.055	0.211	1.271	0.8096	0.0140	0.182
Testers										
2306	0.914	7.015	0.356	1.543	0.214**	1.701**	6.475	3.530	-0.008**	0.724*
2309	-2.419**	-12.418**	-0.628**	-2.207**	-0.136**	1.551**	2.592	-0.550**	-0.018**	-0.159**
2310	-1.253**	-7.118**	-0.078**	-1.441**	-0.403**	-1.732**	2.409	1.090	-0.051**	-0.276**
2311	-0.753**	13.382	0.689 *	-4.091**	-0.553**	-1.066**	-2.791**	-3.463**	-0.036**	-0.909**
2368	0.914	11.382	0.372	3.843*	0.064*	0.751*	6.292	4.117	-0.043**	0.324
2370	0.331	-8.318**	-0.028**	-3.707**	-0.203**	1.00 *	-8.441**	-4.526**	-0.016**	-1.176**
2318	-2.253**	-12.451**	0.372	-1.507**	-0.303**	-0.216**	-4.441**	-4.705**	-0.001**	-1.193**
2381	-5.086**	7.599	0.356	-0.474**	-0.036**	0.568	-4.075**	-1.541**	-0.001**	-0.176**
2325	0.247	10.065	-0.028**	2.543*	0.298**	0.684*	3.875	5.709	-0.019**	0.874**
2327	1.081	3.382	-0.094**	-2.141**	0.014	-0.616**	-1.125**	-2.058**	0.034**	-0.059**
2328	-0.086**	-3.418**	-0.361**	-0.291**	-0.003**	-0.016**	3.909	1.634	0.001	0.207
2329	-0.419**	7.565	-0.294**	-0.424**	0.064*	-0.916**	1.475	0.904	0.007**	0.441
2330	1.081	18.349	0.256	1.343	0.198**	-0.266**	0.175	1.722	0.009**	0.207
2331	1.581	2.549	-0.094**	1.976	-0.103**	-0.466**	-4.808**	-3.801**	0.031**	-0.409**
2332	3.414	0.249	-0.044**	1.926	0.098**	-1.182**	-0.375**	-1.093**	0.012**	-0.209**
2333	-0.25**	1.732	-0.011**	-0.524**	0.131**	1.551**	-1.475**	-0.803**	0.036**	0.391
2337	-2.753**	-6.618**	0.089	-1.957**	0.131**	-0.549**	1.859	2.187	0.006**	0.724*
2382	2.414	14.732	-0.078**	0.809	0.114**	0.001	3.692	2.422	-0.058**	-0.476**
2342	-0.919**	0.015	0.206	-1.941**	-0.269**	-1.132**	4.092	0.000	-0.024**	-0.176**
2386	1.247	4.415	0.472*	-0.624**	0.131**	-1.216 **	3.342	2.002	-0.044**	-0.176**
2348	1.747	1.757	0.256	1.781	-0.061**	-0.631**	0.651	1.447	0.067**	0.686*
2352	-1.086**	-4.151**	-0.261**	-0.991**	0.148**	1.901**	-0.558**	-1.190**	0.012**	-0.009**
2364	0.914	-8.285**	0.139	3.643*	0.164**	0.218	5.375	1.569	-0.001**	0.474
2365	0.914	-6.601**	-0.361**	-0.191**	0.081**	-0.049**	-3.141**	-2.880**	0.086**	0.041
2387	-0.086**	-12.385**	-0.311**	0.459	-0.269**	-1.466**	-0.341**	-0.205**	-0.023**	-0.176**
2394	-2.419**	-4.151**	-0.128**	1.359	0.098**	0.601	-4.258**	0.152	0.046**	0.674*
2395	0.414	-1.651**	-0.028**	0.109	-0.053**	-0.166**	-1.308**	0.224	-0.021**	-0.159**
2396	1.081	5.015	-0.811**	1.693	0.148**	0.401	-2.225**	0.167	0.056**	0.824*
2346	1.747	-2.485**	0.489*	0.076	0.098**	0.201	-4.825**	-2.056**	-0.013**	-0.643**
2349	-0.253**	-19.151**	-0.411**	-0.591**	0.198**	0.551	-2.025**	-0.003**	-0.028**	-0.209**
SE	1.122	7.059	0.331	0.794	0.108	0.413	2.486	1.583	0.027	0.356
CD at 5%	2.222	13.978	0.656	1.572	0.214	0.818	4.923	3.135	0.054	0.705

