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Combining ability studies for grain and dry fodder yield per plant in pearl millet [*Pennisetum glaucum* (L.) R. Br.] Using line x tester analysis over environments

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Abstract

The present study was conducted was carried out to elicit information on magnitude of heterosis, combining ability and stability for grain yield and thirteen component traits. The crossing programme was executed for development of 40 hybrids from four diverse male sterile lines and ten males using line x tester mating during summer 2020 and evaluated along with parents and standard check GHB 1129 in summer 2021 at Instructional Farm, Junagadh Agricultural University, Junagadh, Gujarat. Among all the characters studied under the present investigation grain yield per plant and dry fodder yield per plant were the two most important economic traits which have been discussed for their combining ability in this research paper. The pooled analysis of variance revealed that the genotypes were significantly deviating for both for grain yield per plant and dry fodder yield per plant. Two females ICMA 99222 and ICMA 98444 in all three environments as well as on pooled basis and among males 177-SB-19, 216-SB-19, 217-SB-19 and 222-SB-19 in E_1 and E_3 and 177-SB-19, 216-SB-19 and 217-SB-19 in E_2 and on pooled basis were reported to be good general combiners for grain yield per plant. Two females ICMA 96222 and ICMA 99222 in all three environments and among males 216-SB-19, 217-SB-19 and 222-SB-19 in E_1 and E_2, 216-SB-19 and 217-SB-19 in E_3 and 177-SB-19, 216-SB-19 and 217-SB-19 on pooled basis were reported as the good general combiners for dry fodder yield per plant. Eight crosses *viz.*, ICMA 04999 x 177-SB-19 (13.39), ICMA 96222 x 219-SB-19, ICMA 96222 x 222-SB-19, ICMA 96222 x 228-SB-19, ICMA 99222 x 190-SB-19, ICMA 99222 x 256-SB-19, ICMA 98444 x 205-SB-19 and ICMA 98444 x 216-SB-19 showed significant positive sca effects for grain yield per plant whereas five crosses ICMA 04999 x 177-SB-19, 04999 x 222-SB-19, ICMA 96222 x 190-SB-19, ICMA 99222 x 205-SB-19 and ICMA 99222 x 206-SB-19 showed significant positive sca effects for dry fodder yield per plant. Three males 177-SB-19, 216-SB-19 and 217-SB-19 recorded good gca effect and the cross ICMA 04999 x 177-SB-19 was found with high magnitude of positive sca effect towards both the characters.

Keywords: Combining ability, line x tester mating, environments, GCA effect and sca effect

Introduction

The pearl millet is an annual, tillering diploid (2n=14) crop plant, belongs to family Poaceae and supposed to be originated in Africa which thrives well in the arid and semi-arid tropical regions of Asia and Africa. It is a highly nutritious cereal with high levels of metabolized energy, protein (9 to 15%), fat (5%) and mineral matters (2 to 7%) and rich in vitamins A and B, thiamin and riboflavin contents and imparts substantial energy to the body with easy digestibility (Pal *et al.* 1996) [24]. Its contribution of micronutrients, especially iron [Fe] and zinc [Zn] is higher, varying from 30% to 50% of the intake of these micronutrients from cereals (Rao *et al.* 2006). India is the largest producer of this crop both in terms of area (7.38 million ha) and an annual production of 9.13 million tonnes with an average productivity of 1237 kg/ha (Anon., 2017) [2]. In Gujarat, the cultivated area of pearl millet including *kharif* and summer season is an about 0.40 million hectare and production of 0.92 million tonnes with an average productivity of 2312 kg/ha (Anon., 2018) [3]. The major pearl millet growing states in India are Rajasthan, Gujarat, Maharashtra, Haryana, Uttar Pradesh and Karnataka, where it is grown both in *kharif* and summer seasons.

The cross pollination mechanism due to protogynous condition in pearl millet permits many breeding techniques to be used ranging from population improvement to strict pedigree selection and heterosis breeding. The real breakthrough was made when the first and the most widely used cytoplasmic male sterile line Tift 23A (Burton, 1965) [9] was utilized in development of grain hybrids in India. Extensive testing of single crosses with 23A1, Indian breeders could able to announce the release of 'HB-1' hybrid in 1965 (Athwal, 1965) [4].

Several cytoplasmic genetic male sterility sources *viz.*, A1, A2, A3, A4 and A5 available in pearl millet have facilitated the production and release of a number of hybrids. Exploitation of hybrid vigour is considered to be one of the outstanding achievements in this crop. Cross pollinated nature and availability of male sterile lines in crop had made it feasible to exploit hybrid vigour on commercial scale. Therefore, to identify better heterotic response for grain yield and its components characters are of paramount importance.

The nature and magnitude of combining ability effect helps in identifying superior parents for their utilization in further breeding programme. Combining ability analysis is powerful technique to discriminate good as well as poor combiners and for choosing appropriate parental material in the breeding programme. The resulting total genetic variance is partitioned into the variances due to general combining ability and specific combining ability. This helps the breeder in knowing the relative proportion of additive and non-additive genetic variances involved in the inheritance of various characters as well as deciding the appropriate breeding methods for effective exploitation of available genetic variation. The presence of non-additive genetic variance is the primary justification for initiating the hybrid breeding programme (Cockerham, 1961) [11].

There are several techniques for evaluating the varieties or lines in terms of their combining ability and genetic makeup. Different mating designs have been used but line × tester and diallel mating designs found useful. Among these, line × tester analysis as proposed by Kempthorne (1957) [17] has been extensively used to assess the combining ability of parent and crosses of different quantitative characters as well as to study the extent and magnitude of heterosis for yield and its contributing characters. Line × tester analysis is popular as it helps in testing a large number of genotypes to assess the heterosis, combining ability and gene action.

