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Combining Ability Analysis over Environments in Diallel Crosses of Maize (*Zea mays*)

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A set of seven promising inbred lines were involved in half-diallel mating design to study the combining ability effects for grain yield and yield contributing characters. The experimental material consisted of seven parents and their 21 crosses along with five public/private checks. Yield trials were conducted at three environments during Kharif 2015. Mean squares due to environments were highly significant for all the traits except kernels row^{-1} indicating that these traits were highly influenced by environment factors. Hybrids × environment and hybrids Vs parents × environment interaction was significant for ear length, grain yield and fodder yield. GCA × environment and SCA × environment ($P < 0.05$) interactions were significant for plant height, ear length and fodder yield traits. The magnitude of the interaction of SCA × environments is higher than GCA × environments for flowering and maturity traits, kernel rows ear^{-1}, shelling %, 100 kernel weight, grain yield for combined analysis over three environments. GCA/SCA ratio was less than unity for all the studied traits indicating non additive gene action plays a major role in controlling the traits. Across the environments, BML-51 was a good general combiner for days to 75% dry husk, plant height, ear height, ear length, shelling %, 100 kernel weight, grain yield and fodder yield. BML-13 and BML-10 were good general combiners for flowering traits. Among the crosses, BML-51 × BML-14 had significant and positive SCA effects with high mean values in all three environments and pooled over environments for grain yield and fodder yield.

Key words: Maize, Half-diallel, Combining ability, Environment

Maize (*Zea mays* L.) is an important cereal food crop of the world with highest production and productivity as compared to rice and wheat. Maize production has increased more than 12 times from a mere 1.73 million tons 1950-51 to 21.73 million tons in 2010-11. Presently, it occupies an area of 9.06 million hectares, with production of 24.25 million tonnes and productivity of 2.68 tonnes/ha (Centre for Monitoring Indian Economy, 2014).The progress made in yield improvement is remarkable in spite of ~75% maize area is under rainfed and low input condition, which recurrently affected with vagaries of monsoon.

Selection of genotypes is the foremost activity towards success of any crop improvement program. The better performance of genotypes in a large number of yield trials indicates their relative superiority but not its inherent ability to transmit the desirable character when crosses with a number of similar genotypes. Diallel mating system is frequently used by breeders to detect the offspring performance. The analysis limited to the homozygous parents and F_1 generation allows estimation of genetic parameters unbiased by linkage and assessment of dominance in the polygenic systems (Mather and Jinks, 1982).

Combining ability analysis is targeted to identify the better combiners which can be hybridized to exploit heterosis and to select better crosses for direct use or for further breeding work. According to Allard (1960), the 'expected' value of any particular cross is the sum of the GCA's of its two parental lines, while the deviation from this expected value is called SCA. GCA values describe the general usefulness of the parental form in terms of the concerned trait, whereas SCA indicates importance of the joint action of the genes of parental forms (Baker, 1978).Variability in SCA effects for a given trait in the starting material for breeding is unfavorable as it increases the probability of obtaining hybrid progenies with an average value of that trait. The amount of improvement expected to come from GCA and SCA will be proportional to their variances (Griffing, 1956). The mean square ratio for GCA and SCA is used to determine the prevailing gene actions (additive or non-additive) of a quantitative trait. The closer the ratio is to unity, the greater the performance of the progeny selected based on GCA values (Baker, 1978). Gene action in maize for yield and yield contributing characters were reported differently by various authors. Nigussie and Zelleke (2001), Vacaro *et al.* (2002), El-Shouny *et al.* (2003) and Ojo *et al.* (2007) reported that additive genetic action was more important for maize traits suggesting for rapid improvement in selection. However Chaudhary *et al.* (2000) and Abdel-Moneam *et al.* (2009) reported that dominance

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gene effect was important in the inheritance of maize characters. Nass *et.al* (2000) and Pswarayi and Vivek (2008), obtained significant ($P < 0.05$) GCA × E and SCA × E for almost all traits studied, indicating variation in general combining ability of lines under different environments. Hence, the present study was undertaken to estimate the combining abilities of the inbreds and hybrids at three different locations to estimate the effects of environments on the expression of both GCA and SCA to identify promising hybrids either for cultivation or for extraction of inbred lines for hybrid development.