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

Table.3 Specific combining ability for quantitative traits in pearl millet

Crosses	Days to 50 per cent flowering	Plant height (cm)	Total number of productive tillers per plant	Panicle length (cm)	Panicle width (cm)	1000 grain weight (g)	Fodder yield (t/ha)	Total biomass (t/ha)	Harvest index	Grain yield (t/ha)
ICMA 04999 × 2306	-0.381	-1.643	-0.524	1.310	-0.176	-0.316	0.106	0.236	-0.005	-0.063
ICMA 04999 × 2309	1.953	6.190	0.359	0.960	0.140	-1.199*	7.323*	3.506	0.038	1.120*
ICMA 04999 × 2310	-5.547**	-14.176	-0.191	-0.274	-0.093	0.751	-8.761*	-2.967	0.038	0.004
ICMA 04999 × 2311	-5.047**	-34.610**	-0.524	-2.657*	0.090	0.218	-7.294*	-3.924	0.010	-0.730
ICMA 04999 × 2368	3.286*	3.990	0.259	-0.457	-0.260	-0.399	-3.044	-0.574	-0.040	-0.730
ICMA 04999 × 2370	0.536	18.690	0.192	0.326	0.240	-0.282	5.423	3.600	0.010	0.604
ICMA 04999 × 2318	-3.214*	-3.776	0.359	-0.540	0.140	-0.999	-1.211	1.168	0.012	0.187
ICMA 04999 × 2381	0.953	-12.060	0.242	-1.640	-0.060	-0.416	-3.044	-0.479	0.012	0.004
ICMA 04999 × 2325	1.619	-1.360	0.426	-1.924	-0.193	-0.932	1.973	2.801	-0.023	-0.080
ICMA 04999 × 2327	1.119	-11.276	0.026	-0.774	-0.143	0.201	1.039	-1.809	-0.033	-0.646
ICMA 04999 × 2328	1.619	-1.410	-0.241	-0.190	0.074	0.501	-0.627	-3.084	0.073	0.287
ICMA 04999 × 2329	0.286	14.574	-0.241	-0.057	0.040	-0.932	-1.561	-2.827	0.017	-0.480
ICMA 04999 × 2330	0.453	-1.310	0.176	-1.890	-0.193	0.551	-5.427	-4.302	0.052	-0.380
ICMA 04999 × 2331	-4.714**	-7.176	0.026	0.743	0.007	1.385*	-0.444	-0.359	0.007	-0.096
ICMA 04999 × 2332	0.453	0.124	0.076	-1.074	-0.126	0.301	4.356	0.306	-0.055	-0.296
ICMA 04999 × 2333	1.119	8.640	-0.024	1.176	-0.026	-2.232**	-4.144	-1.354	0.052	0.270
ICMA 04999 × 2337	-0.047	0.324	-0.358	0.010	0.140	0.568	-2.677	-1.044	-0.028	-0.630
ICMA 04999 × 2382	4.453**	27.307**	0.142	3.710**	0.090	-0.149	3.989	3.181	-0.065	-0.530
ICMA 04999 × 2342	-0.547	0.357	0.059	2.126	0.274	0.851	-0.077	0.343	0.015	0.337
ICMA 04999 × 2386	6.619**	1.024	-0.074	1.543	0.174	0.701	6.206	2.788	-0.018	0.137
ICMA 04999 × 2348	0.786	11.949	-0.524	1.771	-0.001	0.550	5.197	4.716*	-0.087*	0.508
ICMA 04999 × 2352	-2.381	1.190	0.192	-1.057	-0.143	0.118	3.473	1.370	-0.018	0.270
ICMA 04999 × 2364	-3.047	-6.343	-0.074	0.343	-0.160	0.968	-1.361	0.131	-0.032	-0.280
ICMA 04999 × 2365	1.286	13.640	0.292	1.610	-0.176	-0.232	-1.744	-0.160	-0.032	-0.013
ICMA 04999 × 2387	-0.381	-8.810	0.242	-0.940	0.174	0.984	2.156	1.785	0.007	0.470
ICMA 04999 × 2394	2.286	2.857	-0.041	-1.607	0.274	-1.749**	3.073	1.255	0.018	0.554
ICMA 04999 × 2395	-4.547**	-16.310	0.292	-2.357*	-0.210	0.851	-2.477	-1.047	0.058	0.487
ICMA 04999 × 2396	-2.214	-9.643	-0.024	-0.607	-0.110	0.085	-1.561	-1.027	0.032	0.170