Materials and Methods

Experimental Materials

The present investigation on was carried out to elicit information on magnitude of heterosis, combining ability and stability for grain yield and thirteen component characters. The crossing material in present investigation involved four female lines *viz.*, ICMA 99222, ICMA 96222, ICMA 98444, ICMA 04999 and ten restorer pollinators like 177-SB-19, 190-SB-19, 206-SB-19, 219-SB-19, 205-SB-19, 216-SB-19, 228-SB-19, 222-SB-19, 217-SB-19, 256-SB-19 were received from Main Pearl Millet Research Station, Junagadh Agricultural University, Jamnagar (Table 1).

Table 1: List of female, male parents and standard check used in the experiment

Sr. No.	Genotype	Pedigree
Female parents		
1.	ICMA 04999	81A cytoplasm (A1) source backcrossed to ICMB 04999
	ICMB 04999	(EBC-Gen-S1-40-2-2-1 x B-line bulk)-25-B-B
2.	ICMA 96222	81A Cyto source (A1) backcrossed to ICMB 96222
	ICMB 96222	126B x (81B x SLR 50-1)-1-1-2 x 852B)-69-1-1
3.	ICMA 98444	81A cytoplasm (A1) source backcrossed to ICMB 98444
	ICMB 98444	(BSECBPT/91-40 x SPF3/S91-529)-12-1-1-5
4.	ICMA 99222	863A (A1) Cytoplasm source backcrossed to ICMB 99222
	ICMB 99222	(BSECBPT/91-40 x SPF3/S91-94)-3-1-1-2
Male parents		
1.	177-SB-19	ICMR 17222= Acid tolerant pop S1-7-1-5-2-B
2.	190-SB-19	AIMP 92901 S1-415-2-1-2-B-B-B-1-B-11
3.	205-SB-19	(MC 94 C2-S1-3-2-2-2-1-3-B-B x AIMP 92901 S1-488-2-1-1-4-B-B)-B-8-3-1-B
4.	206-SB-19	(IPC 337 x SDMV 90031-S1-84-1-1-1-1)-12-5-2-4-B-B-B-B
5.	216-SB-19	[JBV 3 S1-300-1-1-2-2 x JBV 3 S1-18-1-3-3-2]-B-7-4 x [(MC 94 S1-34-1-B x HHVBC)-16-2-1) x (IP 19626-4-2-3)]-B-4-1-3-3-1-2-1-1-4-2
6.	217-SB-19	[JBV 3 S1-300-1-1-2-2 x JBV 3 S1-18-1-3-3-2]-B-7-4 x [(MC 94 S1-34-1-B x HHVBC)-16-2-1) x (IP 19626-4-2-3)]-B-4-1-3-3-1-2-1-1-4-4
7.	219-SB-19	(EERC-HS-29)-B-12-4-1-1-B-B
8.	222-SB-19	(MC 94 C2-S1-3-2-2-2-1-3-B-B x AIMP 92901 S1-488-2-1-1-4-B-B)-B-2-1-1 (EERC-HS-29)-B-12-4-1-1
9.	228-SB-19	[JBV 3 S1-300-1-1-2-2 x JBV 3 S1-18-1-3-3-2]-B-7-4 x [(MC 94 S1-34-1-B x HHVBC)-16-2-1) x (IP 19626-4-2-3)]-B-4-1-3-3-1-2-1-1-1 x JBV 3 S1-237-1-3-3-1-B-20 (long)-4-2-2-4
10.	256-SB-19	HTRC S1's -2102-1-4-4-1-B
Standard check hybrid		
GHB 1129		ICMA 99222 x J-2565

Crossing programme

The crossing programme between the four female and ten male restorer lines was performed in the Instructional Farm, Junagadh Agricultural University, Junagadh using line x tester mating design. The genotypes used as parental lines and their details are enlisted in Table 1. In present investigation, the advantage of cytoplasmic genetic male sterility was harnessed to obtain hybrid seeds. The inflorescences of CGMS lines to be used as a female. Ten R-lines were crossed with four A-lines to produce forty hybrids.

Experimental Details

The complete set of 55 genotypes comprising of 40 hybrids, 14 parents and one standard check GHB 1129 were evaluated in a randomized block design with three replications at Instructional Farm, Junagadh Agricultural University, Junagadh in three different dates of sowing *viz.* 1st week of February 2021 (E_1), 3rd week of February 2021 (E_2) and 1st week of March 2021 (E_3). GHB 1129, a medium maturing bio-fortified hybrid for Zn and Fe released at state level for general cultivation in Gujarat was planted in trial in order to obtain information on superiority of hybrid over this hybrid as standard check. Each entry was accommodated in single row plot of 1.5 meter length with row to row and plant to plant distances of 45 and 15 cm, respectively. All the recommended agronomic practices and plant protection measures were followed in order to obtain a normal and healthy crop stand in the field.

Observations recorded
Observations were recorded for the grain yield per plant and thirteen yield attributing traits such as days to 50% flowering, length of protogyny (in days), number of nodes on the main stem, number of effective tillers per plant, ear head length (cm), ear head girth (cm), ear head weight (g), plant height (cm), days to maturity, grain yield per plant (g), 1000-grain weight (g), dry fodder yield per plant (g), harvest index (%) and threshing index (%).

Statistical Analysis
The replication wise mean values of each genotype for various characters were used for statistical and genetic analysis. Following statistical procedures were used for analysis. The statistical analysis was performed using the following steps.

Analysis of variance for experimental design: Analysis of variance for the experimental design was conducted following the fixed effect model suggested by Panse and Sukhatme (1985) [25].

Estimation of heterobeltiosis and standard heterosis: Heterosis expressed as per cent increase or decrease of F1 over mid-parental value (Briggle, 1963) [8]. The estimation of heterosis over better parent and over standard check is more realistic. Hence, in present investigation heterosis was estimated over better parent (BP) and standard check (SC), referred to as heterobeltiosis and standard heterosis, respectively.