Materials and Methods

Seven promising inbred lines of maize developed at Maize Research Centre, Rajendranagar, Hyderabad were crossed in half diallel fashion and obtained twenty one crosses during rainy season, 2014. All the 21 single crosses along with seven parents and five public /private checks were evaluated during rainy season, 2015 at three diverse agro climatic locations *viz*., MRC, ARI, Rajendranagar, ARS, Karimnagar and RARS, Palem, the main research centres of Professor Jayashankar Telangana State Agricultural University (PJTSAU). Each entry was sown in two rows of 3 m length with 75 cm row to row spacing and 20 cm plant to plant spacing. The data was recorded on ten randomly selected plants for plant height (cm), ear height (cm), ear length (cm), ear diameter (cm), number of kernel rows ear^{-1}and number of kernels row^{-1}, whereas for days to 50% pollen shed, days to 50% silk emergence, days to 75% dry husk, shelling (%), grain yield (kg plot^{-1}), grain yield (kg ha^{-1}), fodder yield (kg plot^{-1}) and 100 kernel weight (g) data was recorded on plot basis. Grain yield (kg plot^{-1}) and fodder yield (kg plot^{-1}) was corrected for stand variation using the methodology of covariance, as suggested by Miranda Filho (Vencovsky and Barriga, 1992); correction was for expected stand (S_e=30) for individual plots using the formula $Y_c= Y_o+ b (S_e – S_o)$, where Y_c is the corrected yield, Y_o is the observed yield, b is the linear regression coefficient of Y_o over the variation of the observed stand (S_o). Further, this hand harvested shelled corn of each entry was adjusted to 15.5 moisture in kg ha^{-1} similar to grain yield in bushels per acre at 15.5 moisture as suggested by Joe Lauer (2002).

Analyses of variance was made for each location separately and then combined over locations after testing the homogeneity of error variances. Data of single crosses and inbreds were subjected to diallel analyses using Griffing (1956) Method II (parents and crosses together), Model I (fixed effects).The mean squares due to entries and its partitions, GCA and SCA were tested using the corresponding interactions with the environment as error terms and all the interactions with environment were tested against the pooled error. Significance of GCA and SCA effects was determined by the t-test, using standard errors of GCA and SCA effects, respectively.

The relative importance of general and specific combining ability on progeny performance was estimated as the ratio (Baker, 1978):

2MSGCA/ (2MSGCA + MSSCA)

where, MSGCA =Mean square of GCA and MSSCA = Mean square of SCA.

Results and Discussion

Analysis of variance (Table 1) for yield and yield contributing traits revealed that mean squares due to environments were highly significant for all the traits except kernels row^{-1}, indicating that these traits

Table 1. Mean squares from analysis of variance and combining ability for grain yield and its components pooled over environments.