Crosses	Days to 50 per cent flowering	Plant height (cm)	Total number of productive tillers per plant	Panicle length (cm)	Panicle width (cm)	1000 grain weight (g)	Fodder yield (t/ha)	Total biomass (t/ha)	Harvest index	Grain yield (t/ha)
ICMA 04999 × 2346	3.453*	9.524	-0.558	-0.124	0.240	-0.149	1.773	1.286	-0.030	0.004
ICMA 04999 × 2349	-0.214	9.524	0.042	2.543*	-0.026	0.401	-0.627	-3.520	0.018	-0.463
ICMA 97111 × 2306	0.381	1.643	0.524	- 1.310	0.176	0.316	-0.106	-0.236	0.005	0.063
ICMA 97111 × 2309	-1.953	- 6.190	-0.359	- 0.960	-0.140	1.199*	-7.323*	-3.506	-0.038	-1.120*
ICMA 97111 × 2310	5.547**	14.176	0.191	0.274	0.093	-0.751	8.761*	2.967	-0.038	-0.004
ICMA 97111 × 2311	5.047**	34.610**	0.524	2.657*	-0.090	-0.218	7.294*	3.924	-0.010	0.730
ICMA 97111 × 2368	-3.286*	-3.990	- 0.259	0.457	0.260	0.399	3.044	0.574	0.040	0.730
ICMA 97111 × 2370	- 0.536	- 18.690	- 0.192	-0.326	-0.240	0.282	-5.423	-3.600	-0.010	-0.604
ICMA 97111 × 2318	3.214*	3.776	-0.359	0.540	-0.140	0.999	1.211	-1.168	-0.012	-0.187
ICMA 97111 × 2381	-0.953	12.060	- 0.242	1.640	0.060	0.416	3.044	0.479	-0.012	-0.004
ICMA 97111 × 2325	- 1.619	1.360	- 0.426	1.924	0.193	0.932	-1.973	-2.801	0.023	0.080
ICMA 97111 × 2327	-1.119	11.276	- 0.026	0.774	0.143	-0.201	-1.039	1.809	0.033	0.646
ICMA 97111 × 2328	- 1.619	1.410	0.241	0.190	-0.074	-0.501	0.627	3.084	-0.073	-0.287
ICMA 97111 × 2329	-0.286	-14.574	0.241	0.057	-0.040	0.932	1.561	2.827	-0.017	0.480
ICMA 97111 × 2330	-0.453	1.310	-0.176	1.890	0.193	-0.551	5.427	4.302	-0.052	0.380
ICMA 97111 × 2331	-4.714**	7.176	-0.026	-0.743	-0.007	-1.385*	0.444	0.359	-0.007	0.096
ICMA 97111 × 2332	-0.453	-0.124	-0.076	1.074	0.126	-0.301	-4.356	-0.306	0.055	0.296
ICMA 97111 × 2333	-1.119	-8.640	0.024	-1.176	0.026	2.232**	4.144	1.354	-0.052	-0.270
ICMA 97111 × 2337	0.047	-0.324	0.358	-0.010	-0.140	-0.568	2.677	1.044	0.028	0.630
ICMA 97111 × 2382	-4.453**	-27.307**	-0.142	-3.710**	-0.090	0.149	-3.989	-3.181	0.065	0.530
ICMA 97111 × 2342	0.547	-0.357	-0.059	-2.126	-0.274	-0.851	0.077	-0.343	-0.015	-0.337
ICMA 97111 × 2386	-6.619**	-1.024	0.074	-1.543	-0.174	-0.701	-6.206	-2.788	0.018	-0.137
ICMA 97111 × 2348	-0.786	-11.949	0.524	-1.771	0.001	-0.550	-5.197	-4.716*	0.087*	-0.508
ICMA 97111 × 2352	2.381	-1.190	-0.192	1.057	0.143	-0.118	-3.473	-1.370	0.018	-0.270
ICMA 97111 × 2364	3.047	6.343	0.074	-0.343	0.160	-0.968	1.361	-0.131	0.032	0.280
ICMA 97111 × 2365	-1.286	-13.640	-0.292	-1.610	0.176	0.232	1.744	0.160	0.032	0.013
ICMA 97111 × 2387	0.381	8.810	-0.242	0.940	-0.174	-0.984	-2.156	-1.785	-0.007	-0.470
ICMA 97111 × 2394	-2.286	-2.857	0.041	1.607	-0.274	1.749**	-3.073	-1.255	-0.018	-0.554
ICMA 97111 × 2395	4.547**	16.310	-0.292	2.357*	0.210	-0.851	2.477	1.047	-0.058	-0.487
ICMA 97111 × 2396	2.214	9.643	0.024	0.607	0.110	-0.085	1.561	1.027	-0.032	-0.170
ICMA 97111 × 2346	-3.453*	-9.524	0.558	0.124	-0.240	0.149	-1.773	-1.286	0.030	-0.004
ICMA 97111 × 2349	-0.214	-9.524	-0.042	-2.543*	0.026	-0.401	0.627	3.520	-0.018	0.463
SE	1.587	9.983	0.468	1.123	0.153	0.584	3.515	2.239	0.038	0.503
CD at 5%	3.143	19.768	0.928	2.224	0.303	1.158	6.962	4.434	0.076	0.997