Analysis of variance for combining ability analysis: Analysis of variance for combining ability using line x tester design in accordance with the procedure suggested by Kempthorne (1957) [17]. The variation among the hybrids was partitioned further into sources attributed to general combining ability (gca) and specific combining ability (sca) components in accordance with the procedure suggested by Kempthorne (1957) [17].

Analysis of genotype x environment interaction and stability parameters: The statistical analysis for genotype x environment interaction and phenotypic stability was carried out according to Eberhart and Russell (1966) [13] for grain yield and its components.

Experimental Results
Here we have discussed regarding the general and specific combining ability of the parental lines and crosses for two most important economic traits i.e. grain yield per plant (g) and dry fodder yield per plant (g).

Pooled analysis of variance for the characters in the present study
The pooled analysis of variance (Table 2) revealed that the genotypes were significantly different for both for grain yield per plant (g) and dry fodder yield per plant (g). Further classification of genotypes revealed significant difference among parents. Among parents females were recorded for significant difference only for grain yield per plant (g) whereas males recorded for significant difference for both the characters.

Table 2: Pooled analysis of variance for grain yield per plant (g) and dry fodder yield per plant (g)

Source	df	Grain yield per plant (g)	Dry fodder yield per plant (g)
Replications within environment	6	249.65**	1262.00**
Environments	2	127709.76**	846683.51**
Genotypes	53	191.52**	484.94**
Parents	13	84.69**	117.42**
Females	3	102.66**	65.91
Males	9	83.54**	122.45**
Females vs males	1	41.15*	226.73*
Crosses	39	227.95**	615.64**
Parents vs crosses	1	159.20**	165.48*
Genotypes x Environments	106	234.43**	842.29**
Parents x Environments	26	84.69**	117.42**
Females x Environments	6	102.66**	65.91
Males x Environments	18	83.54**	122.45**
(Females vs males) x Environments	2	41.15*	226.73**
Crosses x Environments	78	289.27**	1101.69**
(Parents vs crosses) x Environments	2	42.47**	149.02*
Pooled error	318	8.92	42.72

*,** = Significant at 5% and 1% levels of probability, respectively

Mean sum of squares for environment and replications within environment were found significant for both the characters. Significant mean sum of squares for Females Vs males revealed that the female and male parents differed significantly from each other for both grain and dry fodder yield per plant. The 40 crosses showed significant difference for both the characters and also differed significantly from the 14 parents as indicated in the Table 2. Significant mean sum of squares were reported for the characters for the component genotypes x environments. The sub components under the head genotypes x environments i.e. parents x environments, females x environments, males x environments, (females vs males) x environments, crosses x environments and (parents Vs crosses) x environments were recorded for significant mean sum of squares except for dry fodder yield per plant (g) for females x environments indicating non-significant deviation for the trait among females in different environments.

Analysis of variance for combining ability
Analysis of variance for combining ability for all the characters was done according to line x tester analysis proposed by Kempthrone (1957).

Grain yield per plant (g)
The results of combining ability analysis for grain yield per plant indicated that mean squares for lines, testers and lines x testers were found significant in all three environments as well as on pooled basis (Table 3). Mean squares for lines and testers in all three environments as well as on pooled basis were also found significant when tested against lines x testers interaction mean square. The pooled analysis of variance for combining ability indicated that the variance due to L x E, T x E and L x T x E were found significant when tested against pooled error mean square. Similarly the mean squares for L x E and T x E found significant when tested against L x T x E interaction mean square. The estimated components of variance showed that the magnitude of σ^2_t was higher than σ^2_l under all three environments and on pooled basis. σ^2_{lt} was higher in magnitude than lines in all three environments and on pooled basis while its magnitude was less than that of testers under all environments as well as on pooled basis. The estimate of $\sigma^2_{lt\,x\,e}$ was considerably higher than $\sigma^2_{l\,x\,e}$ and $\sigma^2_{t\,x\,e}$ interactions. The variance ratio $\sigma^2_{GCA}/\sigma^2_{SCA}$ was recorded more than one in all three environments and less than one on pooled basis.

Dry fodder yield per plant (g): Mean squares for testers and lines x testers were found significant in all three environments and on pooled basis whereas mean squares for lines found non-significant under all the environments as well as on pooled basis (Table 3). Mean squares for lines and testers in all three environments as well as on pooled basis found significant when tested against lines x testers interaction mean square. The pooled analysis of variance for combining ability indicated that the variance due to T x E and L x T x E were found significant when tested against pooled error mean square, while that for mean square of L x E recorded non-significant. The mean squares for L x E and T x E found significant when tested against L x T x E interaction mean square. The estimated components of variance showed that the magnitude of σ^2_t was higher than σ^2_l under all three environments and on pooled basis. Magnitude of σ^2_{lt} was recorded higher than both lines and testers in all three environments and on pooled basis. The estimate of $\sigma^2_{lt\,x\,e}$ was considerably higher than $\sigma^2_{l\,x\,e}$ and $\sigma^2_{t\,x\,e}$ interactions. The variance ratio $\sigma^2_{GCA}/\sigma^2_{SCA}$ was recorded less than one in all three environments as well as on pooled basis.

General combining ability effects
Grain yield per plant (g)
Two females ICMA 99222 and ICMA 98444 displayed significant and desirable (positive) general combining ability in all three environments as well as on pooled basis. Among these two lines ICMA 99222 showed the higher magnitude for general combining ability for grain yield per plant (Table 4).
Among males 177-SB-19, 216-SB-19, 217-SB-19 and 222-SB-19 in E_1 and E_3 and 177-SB-19, 216-SB-19 and 217-SB-19 in E_2 and on pooled basis were reported to be good general combiners as they displayed significant and positive combining ability for grain yield per plant (Figure 1).