Source of variation	d.f.	Days to 50% pollen shed	Days to 50% silk emergence	Days to 75% dry husk	Plant height	Ear height	Ear length	Ear diameter
Environments	2	366.167**	442.310**	2715.185**	4917.792**	4928.292**	34.259**	1.535**
Rep	3	8.833	3.738	18.298*	634.083**	330.821**	3.617*	0.256**
Treatemnts	27	63.832**	51.243**	36.117**	5099.844**	1693.629**	39.993**	1.074**
Parents	6	91.262**	73.048**	74.746**	8106.207**	2404.040**	9.215**	0.339**
Hybrids	20	34.975**	30.750**	24.102**	1557.927**	568.272**	8.129**	0.140**
Parents vs.Hybrids	1	476.389**	330.286**	44.643**	57900.008**	19938.293**	861.930**	24.165**
Treatment × Environments	54	7.006	7.939*	13.061**	244.292**	84.600	2.624**	0.078
Parent × Environments	12	2.571	6.429	14.460**	191.683	53.278	3.055**	0.067
Hybrids × Environments	40	7.822	8.031	10.640**	161.958	84.281	2.254**	0.071
Parent vs.Hybrids × Env.	2	17.294*	15.167	53.077**	2206.621**	278.931*	7.428**	0.290**
Error	81	5.512	5.281	5.273	133.454	69.340	1.097	0.053
Total	167	19.803	18.778	45.466	1038.534	399.772	8.322	0.248
GCA	6	79.903**	63.261**	44.340**	5853.357**	1748.580**	9.432**	0.195**
SCA	21	18.205**	14.868**	10.550**	1606.083**	589.167**	23.015**	0.635**
GCA/SCA		0.90	0.89	0.89	0.88	0.86	0.45	0.38
Environmnets	2	122.056**	147.437**	905.062**	1639.264**	1642.764**	11.420**	0.512**
GCA×Environments	12	2.847	2.294	4.846	150.639*	64.151	1.512**	0.046
SCA×Environments	42	3.690	4.448*	7.012**	114.005*	36.057	1.255**	0.037
Pooled Error	81	2.756	2.641	2.636	66.727	34.670	0.548	0.027

*,**: Significance at 0.05 and 0.01 levels of probability, respectively.

were highly influenced by environment factors. Treatment effects and Treatment × environment interactions were significant for days to 75% dry husk, plant height, ear length, 100 kernel weight, fodder yield and grain yield. Hybrids × environment and hybrids Vs parents × environment interaction was significant for grain yield and fodder yield. Significant GCA × environment and SCA × environment ($P < 0.05$) for plant height, ear length and fodder yield traits showed that performance of inbreds and F_1 hybrids under different environments will ensure selection of stable parents that can perform to the potential of that environment (Machado *et al*. 2009) or emphasizing the importance of environment in phenotypic expression of agronomic characters (Bello and Olaoye, 2009). Multilocational testing of inbreds under various environments is important to ensure stable tester for hybridization. Desai and Singh (2000), Nass *et al*. (2000) and Aguiar *et al*. (2003) reported highly significant effects of environments, GCA, SCA, and their interaction with environment. GCA and SCA variances were highly significant for all the studied traits inferring that inbreds and hybrids were different from each other for all the traits studied and the variability in the breeding material was attributed to additive and non-additive gene effects. Similar results were reported by Chaudhary *et al*. (2000), Habtamu (2000) and Murthada *et al*. (2016). GCA/SCA ratio was found to be less than unity for all the studied traits indicating that these traits were purely under dominance effect of gene and that selection for these characters should be based on recurrent selection. GCA/SCA ratio was highest for days to 50 % pollen shed while lowest was observed for grain yield at combined environments.This is in agreement with earlier reports of Murthada *et al*. (2016), Machado *et al*. (2009) and Abdel-Moneam *et al*. (2009). Contrary to this, other researchers indicated predominance of additive genetic effects for kernels per row, plant height (Vacaro *et al*. 2002) and grain yield (Ojo *et al*. 2007).

(Contd…)