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

Table.4 Range of heterosis and number of crosses showing significant heterosis in desirable direction

S. No.	Character	Mid parent heterosis		Heterobeltiosis		Standard heterosis	
		Range	No. of crosses	Range	No. of crosses	Range	No. of crosses
1.	Days to 50 per cent flowering	-19.00 to 20.85	25	-28.99 to 20.42	38	-12.75 to 16.78	4
2.	Plant height (cm)	-11.12 to 58.39	28	-25.26 to 53.92	4	-11.92 to 33.61	5
3.	Number of productive tillers per plant	-74.24 to 30.37	0	-75.38 to -7.00	0	-57.81 to 45.31	0
4.	Panicle length (cm)	-19.63 to 35.26	28	-30.68 to 32.85	11	-33.24 to 9.57	0
5.	Panicle width (cm)	-26.86 to 62.26	12	42.31 to 21.13	1	-23.68 to 21.05	4
6.	1000-grain weight (g)	-21.61 to 48.50	27	-28.53 to 44.58	14	10.45 to 95.91	54
7.	Fodder yield (t/ha)	-76.00 to 199.68	8	-82.56 to 96.67	2	-64.83 to 64.66	5
8.	Total biomass (t/ha)	21.46 to 417.60	42	-56.84 to 474.18	22	-70.24 to 286.11	5
9.	Harvest index	-76.92 to -30.84	0	-67.03 to 57.52	1	-75.38 to -30.84	0
10.	Grain yield (t/ha)	-71.11 to 304.37	18	-71.11 to 128.00	6	-71.11 to 34.44	0

Table.5 Top ranking genotypes based on *per se* performance, *gca*, *sca* and heterosis