Table 3: Analysis of variance for combining ability under individual environments as well as pooled over environment for grain yield per plant (g) and dry fodder yield per plant (g)

Sources	df	Grain yield per plant (g)				Dry fodder yield per plant (g)			
		E1	E2	E3	Pooled	E1	E2	E3	Pooled
Lines (L)	3	316.58**++	251.27**++	308.00**++	102.66**++	29.39++	145.03++	197.75++	65.91++
Testers (T)	9	131.13**++	159.24**++	250.64**++	83.54**++	384.40**++	325.92**++	367.36**++	122.45**++
Lines x Testers (L x T)	27	105.64**	110.36**	131.45**	131.19**	687.83**	646.45**	645.72**	511.66**
Error	106	25.82	24.90	24.35	-	131.63	111.42	126.01	-
L x E	6	-	-	-	102.66**++	-	-	-	65.91++
T x E	18	-	-	-	83.54**++	-	-	-	122.45**++
L x T x E	54	-	-	-	166.67**	-	-	-	959.84**
Pooled Error	318	-	-	-	8.92	-	-	-	42.72
Estimates of genetic components of variance									
σ^2_l		42.88	53.97	58.72	2.88	59.83	69.32	81.21	0.20
σ^2_t		72.04	85.45	87.15	13.83	160.91	141.28	132.32	29.95
σ^2_{GCA}		51.21	62.97	66.84	6.01	88.71	89.89	95.81	8.70
σ^2_{lt} (σ^2_{SCA})		27.61	29.54	37.84	13.79	190.53	189.38	180.02	52.83
$\sigma^2_{GCA}/\sigma^2_{SCA}$		1.85	2.13	1.76	0.43	0.46	0.47	0.53	0.16
$\sigma^2_{l\,x\,e}$		-	-	-	30.52	-	-	-	70.01
$\sigma^2_{t\,x\,e}$		-	-	-	36.56	-	-	-	95.50
$\sigma^2_{lt\,x\,e}$		-	-	-	53.20	-	-	-	307.88

*,** = Significant at 5% and 1% levels of probability, respectively against error mean square
+,++ = Significant at 5% and 1% levels of probability, respectively against interaction mean square

Dry fodder yield per plant (g)
Two females ICMA 96222 and ICMA 99222 recorded as good general combiners as they showed significant and desirable (positive) combining ability for dry fodder yield per plant in all three environments (Table 4).
Among males 216-SB-19, 217-SB-19 and 222-SB-19 in E_1 and E_2, 216-SB-19 and 217-SB-19 in E_3 and 177-SB-19, 216-SB-19 and 217-SB-19 on pooled basis were reported as the good general combiners for dry fodder yield per plant (Figure 2).

Table 4: General combining ability effects for lines and testers under individual environments as well as pooled over environment for grain yield per plant (g) and dry fodder yield per plant (g)

Parents	Grain yield per plant (g)				Dry fodder yield per plant (g)			
	E1	E2	E3	Pooled	E1	E2	E3	Pooled
Females								
ICMA 04999	-7.73**	-9.23**	-9.84**	-1.61**	-11.28**	-12.08**	-13.49**	-0.64
ICMA 96222	-3.09**	-2.64**	-2.40**	-1.35**	7.17**	7.53**	6.90**	1.01
ICMA 99222	6.62**	6.76**	6.49**	1.60**	3.44*	3.44*	4.47**	0.20
ICMA 98444	4.20**	5.11**	5.75**	1.36**	0.67	1.10	2.11	-0.58
SE Gca ± females	0.87	0.85	0.77	0.28	1.96	1.61	1.87	0.63
Males								
177-SB-19	2.97*	3.83**	2.65*	5.89**	1.24	-1.03	-1.31	11.13**
190-SB-19	-4.68**	-3.41*	-4.38**	-2.01**	-19.85**	-16.92**	-15.67**	-6.51**
205-SB-19	-3.15*	-3.36*	-2.73*	-1.46*	1.21	-1.05	-1.54	-1.80
206-SB-19	-15.08**	-18.16*	-18.09**	-6.58**	-20.34**	-20.07**	-20.28**	-8.04**
216-SB-19	15.86**	15.87**	16.59**	4.97**	19.30**	16.57**	16.80**	4.31**
217-SB-19	9.50**	10.94**	10.50**	2.94**	17.15**	18.19**	17.12**	4.42**
219-SB-19	-0.24	0.44	1.60	-0.02	-1.29	-0.62**	-0.73	-1.53
222-SB-19	3.76**	2.57	2.82*	0.38	6.24*	5.62*	5.69	0.61
228-SB-19	-3.74**	-3.53*	-4.64**	-2.10**	0.39	0.22	0.07	-1.26
256-SB-19	-5.20**	-5.19**	-4.34**	-2.00**	-4.04	-0.89	-0.14	-1.33
SE gca ± males	1.37	1.34	1.20	0.44	3.11	2.55	2.96	1.00