Source of variation	d.f.	Kernel rows ear^{-1}	Kernels row^{-1}	Shelling%	100 kernel weight (g)	Grain yield (kg plot^{-1})	Fodder yield (kg plot^{-1})	Grain yield (kg ha^{-1})
Environments	2	8.441**	7.118	191.960**	976.512**	6.290**	22.250**	31251452**
Rep (Env.)	3	0.565	21.098*	4.545	21.121	0.591*	0.927*	2944522*
Treatemnts	27	5.655**	245.711**	65.218**	190.669**	3.967**	2.563**	19615414**
Parents	6	4.627**	54.229**	157.410**	219.004**	0.115	0.408	569389
Hybrids	20	3.678**	39.593**	19.911**	86.620**	0.524**	0.799**	2594075**
Parents vs.Hybrids	1	51.367**	5516.977**	418.200**	2101.651**	95.936**	50.774**	474318368 **
Treatment × Environments	54	0.539	9.469	4.698	16.663**	0.259*	0.512**	1279246*
Parent × Environments	12	0.588	13.578*	9.236**	23.214**	0.065	0.086	318849
Hybrids × Environments	40	0.363	7.791	3.436	11.539	0.245*	0.569**	1207957*
Parent vs.Hybrids × Env.	2	3.748**	18.393	2.719	79.831**	1.713**	1.919**	8467397**
Error	81	0.361	6.830	3.691	9.249	0.151	0.243	744288
Total	167	1.375	46.565	16.234	52.775	0.884	0.981	4373169
GCA	6	6.832**	69.512**	82.430**	195.489**	0.333**	0.596**	1645464**
SCA	21	1.683**	138.097**	18.375**	66.719**	2.455**	1.477**	12139777**
GCA/SCA		0.89	0.50	0.90	0.85	0.21	0.45	0.21
Environmnets	2	2.814**	2.373	63.987**	325.504**	2.097**	7.417**	10417151**
GCA×Environments	12	0.163	6.037	1.866	8.227	0.029	0.338**	143852
SCA×Environments	42	0.300*	4.363	2.487	8.362*	0.158**	0.232**	781272**
Pooled Error	81	0.180	3.415	1.845	4.625	0.075	0.121	372144

*,**: Significance at 0.05 and 0.01 levels of probability, respectively.

Mean performance of grain yield and yield contributing characters at individual environments (Table 2) showed that for flowering and maturity traits, Karimnagar location was found to be early when compared to other two locations. Hyderabad and Palem locations were found be similar for majority of the traits days to 50% pollen shed, days to 50% silk emergence, days to 75% dry husk, ear length, ear diameter, kernels row-1, shelling %, 100 kernel weight and grain yield, a coincidence of these two locations in the same agro climatic zone. Performance of maize genotypes for all the characters at combined environments was presented (Table 3). The results revealed that BML-51 × BML-14 recorded