Character	**Best general combiners**		**Best specific combiners**		**Mid parent heterosis**	**Heterobeltiosis**	**Standard heterosis**
	Based on *gca*	**Based on *per se* performance**	**Based on *sca***	**Based on *per se* performance**			
Days to 50 per cent flowering	ICMA04999 2381 237	ICMA 97111 ICMA 04999 2306, 2349	ICMA 97111 × 2386 ICMA 04999 × 2310 ICMA 04999 × 2311	ICMA 04999 × 2310 ICMA 04999 × 2311 ICMA 04999 × 2318	ICMA 04999 × 2310 ICMA 97111 × 2386 ICMA 04999 × 2311	ICMA 97111 × 2328 ICMA 04999 ×2328 ICMA 04999 × 2310	ICMA 04999 × 2310 ICMA 04999 × 2311 ICMA 04999 × 2318
Plant height (cm)	ICMA 97111, 2318 (for dwarfness)	ICMA 04999, 2329(for dwarfness) 2368, 2325, 2382 (for	ICMA 04999 × 2311 ICMA 97111 × 2382 (for dwarf types) ICMA 97111 × 2311 ICMA 04999 × 2382	ICMA 97111 × 2349 ICMA 97111 × 2370 (for dwarf types) ICMA 97111 × 2311 ICMA 04999 × 2382	ICMA 04999 × 2329 ICMA 97111 × 2311 ICMA 04999 ×	ICMA 04999 × 2329 ICMA 97111 × 2311 ICMA 97111 ×	ICMA 97111 × 2311 ICMA 04999 × 2382 ICMA 04999 ×

		tallness)	(for tallness)	(for tallness)	2330	2330	2329
Total number of productive tillers per plant	2311 2346 2386	2368 2387 2309	-	ICMA 97111 × 2311 ICMA 97111 × 2306 ICMA 04999 × 2318	-	-	-
Panicle length (cm)	ICMA 04999 2368 2364	2325 2327 2370	ICMA 04999 × 2382 ICMA 97111 × 2311 ICMA 04999 × 2349	ICMA 04999 × 2382 ICMA 04999 × 2364 ICMA 97111 × 2368	ICMA 97111 × 2368 ICMA 97111 × 2330 ICMA 97111 × 2387	ICMA 97111 × 2368 ICMA 97111 × 2330 ICMA 97111 × 2387	ICMA 97111 × 2368 ICMA 97111 × 2330 ICMA 97111 × 2395
Panicle width (cm)	-	2365 2370 2328	-	ICMA 97111 × 2325 ICMA 04999 × 2394 ICMA 97111 × 2306	ICMA 04999 × 2337 ICMA 04999 × 2309 ICMA 97111 ×2337	ICMA 04999 × 2337	ICMA 97111 × 2325 ICMA 04999 × 2394 ICMA 97111 × 2306
1000 grain weight (g)	ICMA 97111 2352 2306, 2309	ICMA 97111 2349 2342	ICMA 97111 × 2333 ICMA 97111 × 2394 ICMA 04999 × 2331	ICMA 97111 × 2333 ICMA 97111 × 2309 ICMA 97111 × 2394	ICMA 04999 × 2387 ICMA 04999 × 2337 ICMA 04999 × 2364	ICMA 04999 × 2364 ICMA 04999 × 2328 ICMA 04999 ×2309	ICMA 97111 × 2333 ICMA 97111 × 2309 ICMA 97111 × 2394
Fodder yield (t/ha)	-	2368 ICMA 97111 2325	ICMA 97111 × 2310 ICMA 04999 × 2309 ICMA 97111 × 2311	ICMA 97111 × 2310 ICMA 04999 × 2309 ICMA 04999 × 2386	ICMA 04999 × 2309 ICMA 04999 × 2329 ICMA 04999 × 2348	ICMA 04999 × 2309 ICMA 04999 × 2348	ICMA 97111 × 2310 ICMA 04999 × 2309 ICMA 04999 × 2386
Total biomass (t/ha)	ICMA 04999	2325 2352 2330	ICMA 04999× 2348	ICMA 04999 × 2325 ICMA 04999 × 2382 ICMA 04999 × 2386	ICMA 04999 × 2325 ICMA 04999 × 2348 ICMA 04999 × 2382	ICMA 04999 × 2309 ICMA 97111 × 2329 ICMA 97111 × 2310	ICMA 04999 × 2309 ICMA 97111 × 2329 ICMA 97111 × 2310

Table. 5 (Contd.)