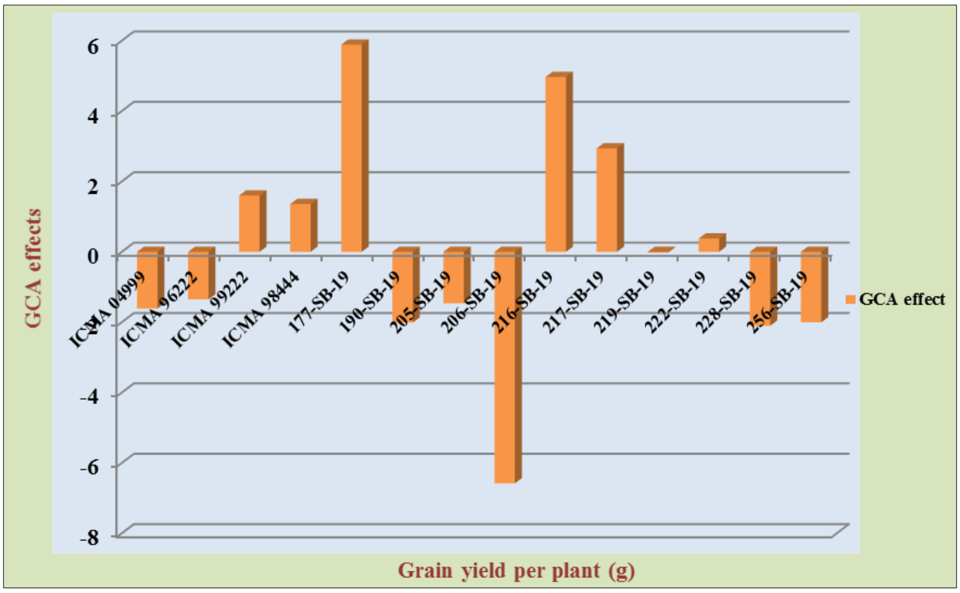

Fig 1: General combining ability effects of parents pooled over environments for grain yield per plant (g)

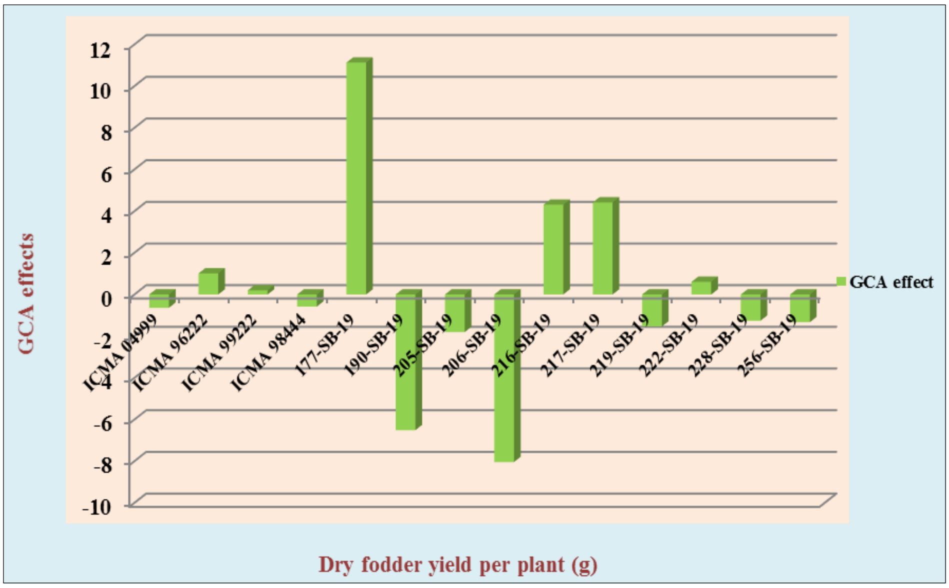

Fig 2: General combining ability effects of parents pooled over environments for dry fodder yield per plant (g)

Specific combining ability effects

Grain yield per plant (g)

Seven crosses *viz.*, ICMA 04999 x 190-SB-19, ICMA 04999 x 206-SB-19, ICMA 96222 x 219-SB-19, ICMA 96222 x 228-SB-19, ICMA 99222 x 256-SB-19, ICMA 98444 x 177-SB-19 and ICMA 98444 x 205-SB-19 showed significant positive sca effects in E_1. Eight crosses *viz.*, ICMA 04999 x 190-SB-19, ICMA 04999 x 206-SB-19, ICMA 96222 x 219-SB-19, ICMA 96222 x 228-SB-19, ICMA 99222 x 256-SB-19, ICMA 98444 x 177-SB-19, ICMA 98444 x 205-SB-19 and ICMA 98444 x 216-SB-19 showed significant positive sca effects in E_2. Ten crosses *viz.*, ICMA 04999 x 190-SB-19, ICMA 04999 x 206-SB-19, ICMA 04999 x 228-SB-19, ICMA 96222 x 219-SB-19, ICMA 96222 x 228-SB-19, ICMA 99222 x 190-SB-19, ICMA 99222 x 256-SB-19, ICMA 98444 x 177-SB-19, ICMA 98444 x 205-SB-19 and ICMA 98444 x 216-SB-19 showed significant positive sca effects in E_3 (Table 5).

On pooled basis eight cross combinations *viz.*, ICMA 04999 x 177-SB-19 (13.39), ICMA 96222 x 219-SB-19 (2.52), ICMA 96222 x 222-SB-19 (0.48), ICMA 96222 x 228-SB-19 (2.58), ICMA 99222 x 190-SB-19 (2.80), ICMA 99222 x 256-SB-19 (0.04), ICMA 98444 x 205-SB-19 (3.23) and ICMA 98444 x 216-SB-19 (2.55) showed significant positive sca effects for grain yield per plant (Figure 3).

Dry fodder yield per plant (g)

Six crosses *viz.*, ICMA 04999 x 217-SB-19, ICMA 04999 x 222-SB-19, ICMA 96222 x 177-SB-19, ICMA 96222 x 190-SB-19, ICMA 99222 x 206-SB-19 and ICMA 98444 x 205-SB-19 showed significant positive sca effects in E_1. Eight crosses *viz.*, ICMA 04999 x 216-SB-19, ICMA 04999 x 217-SB-19, ICMA 04999 x 222-SB-19, ICMA 96222 x 190-SB-19, ICMA 99222 x 177-SB-19, ICMA 99222 x 205-SB-19, ICMA 99222 x 206-SB-19 and ICMA 98444 x 205-SB-19 showed significant positive sca effects in E_2. Seven crosses *viz.*, ICMA 04999 x 216-SB-19, ICMA 04999 x 217-SB-19, ICMA 04999 x 222-SB-19, ICMA 96222 x 190-SB-19, ICMA 99222 x 205-SB-19, ICMA 99222 x 206-SB-19 and ICMA 98444 x 205-SB-19 showed significant positive sca effects in E_3 (Table 5).