Table 3. Mean performance of parents and crosses pooled over three environments

Entry	Days to 50% pollen shed	Days to 50% silk emergence	Days to 75% dry husk	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	Kernel rows ear^{-1}	Kernels row^{-1}	Shelling %	100 kernel weight (g)	Grain yield (kg plot^{-1})	Fodderyield (kg plot^{-1})	Grain yield (kg ha^{-1})
BML-51	61.5	62.5	93.7	187.5	100.2	14.1	3.4	11.4	23.0	85.5	32.2	1.73	2.03	3829
BML-32	60.5	61.5	90.2	172.7	83.3	14.2	3.5	12.0	21.2	80.3	29.7	1.53	1.49	3385
BML-14	62.5	64.2	97.7	140.8	58.7	12.5	3.4	11.2	16.0	75.1	32.1	1.28	1.44	2837
BML-13	54.8	57.5	89.0	83.7	41.7	13.4	3.2	12.2	21.8	84.0	19.5	1.41	1.26	3134
BML-10	52.3	54.7	88.8	106.0	50.7	11.3	3.3	12.8	17.7	77.5	20.8	1.45	1.63	3225
BML-7	61.3	63.3	96.2	157.8	68.2	14.6	3.8	13.1	19.1	73.8	26.5	1.41	1.51	3139
BML-6	60.8	62.7	94.2	128.3	75.3	14.7	3.8	13.5	24.5	72.0	18.2	1.53	1.86	3406
BML-51×BML-32	56.0	57.3	89.8	199.3	104.0	19.7	4.0	12.3	33.6	82.5	34.8	3.40	2.75	7559
BML-51×BML-14	54.0	56.8	92.0	201.2	103.3	19.0	4.3	12.7	31.8	82.5	41.8	3.93	4.12	8733
BML-51×BML-13	53.8	55.7	88.7	187.8	98.0	18.8	4.2	13.0	34.3	83.7	35.2	3.23	2.77	7182
BML-51×BML-10	52.8	55.8	90.7	182.7	92.5	18.7	4.3	13.2	31.8	82.3	36.0	3.11	2.56	6903
BML-51×BML-7	55.7	57.2	89.7	200.3	105.8	18.7	4.4	13.0	33.3	82.1	36.7	3.51	3.24	7798
BML-51×BML-6	54.2	57.0	91.2	210.5	113.8	19.6	4.5	13.7	37.3	83.2	35.3	3.64	3.18	8096
BML-32×BML-14	58.5	60.3	95.3	182.5	83.5	19.8	4.3	12.8	34.8	82.6	34.7	3.00	2.70	6666
BML-32×BML-13	56.7	59.0	91.7	171.0	86.2	20.8	4.4	13.2	37.9	85.6	32.3	3.44	2.60	7637
BML-32×BML-10	55.2	57.7	90.3	184.8	89.2	21.0	4.3	14.6	36.1	83.5	29.8	3.17	2.42	7048
BML-32×BML-7	60.7	62.5	96.8	198.8	96.2	20.1	4.4	13.3	35.8	82.3	32.0	3.10	2.95	6884
BML-32×BML-6	57.7	60.0	93.8	192.8	99.0	19.1	4.7	15.0	38.3	83.4	31.4	3.51	2.64	7801
BML-14×BML-13	54.2	56.2	90.3	162.0	82.8	18.4	4.4	12.9	30.3	83.2	40.2	3.30	3.17	7338
BML-14×BML-10	52.2	55.0	91.2	170.0	85.2	17.5	4.5	13.6	29.1	78.6	34.1	3.12	2.78	6938
BML-14×BML-7	57.3	60.0	94.2	188.8	94.2	18.6	4.5	13.4	32.2	78.4	37.7	3.41	2.96	7585
BML-14×BML-6	55.8	57.7	91.7	173.0	79.3	17.5	4.2	13.8	31.4	82.0	30.9	3.07	2.98	6820
BML-13×BML-10	50.2	52.7	89.8	148.8	79.7	17.3	4.2	13.5	30.9	81.8	30.8	2.80	2.73	6208
BML-13×BML-7	54.8	57.0	89.7	155.7	80.2	18.5	4.3	13.0	33.0	81.8	33.9	2.87	2.54	6383
BML-13×BML-6	52.0	55.3	91.8	175.8	96.5	18.5	4.4	13.8	36.6	82.8	29.9	3.14	3.00	6971
BML-10×BML-7	54.8	58.3	91.3	181.5	97.7	18.9	4.4	14.5	32.6	79.8	36.6	3.31	2.91	7347
BML-10×BML-6	55.8	59.0	91.8	169.2	91.5	16.3	4.3	15.2	32.6	79.2	27.6	2.81	2.71	6241
BML-7×BML-6	57.5	60.5	92.2	194.2	103.8	17.5	4.5	14.4	34.5	79.9	27.2	2.80	2.57	6215
DHM-117	58.7	61.7	93.0	196.7	100.2	18.1	4.7	14.3	33.9	77.3	30.8	2.99	2.59	6634
KNMH-4010131	56.8	58.3	92.7	207.2	102.3	18.1	4.5	13.9	30.8	79.0	34.6	3.30	3.16	7334
Ekka 2288	56.3	58.5	94.0	187.5	90.5	20.5	4.5	14.3	37.7	85.0	32.3	3.23	2.33	7183
NK 6240	55.3	58.0	91.7	172.2	85.0	18.2	4.5	14.0	31.8	81.7	32.4	3.22	2.44	7151
900 M Gold	57.2	58.3	91.5	177.2	88.0	17.8	4.5	14.9	37.2	82.5	27.2	2.83	2.34	6293
LSD (0.05)	2.3	2.3	2.3	11.6	8.3	1.0	0.2	0.6	2.6	1.9	3.0	0.39	0.49	863
LSD (0.01)	6.2	6.1	6.1	30.5	22.0	2.8	0.6	1.6	6.9	5.1	8.0	1.02	1.30	2276

significantly superior grain yield over the high yielding check KNMH-4010131. The observed increase in the values of flowering, maturity, morphological and yield contributing traits confirmed that each and every trait plays an important role towards maize growth and yield.