Character	**Best general combiners**		**Best specific combiners**		**Mid parent heterosis**	**Heterobeltiosis**	**Standard heterosis**
	Based on *gca*	**Based on *per se* performance**	**Based on *sca***	**Based on *per se* performance**			
Harvest index	ICMA 97111, 2365	ICMA 97111 2348 ICMA 04999	ICMA 97111 × 2348	ICMA 97111 × 2348 ICMA 97111 × 2365 ICMA 04999 × 2333 ICMA 97111 × 2327 ICMA 97111 × 2332	-	ICMA 04999 × 2328	-
Grain yield (t/ha)	ICMA 04999 2325,2396,2306, 2337, 2348, 2394	2348 2332 2331, 2370, ICMA 97111	ICMA 04999 × 2309	ICMA 04999 × 2394 ICMA 04999 × 2348 ICMA 97111 × 2337 ICMA 04999 × 2309	ICMA 04999 × 2309 ICMA 04999 × 2328 ICMA 04999 × 2333	ICMA 04999 × 2396 ICMA 04999 × 2309 ICMA 04999 × 2333	-

Peng and Virmani (1990) reported possibility of interaction between positive alleles from good combiners and negative alleles from poor combiners in high × low or low × high combiner crosses and suggested for the exploitation of heterosis in F_1 generation as their high yield potential would be unfixable in succeeding generations.

The estimates of heterosis revealed that, out of 60 crosses the cross ICMA 04999 × 2309 recorded significant heterosis over mid parent and better parent along with high *sca* effects in desirable direction for grain yield and fodder yield. The crosses ICMA 04999 × 2310 and ICMA 04999 × 2311 recorded significant mid parent heterosis, heterobeltiosis and standard heterosis in addition to high *sca* effects for days to 50% flowering, indicating earliness in flowering. The crosses ICMA 04999 × 2329 and ICMA 97111 × 2311 recorded significant positive heterosis for plant height over mid parent, better parent and standard parent. These hybrids will help in production of tall genotypes to improve the fodder yield. The crosses ICMA 97111 × 2368 and ICMA 97111 × 2330 recorded significant heterosis over mid parent and better parent with lack of significant *sca* effect in desirable direction for panicle length. The crosses ICMA 04999 × 2337 and ICMA 04999 × 2364 recorded high significant positive heterosis over mid parent and better parent for panicle width and 1000-grain weight respectively. The crosses ICMA 04999 × 2309, ICMA 97111 × 2329 and ICMA 97111 × 2310 were best over better parent and standard check for total biomass. ICMA 97111 × 2325 showed high standard heterosis for panicle width. ICMA 04999 × 2328 recorded high heterobeltiosis for harvest index. Similar results for yield and its components were earlier reported by Kanfany *et al.,* (2018) for grain yield; Athoni *et al.,* (2016) for panicle length, panicle width and fodder yield; Bhasker *et al.,* (2017) for days to 50 per cent flowering and plant height; Acharya *et al.,* (2017) for total biomass and harvest index. The range of heterosis and number of significant crosses are presented in Table 4.

In the present study, Table 5 revealed that there is a lack of relation between *per se* performance, *sca* effects and heterosis which means that the cross recording high *sca* effect may not have high heterosis. Hence consideration of these three criterion will be effective for selection of best cross combinations. Based on *per se* performance, *sca* effect and heterosis, the crosses ICMA 04999 × 2309 for grain yield and fodder yield; ICMA 97111 × 2311 for plant height; ICMA 97111 × 2333 for 1000-grain weight; ICMA 04999 × 2348 for total biomass are the best cross combinations deduced from the study.

From the present investigation it can be concluded that all the characters are governed by non-additive gene action. The good combiner parents for different traits are 2325 for grain yield, panicle width, panicle length and 1000-grain weight; 2381 for days to 50 per cent flowering; 2349 for plant height; 2368 for panicle length and 1000-grain weight; 2365 for harvest index. These good combiner parents could be further used in the hybrid breeding programmes to produce better crosses or to develop better base/parent material.

The developed parental material could be used in breeding programmes for development of improved genotypes. The cross ICMA 04999 × 2309 recorded significant specific combing ability, mid parent heterosis and heterobeltiosis for grain yield and green fodder yield. Hence this cross was selected for dual purpose. In this study, a single cross did not record significant heterosis for majority of traits indicating the presence of more genetic variation in the parental material and possibility of genetic improvement through recurrent selection.

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