On pooled basis five cross combinations *viz.*, ICMA 04999 x 177-SB-19 (26.00), 04999 x 222-SB-19 (5.49), ICMA 96222 x 190-SB-19 (5.69), ICMA 99222 x 205-SB-19 (3.36) and ICMA 99222 x 206-SB-19 (5.99) showed significant positive sca effects for dry fodder yield per plant (Figure 4).

Discussion

Analysis of variance for combining ability

Analysis of variance for combining ability has been discussed based on pooled analysis carried out over the three different environments. The mean squares due to lines found significant for characters for all the traits except plant height, dry fodder yield per plant and threshing index. Mean squares for testers found significant for all the fourteen characters under study. This indicated significance contribution of both lines and testers towards total variation due to general combining ability (gca) and also the additive genetic variance in the inheritance of different traits. The mean squares due to lines x testers were significant for all the characters. Hence non-additive genetic variance was found equally important in the inheritance of various traits. Similar results were also reported in pearl millet by Patel (2012) [27], Mungra (2014) [22], Acharya (2017) [1], Katba (2017) [16] and Badurkar *et al.* (2018) [5].

Table 5: Specific combining ability effects for crosses under individual environments as well as pooled over environment for grain yield per plant (g) and dry fodder yield per plant (g)

Crosses	Grain yield per plant (g)				Dry fodder yield per plant (g)			
	E1	E2	E3	Pooled	E1	E2	E3	Pooled
ICMA 04999 x 177-SB-19	-5.70*	-5.69*	-4.79	13.39**	-27.55**	-27.70**	-26.14**	26.00**
ICMA 04999 x 190-SB-19	9.47**	6.30*	5.52*	0.17	-14.20*	-17.56**	-19.30**	-10.29**
ICMA 04999 x 205-SB-19	-1.71	-1.62	-1.66	-2.22	-26.02**	-26.29**	-26.51**	-12.69**
ICMA 04999 x 206-SB-19	7.8**	11.27**	11.29**	2.09	3.34	-1.31	-2.16	-4.57
ICMA 04999 x 216-SB-19	-1.07	-5.14	-5.27*	-3.42*	9.65	12.30*	13.62*	0.68
ICMA 04999 x 217-SB-19	-3.7	-2.46	-4.50	-3.16*	22.48**	20.01**	22.88**	3.77
ICMA 04999 x 219-SB-19	1.27	0.93	1.10	-1.29	-3.43	-2.03	-1.47	-4.35
ICMA 04999 x 222-SB-19	-2.12	0.49	0.70	-1.43	31.36**	31.18**	28.05**	5.49*
ICMA 04999 x 228-SB-19	2.49	3.46	6.05*	0.35	4.23	5.15	5.84	-1.90
ICMA 04999 x 256-SB-19	-6.82*	-7.53**	-8.45**	-4.48**	0.13	6.24	5.18	-2.13
ICMA 96222 x 177-SB-19	-1.17	-1.36	-0.01	-4.99	12.65*	8.92	7.65	-9.02**
ICMA 96222 x 190-SB-19	-5.49*	-2.99	-0.83	0.27	16.93**	14.95**	13.21*	5.69*
ICMA 96222 x 205-SB-19	-5.51*	-5.32	-6.10*	-1.48	-7.89	-4.81	-8.52	-1.55
ICMA 96222 x 206-SB-19	-5.92*	-4.11	-4.72	-8.68	-8.92	-4.49	-3.51	0.11
ICMA 96222 x 216-SB-19	-2.94	-2.62	-3.18	-5.00	5.47	5.10	5.51	3.12
ICMA 96222 x 217-SB-19	-0.04	-1.19	-0.84	0.27	-7.32	-8.97	-8.24	-1.46
ICMA 96222 x 219-SB-19	6.11*	6.67*	5.89*	2.52*	4.16	5.54	5.46	3.10
ICMA 96222 x 222-SB-19	3.92	0.72	-0.22	0.48*	-15.05*	-16.40**	-15.00*	-3.71
ICMA 96222 x 228-SB-19	6.96*	6.38*	5.93*	2.58*	-6.98	-4.69	-4.89	-0.34
ICMA 96222 x 256-SB-19	4.33	3.83	3.63	1.76	6.95	4.86	8.34	4.06
ICMA 99222 x 177-SB-19	-3.89	-2.72	-4.16	-6.38**	9.27	12.75*	11.45	-7.75*
ICMA 99222 x 190-SB-19	3.78	4.70	6.75**	2.80*	5.22	6.17	6.07	3.30
ICMA 99222 x 205-SB-19	0.36	1.43	-0.27	0.46	9.97	14.65**	15.24*	3.36*