General combining ability (GCA) effects of maize inbreds combined over the environments are presented (Table 4). Estimates of the GCA effects revealed that none of the parents had good general combining ability for all traits across the environments. Across the environments, BML-51 had significant and negative GCA effects for days to 75% dry husk and significant and positive GCA effects for plant height, ear height, ear length, shelling %, 100 kernel weight, grain yield and fodder yield. For kernel rows ear^{-1} BML-6, BML-7 and BML-10; for kernels row^{-1} BML-32 and BML-6; for shelling % BML-51, BML-32 and BML-13; for 100 kernel weight and fodder yield, BML-51 and BML-14 were found to be good general combiners with significant and positive GCA effects. Inbreds BML-13 and BML-10 were early in flowering and maturity with significant and negative GCA effects. BML-10 showed significant and negative GCA effects for all the traits except fodder yield plot^{-1}, where as BML-13 showed significant and negative GCA effects for all the traits except ear length, kernels row^{-1}, shelling %, grain yield and fodder yield traits. It clearly showed that good combines for earliness don't have good combining ability for grain yield and yield component traits.

Table 2. Mean performance of single crosses for yield and yield contributing characters in maize under three environments

Characters	Hyderabad	Karimnagar	Palem	LSD 0.05	LSD 0.01
Days to 50% pollen shed	56.738	51.929	57.024	0.932	1.251
Days to 50% silk emergence	58.929	54.167	59.905	0.978	1.313
Days to 75% dry husk	96.476	82.952	95.429	0.839	1.126
Plant height (cm)	194.190	169.548	183.524	5.424	7.287
Ear height (cm)	102.167	82.5	95.667	3.261	4.382
Ear length (cm)	18.240	19.521	18.545	0.517	0.694
Ear diameter (cm)	4.528	4.146	4.422	0.088	0.119
Kernel rows ear^{-1}	14.062	13.467	13.231	0.253	0.340
Kernels row^{-1}	33.567	34.233	33.352	1.135	1.525
Shelling %	83.198	79.983	82.679	0.512	0.688
100 kernel weight (g)	37.238	28.261	35.743	1.556	2.090
Grain yield (kg plot^{-1})	3.291	2.892	3.482	0.198	0.266
Fodder yield (kg plot^{-1})	3.714	2.526	2.372	0.179	0.240
Grain yield (kg ha^{-1})	7312	6427	7740	440	591

Table 4. Estimates of GCA effects across the environments for grain yield and yield components

