

RESEARCH ARTICLE

Genetic studies in pearl millet (*Pennisetum glaucum* L.)

■ S. B. Borgaonkar, J. E. Jahagirdar, D. K. Patil and H. V. Kalpande

SUMMARY

The present investigation on “Studies on heterosis for yield and its components in pearl millet (*Pennisetum glaucum* L.)” was conducted during *Kharif*-2020, at Department of Agriculture Botany, Vasant Rao Naik Krishi Vidyapeeth, Parbhani, National Agricultural Research Project, Aurangabad and College of Agriculture, Golegaon. The experimental material included in the present study comprised of five females (lines) and twelve restorers (testers) and sixty crosses. The experimental material was evaluated for twelve characters *viz*; days to 50% flowering, days to maturity, earhead length (cm), earhead girth (cm), number of nodes per plant, plant height (cm), total number of tillers per plant, number of effective tillers per plant, Fe content (ppm), Zn content (ppm), grain yield per plant (g) and grain yield per hectare (kg). The hybrids 02888A x 15006R, 02333A x 15006R, 00444A x 15351R, 99111A x 15020R and 99111A x 15713R exhibited high mean values for grain yield per plant and highly significant specific combining ability effects and wider adaptation across the environments. These hybrids could be utilized to exploit heterosis for grain yield. The hybrids 00444A x 15351R, 99111A x 15020R, 00111A x 15713R and 02888A x 15392R were found early for days to maturity. The hybrids 02888A x 15006R, 00444A x 15351R and 02333A x 15351R were found to contain high Fe content, whereas 99111A x 15020R, 02333A x 15351R and 02333A x 15020R had high Zn content.

Key Words : Combining ability, Good general combiner, Average general combiner

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India is a major pearl millet producing country with 43.3 per cent of the world's area and 42 per cent of world's production. It is mainly cultivated in the states of Rajasthan, Maharashtra, Gujarat, Madhya Pradesh, Karnataka, Andhra Pradesh, Uttar Pradesh and Tamil Nadu on a total area of 7.41 million hectares with the production of 10.3 million tones and national average productivity of 1391 kg/ha. While in Maharashtra, it is grown on an area of 6.37 lakh hectares with an annual production of 8.16 lakh tonnes. The state average

productivity is 1282 kg/ha (Anonymous, 2021). Its protogynous nature of flowering can be used to make hybrids. The principal aim of any breeding programme is to increase the yield potential. The yield is a complex character comprising of a number of components each of which is genetically controlled and susceptible to environmental fluctuations. The concept of combining ability is gaining importance in plant breeding as it provides valuable genetic information about the parents and the characters under study. It helps in assessing the breeding value of parental lines in terms of their superiority in hybrid combinations and also provides the information regarding the nature and extent of gene action involved in controlling the inheritance of characters in question, like yield and yield attributing characters, thus helps in deciding upon the future breeding strategy. Hence the present investigation based on 'line x tester' analysis was designed, to collect the information regarding the genetic composition of various quantitatively inherited yield contributing traits including grain yield in pearl millet. During the past three decades, single-cross F_1 hybrids based on cytoplasmic-nuclear male sterility (CMS) system have contributed significantly in increasing pearl millet productivity in India. So far very limited research work has been carried out on these lines. Considering the importance of the crop and the above facts, there is need to generate information on combining ability for yield and yield contributing traits. The information about current breeding material generated in *Kharif* 2019 and evaluated in *Kharif* 2020 to create new hybrids with grain yield potential.

MATERIAL AND METHODS

The present investigation on "Studies on heterosis, combining ability and stability analysis for yield and its components in pearl millet [*Pennisetum glaucum* (L.)]" was conducted during *Kharif*-2020, at three locations viz. Department of Agricultural Botany, Vasant Rao Naik Marathwada Krishi Vidyapeeth, Parbhani (L_1), National Agricultural Research Project, Aurangabad (L_2) and College of Agriculture, Golegaon (L_3). The experimental material included in the present study comprised of five females (lines) and twelve restorers (testers) which are mated in a Line X Tester design to obtain sixty crosses. The males (Restorer lines) and females (male sterile lines) were bagged before anthesis. This will be followed by hand pollination of collected pollen grains from desired restorers and dusted on selected female line to obtain

hybrid seed production. Five male sterile lines (lines) and twelve restorers (testers) were crossed in L x T mating design to obtain sufficient quantity seeds for obtaining the cross seeds, parents were grown at Department of Agricultural Botany to generate 60 F_1 hybrids. These 60 F_1 hybrids along with 12 restorers and 5 B lines with three standard checks were grown in randomized block design during *Kharif* 2020 season. The observations were recorded on twelve characters viz; days to 50% flowering, days to maturity, earhead length (cm), earhead girth (cm), number of nodes per plant, plant height (cm), total number of tillers per plant, number of effective tillers per plant, Fe content (ppm), Zn content (ppm), grain yield per plant (g) and grain yield per hectare (kg). Heterosis is the superiority of F_1 hybrid over both the parents in terms of yield or some other characters and is expressed as per cent. In the present investigation combining ability has been estimated by using line x tester analysis as outlined by Kempthorne (1957). The general combining ability (GCA) and specific combining ability (SCA) variances and effects were worked out according to Method II, Model I of Griffing (1956).