Table 5: Contd…

Crosses	Grain yield per plant (g)				Dry fodder yield per plant (g)			
	E1	E2	E3	Pooled	E1	E2	E3	Pooled
ICMA 99222 x 206-SB-19	0.68	-3.12	-3.62	-0.65	16.95**	15.48**	14.13*	5.99*
ICMA 99222 x 216-SB-19	2.23	2.18	2.45	1.37	-7.22	-10.95*	-10.27	-2.13
ICMA 99222 x 217-SB-19	2.69	2.34	-3.33	1.66	-15.75*	-11.60*	-12.36*	-2.83
ICMA 99222 x 219-SB-19	-5.53*	-6.69*	-7.39**	-1.91	-1.43	-3.15	-3.67	0.06
ICMA 99222 x 222-SB-19	-2.79	-1.29	-1.01	0.21	-10.95	-12.01	-9.11	-1.75
ICMA 99222 x 228-SB-19	-5.98*	-6.57*	-6.54**	-1.62	-4.39	-5.97	-5.95	-0.70
ICMA 99222 x 256-SB-19	8.74**	9.74**	10.47**	0.04**	-1.67	-5.36	-5.51	-0.55
ICMA 98444 x 177-SB-19	10.77**	9.78**	8.95**	-2.01	5.63	6.03	7.03	-9.22**
ICMA 98444 x 190-SB-19	-7.75**	-8.01**	-11.44**	-3.26*	-7.95	-3.56	0.01	1.29
ICMA 98444 x 205-SB-19	6.86*	5.51*	8.04**	3.23*	23.93**	16.45**	19.79**	7.88
ICMA 98444 x 206-SB-19	-2.44	-4.03	-3.39	-0.56	-11.38	-9.67	-8.45	-1.53
ICMA 98444 x 216-SB-19	1.79	5.59*	6.00*	2.55*	-7.90	-6.46	-8.86	-1.66
ICMA 98444 x 217-SB-19	0.82	1.30	2.00	1.22	0.58	0.56	-2.27	0.52
ICMA 98444 x 219-SB-19	-1.85	-0.91	0.39	0.68	0.70	-0.35	-0.31	1.81
ICMA 98444 x 222-SB-19	0.99	0.06	0.52	0.73	-5.35	2.76	-3.93	-0.02
ICMA 98444 x 228-SB-19	-3.19	-3.27	-4.53*	-1.25	7.14	5.51	5.00	2.95
ICMA 98444 x 256-SB-19	-5.98*	-6.04*	-5.65*	-1.33	-5.41	-5.74	-8.01	-1.38
S.E. ±	2.75	2.69	2.44	0.88	6.22	5.10	5.93	2.00

*,** = Significant at 5% and 1% levels of probability, respectively

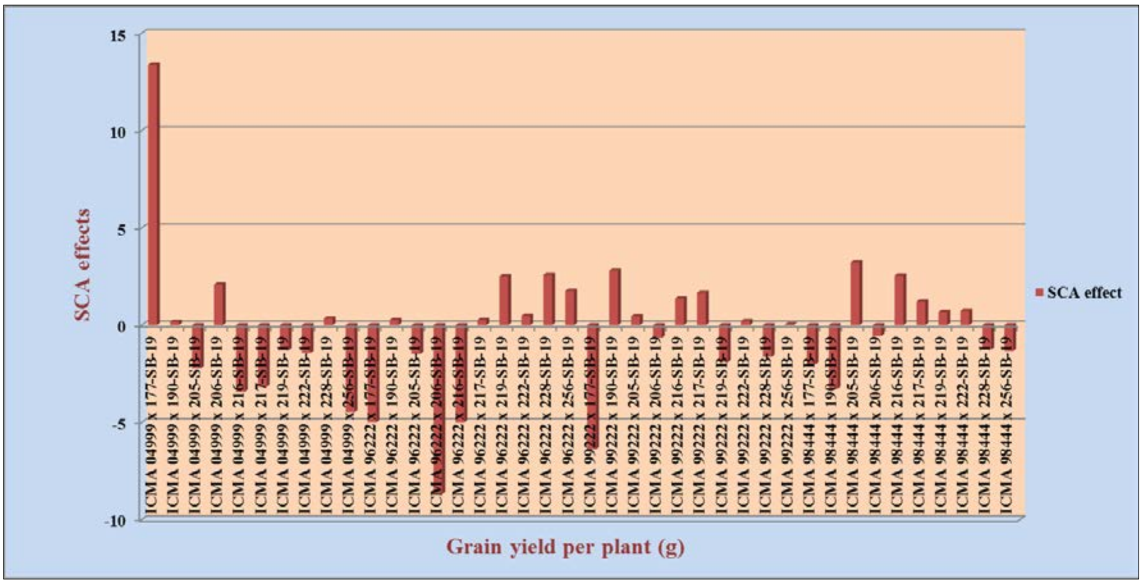

Fig 3: Specific combining ability effects of crosses pooled over environments for grain yield per plant (g)