Traits	BML-51	BML-32	BML-14	BML-13	BML-10	BML-7	BML-6	gi (0.05)	gi (0.01)	gi-gj (0.05)	gi-gj (0.01)
Days to 50% pollen shed	-0.01	1.78**	0.82**	-2.03**	-2.66**	1.54**	0.56	0.57	0.75	0.90	1.19
Days to 50% silk emergence	-0.33	1.34**	0.72*	-1.89**	-2.22**	1.60**	0.78**	0.57	0.75	0.88	1.17
Days to 75% dry husk	-0.67*	0.31	1.63**	-1.70**	-1.39**	1.20**	0.61*	0.57	0.74	0.88	1.17
Plant height (cm)	20.36**	11.23**	-1.61	-22.79**	-13.85**	6.82**	-0.16	2.85	3.75	4.42	5.86
Ear height (cm)	13.40**	3.05**	-5.73**	-10.06**	-6.69**	1.88	4.16**	2.06	2.70	3.19	4.23
Ear length (cm)	0.31*	1.02**	-0.43**	-0.06	-0.84**	0.18	-0.19	0.26	0.34	0.40	0.53
Ear diameter (cm)	-0.06*	0	-0.01	-0.11**	-0.06*	0.10**	0.13**	0.06	0.07	0.09	0.12
Kernel rows ear^{-1}	-0.60**	-0.09	-0.50**	-0.24**	0.46**	0.21**	0.76**	0.15	0.20	0.23	0.30
Kernels row^{-1}	0.54	1.73**	-2.42**	0.38	-1.64**	-0.4	1.82**	0.64	0.85	1.00	1.33
Shelling %	2.09**	1.34**	-1.20**	2.04**	-0.90**	-1.82**	-1.54**	0.47	0.62	0.74	0.98
100Kernel weight (g)	3.38**	0.09	3.33**	-1.39**	-1.91**	0.39	-3.89**	0.75	0.99	1.16	1.54
Grain yield (kg plot^{-1})	0.22**	0.04	0.01	-0.08	-0.12*	-0.05	-0.03	0.10	0.13	0.15	0.20
Fodder yield (kg plot^{-1})	0.25**	-0.15*	0.13*	-0.12	-0.12	-0.03	0.04	0.12	0.16	0.19	0.25
Grain yield (kg ha^{-1})	490.25**	94.23	26.32	-170.07	-264.44*	-114.16	-62.14	213.04	279.99	330.35	437.97

Note: *,**: Significance at 0.05 and 0.01 levels of probability, respectively.

Specific combining ability effects of crosses for grain yield and yield components under the combined environments are presented (Table 5). BML-51 × BML-32 and BML-51 × BML-7 had significant and negative SCA effects for flowering and maturity traits. The cross combinations involving inbred BML-51 with BML-13 and BML-6, BML-13 with BML-14 and BML-6 and cross BML-10 × BML-7 had significant and positive SCA effects for plant height, ear height, ear length, ear diameter, 100 kernel weight and grain yield.

Table 5. Estimates of SCA effects across the environments for grain yield and yield components