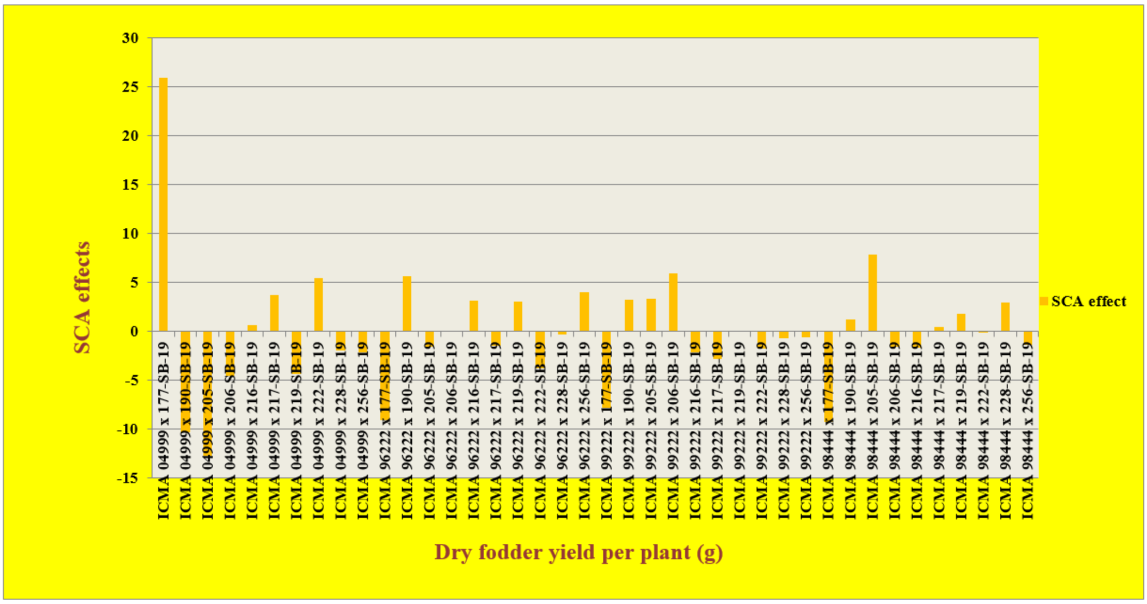

Fig 4: Specific combining ability effects of crosses pooled over environments for dry fodder yield per plant (g)

The mean squares for the pooled interaction components L x E reported significant for all the characters except for two i.e. dry fodder yield per plant and threshing index. On the contrary, other two interaction components T x E and L x T x E under pooled analysis were recorded for significant mean squares for all the characters studied under the present investigation. Per cent contribution of variances due to lines, testers and lines x testers interaction revealed the contribution of testers towards general combining ability variances were higher than lines for major of the studied characters except threshing index. This was recognized by high magnitude of unbiased estimates of variance due to testers as compared to lines. The ratio of variance due to general and specific combining ability was found less than unity for all the characters suggested that these traits were governed by non-additive gene action under pooled analysis over the three environments. These findings were in accordance with previous studies of Valu (2006) [31], Dangaria *et al* (2009b) [12], Shah (2009) [29], Chotaliya *et al*. (2010) [10], Lakshman *et al*. (2011) [21], Yadav *et al.* (2012) [32], Parmar *et al*. (2013) [26], Bhadalia *et al*. (2014) [7], Mungra (2014) [22], Nandaniya (2016) [23], Bagra *et al*. (2017b) [6], Krishnan *et al.* (2017) [18], Solanki *et al*. (2017) [30], Badurkar *et al.* (2018) [5], Ladumor *et al.* (2018b) [20] and Kumawat *et al*. (2019) [19].

General combining ability effect

Two females ICMA 99222 and ICMA 98444 and three males 177-SB-19, 216-SB-19 and 217-SB-19 recorded good gca effect towards grain yield per plant. Among the parents only three males *viz.*, 177-SB-19, 216-SB-19 and 217-SB-19 were found good general combiners for dry fodder yield per plant. The line ICMA 99222 also recorded with good general combiners for characters like days to 50% flowering, ear head girth, days to maturity, harvest index and threshing index. Likely ICMA 98444 reported as a good general combiners for traits like days to 50% flowering, length of protogyny, number of nodes on the main stem, plant height, days to maturity and harvest index. The tester 177-SB-19 was also reported as good general combiners for all the characters except days to 50% flowering, length of protogyny and days to maturity. The male parent 216-SB-19 was also reported as good general combiners for the characters like days to 50% flowering, ear head length, ear head weight, days to maturity, 1000-grain weight, dry fodder yield per plant and harvest index. The male parent 216-SB-19 was also reported as good general combiners for the characters like days to 50% flowering, number of nodes on the main stem, ear head length, ear head girth, plant height, days to maturity, 1000-grain weight and dry fodder yield per plant. Thus, the parents were good general combiner for grain yield per plant also showed good general combining ability for at least one component traits. These findings are in concurrence with of Mungra (2014) [22], Patel (2014) [28], Acharya (2017) [1], Badurkar *et al.* (2018) [5] and Kumawat *et al.* (2019) [19] in pearl millet.

Specific combining ability effect

The highest sca effect for grain yield per plant was manifested by, ICMA 04999 x 177-SB-19 which also exhibited significant sca effects in desired direction for most of the characters except days to 50% flowering, length of protogyny and days to maturity. This cross was involved poor x good general combining parents for grain yield per plant. The second highest sca effect in desired direction was recorded by cross, ICMA 98444 x 205-SB-19 involved good x poor general combiners for grain yield per plant which also exhibited significant sca effects in desired direction for threshing index. Likewise ICMA 99222 x 190-SB-19 had registered significantly positive (third highest) sca effect for grain yield per plant involved good x poor general combiners for grain yield per plant. Out of six top most cross combinations for sca effects, only two cross combinations *viz.*, ICMA 96222 x 219-SB-19, ICMA 04999 x 177-SB-19, ICMA 96222 x 228-SB-19 and ICMA 99222 x 190-SB-19 manifested high mean values for grain yield per plant over the environments which involved at least one poor and one good general combiners. These results were accordance with the earlier findings of Acharya (2017) [1]. Katba (2017) [16], Solanki *et al.* (2017) [30], Kanfany *et al.* (2018) [15], Badurkar *et al*. (2018) [5], Gavali *et al*. (2018) [14] and Kumawat *et al*. (2019) [19].

Conclusion

From the ongoing discussion, it was concluded that significant contribution of both lines and testers towards total variation due to general combining ability and also the additive genetic variance in the inheritance of different traits. The ratio of variance due to general and specific combining ability was found less than unity for all the characters suggested that these traits were governed by non-additive gene action over the environments. Among the parents three males namely 177-SB-19, 216-SB-19 and 217-SB-19 recorded good gca effect towards grain yield per plant as well as dry fodder yield per plant. Only three males *viz.*, 177-SB-19, 216-SB-19 and 217-SB-19 were found good general combiners for dry fodder yield per plant. The cross ICMA 04999 x 177-SB-19 was found with high magnitude of positive sca effect for both grain yield per plant and dry fodder yield per plant.

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