Cross	Days to 50% pollen shed	Days to 50% silk emergence	Days to 75% dry husk	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	Kernel rows ear^{-1}	Kernels row^{-1}	Shelling %	100 kernel weight (g)	Grain yield (kg plot^{-1})	Fodder yield (kg plot^{-1})	Grain yield (kg ha^{-1})
P1×P2	-1.97*	-2.15*	-1.73*	-3.95	0.40	0.87*	-0.08	-0.27	-2.52*	2.13	0.93**	-0.19	0.10	784.51*
P1×P3	-3.01**	-2.04*	-0.88	10.71*	8.51**	1.61**	0.19*	0.57*	0.42	6.79**	0.98**	2.51	1.19**	2026.58**
P1×P4	-0.32	-0.59	-0.88	18.56**	7.51*	1.08**	0.23**	0.54*	-1.00	1.81	0.69**	3.32*	0.09	672.14*
P1×P5	-0.69	-0.09	0.81	4.45	-1.36	1.73**	0.27**	0.11	-0.07	2.24	-0.13	4.28**	-0.13	488.01
P1×P6	-2.06*	-2.57**	-2.79**	1.45	3.40	0.71	0.25**	0.13	-0.05	3.65*	0.61**	3.31*	0.46*	1231.90**
P1×P7	-2.58**	-1.93*	-0.69	18.60**	9.12**	2.07**	0.33**	0.31	0.86	4.78**	0.62**	2.39	0.34	1478.55**
P2×P3	-0.31	-0.20	1.47	1.18	-0.97	1.78**	0.18*	0.15	0.32	-1.09	-0.13	6.62**	0.17	355.94
P2×P4	0.71	1.07	1.14	10.86*	6.03	2.41**	0.33**	0.30	2.01	3.24	0.79**	6.58**	0.32	1523.16**
P2×P5	-0.16	0.07	-0.51	15.75**	5.66	3.30**	0.19*	1.00**	2.53*	-0.24	0.66**	1.64	0.14	1028.86**
P2×P6	1.14	1.09	3.40**	9.08*	4.08	1.42**	0.15	-0.05	1.15	0.87	0.32	3.37*	0.58**	714.08*
P2×P7	-0.88	-0.59	0.99	10.06*	4.64	0.86*	0.45**	1.04**	2.22	1.60	0.91**	4.36**	0.20	1579.73**
P3×P4	-0.82	-1.15	-1.51	14.69**	11.47**	1.44**	0.38**	0.40	-0.91	10.50**	0.70**	3.13*	0.61**	1292.23**
P3×P5	-2.19*	-1.98*	-0.99	13.75**	10.44**	1.32**	0.45**	0.40	-0.53	1.43	0.38	2.59	0.21	986.94**
P3×P6	-1.23	-0.80	-0.58	11.92**	10.86**	1.39**	0.30**	0.45*	2.08	2.44	0.70**	5.17**	0.30	1482.82**
P3×7	-1.75*	-2.31**	-2.49**	3.06	-6.25*	0.68	-0.05	0.23	4.00**	-1.03	0.71**	1.66	0.26	666.14*
P4×P5	-1.34	-1.70*	1.01	13.77**	9.27**	0.73	0.21*	0.03	-0.25	1.15	0.21	2.26	0.42*	453.16
P4×P6	-0.88	-1.19	-1.75*	-0.06	1.19	0.87*	0.15	-0.22	1.62	3.36*	0.46*	0.28	0.14	477.88
P4×P7	-2.73**	-2.04*	1.01	27.08**	15.25**	1.26**	0.26**	0.04	0.08	5.69**	0.51*	5.47**	0.52**	1013.19**
P5×P6	-0.25	0.48	-0.40	16.82**	15.32**	2.04**	0.19*	0.60**	2.05	8.88**	1.28**	4.24**	0.50**	1536.25**
P5×P7	1.73*	1.96*	0.69	11.47**	6.88*	-0.15	0.11	0.74**	1.31	-0.79	0.31	2.93*	0.24	378.06
P6×P7	-0.81	-0.35	-1.56	15.81**	10.64**	0.05	0.09	0.19	1.53	0.02	-0.09	7.11**	0.00	202.12
Sij (0.05)	2.54	2.49	2.49	12.51	9.02	1.13	0.25	0.65	2.41	3.27	0.44	2.67	0.53	934.37
Sij (0.01)	3.37	3.30	3.30	16.59	11.96	1.50	0.33	0.86	3.28	4.46	0.61	3.64	0.71	1238.77
Sii-Sjj (0.05)	2.38	2.33	2.33	11.70	8.44	1.06	0.23	0.61	2.83	3.84	0.52	3.14	0.50	874.03
Sii-Sjj (0.01)	3.15	3.09	3.08	15.52	11.18	1.41	0.31	0.81	3.86	5.24	0.71	4.28	0.66	1158.76

Note: P1-BML-51, P2-BML-32, P3-BML-14, P4-BML-13, P5-BML-10, P6-BML-7, P7-BML-6

*,**: Significance at 0.05 and 0.01 levels of probability, respectively.

Crosses involving at least one parent with high GCA effect would produce good segregates, if the additive genetic system present in one parent and complementary epistatic effects in the other act in the same direction to maximize the desirable plant attribute (Singh and Chaudhary, 1995). In the present study, majority of the hybrids with a good level of specific combining abilities are the products of parents with weak or negative GCA for grain yield. The exceptions are hybrids with high SCA coming from low × high GCA parents. The high SCA crosses involved BML-51 and BML-32 as one of the parent with good general combining ability either for grain yield and yield component traits or yield component traits alone. Finally, it can be concluded that BML-51 was a good general combiner and BML-51 × BML-14 was a good specific combiner for grain yield and yield related traits with significantly superior grain yield over the high yielding check.

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