RESULTS AND DISCUSSION

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

Analysis of variance for combining ability :

The efficiency of parental selection in most crops including pearl millet can be significantly improved by estimating the combining ability effects. Selection of superior parents for hybridization is very important step in crop improvement programme. Estimating combining ability can be used to determine the usefulness of the inbred lines in making heterotic cross combinations. The most promising crosses are those that are derived from crossing of genetically diverse parents, where at least one of them has high general combining ability effects (GCA) effect. The mean sum of squares due to environment effects were found significant for days to 50% flowering, days to maturity, earhead length, earhead girth, plant height, number of effective tillers, grain yield per plant, grain yield per hectare, Fe content and Zn content (Table 1). Whereas, mean sum of squares due to line effects were found significant for plant height and number of nodes per plant. The mean sum of squares due to tester effects were found significant for earhead

Table 1: Pooled analysis of variance for combining ability in pearl millet

Source of variation	DF	Mean sum of squares (MSS)										
		Days to 50 % flowering	Days to maturity	Plant height	Total number of tillers per plant	Number of effective tillers per plant	Earhead length	Earhead girth	Number of nodes per plant	Grain yield per plant	Fe content	Zn content
Replications	1	13.23	9.35	93.67	0.01	0.00	4.32	5.26	0.03	13.22	13.63	5.08
Environments	2	270.63**	269.25**	1171.77**	0.06	0.25	11.66**	2.70*	0.57**	8.69**	209.29**	60.87**
Rep x Env.	2	4.91	7.37	23.55	0.05	0.00	4.11	0.13	0.06	0.05	4.36	0.12
Crosses	59	170.64**	135.41**	1003.03**	4.44**	2.05**	82.17**	6.45**	5.69**	256.22**	1916.36**	624.24**
Line effect	4	202.37	206.89	2852.37*	5.38	4.70	82.31	9.57	21.51**	136.17	474.99	535.07
Tester effect	11	263.87	176.46	777.73	5.04	1.52	131.02	12.38*	3.36	413.44	4381.55**	973.59
Line x Tester effect	44	144.44**	118.65**	891.23**	4.21**	1.95**	69.95**	4.68**	4.84**	227.84**	1431.10**	545.01**
Env x Crosses	118	17.67**	47.13**	692.96**	0.31**	0.17	7.66**	1.56**	0.21	21.32**	83.62**	39.62**
Env x Line effect	8	47.40**	41.76	1330.10	0.07	0.11**	3.11	0.95	0.15	12.84	113.46	31.37
Env x Tester effect	22	22.40	57.01	261.03	0.32	0.13**	9.83	1.87	0.29**	21.86	62.24	30.29
Env x L x T effect	88	13.78**	45.15**	743.01**	0.33**	0.18**	7.53**	1.54**	0.19**	21.96**	86.25**	42.70**
Error	177	3.44	5.48	47.65	0.02	0.02	2.20	0.87	0.02	8.31	3.82	2.47
Total	359	37.12	42.08	423.17	0.84	0.41	17.37	2.07	1.02	53.30	345.54	117.19

* and ** indicate significance of values at P=0.05 and 0.01, respectively

Table 2: General combining ability (gca) effect of parents for various characters of pearl millet at pooled over environments

Sr. No.	Genotypes	Days to 50 % flowering	Days to maturity	Plant height	Total number of tillers per plant	Number of effective tillers per plant	Earhead length	Earhead girth	Number of nodes per plant	Fe content	Zn content	Grain yield per plant
Lines												
1.	00111A	-2.22**	-2.46**	2.01**	0.28**	0.13**	-0.15	-0.12	-0.21**	-1.18**	-0.07	-0.58
2.	02333A	0.01	0.30	5.06**	-0.29**	-0.11**	1.29**	0.33**	0.89**	2.24**	4.69**	1.30**
3.	02888A	-0.75**	-0.27	1.52*	0.24**	0.22**	0.86**	0.42**	-0.13**	1.31**	-2.11**	1.65**
4.	00444A	-0.65**	0.15	-6.12**	-0.28**	-0.18**	-1.26**	-0.43**	0.03	-3.96	-1.27**	-1.15**
5.	99111A	2.31**	2.28**	-2.48**	0.05**	-0.06**	-0.74**	-0.18	-0.58**	1.58**	-1.24**	-1.22**
Testers												
1.	15006 R	-5.64**	-3.32**	4.23**	0.37**	0.24**	2.47**	0.61**	0.41**	13.32**	2.32**	2.45**
2.	15020 R	1.02**	-2.88**	-1.66	-0.12**	0.05	-0.42	-0.52**	-0.58**	3.65**	7.33**	0.30
3.	15183 R	0.69*	2.98**	5.49**	-0.10**	-0.09**	0.14	-0.05	-0.10**	-1.37**	-1.04**	2.56**
4.	15223 R	4.45**	0.74	1.69	-0.69**	-0.39**	-0.72**	-0.19	-0.36**	-10.91**	-6.15**	-2.89**
5.	15351 R	-3.60**	-1.78	1.23	0.64**	0.40**	4.47**	1.52**	0.18**	27.82**	8.46**	7.55**
6.	15392 R	2.35**	0.01	8.29**	0.77**	0.30**	-0.25	-0.17	0.44**	-9.38**	0.18	2.53**
7.	15706 R	0.99**	2.07**	-3.66**	-0.30**	-0.20**	-1.25**	-0.02	-0.49**	-3.35**	-2.48**	-1.16*
8.	15713 R	-3.64**	-2.72**	2.26	-0.20**	-0.01	2.37**	0.45*	0.29**	7.52**	5.57**	2.80**
9.	15934 R	-0.61	-0.32	0.36	-0.07*	-0.05	-0.55*	0.28	0.15**	-9.93**	-7.15**	-1.56**
10.	17592 R	-0.34	-0.88*	-12.30**	0.06*	0.01	-1.85**	-0.65**	-0.01	4.62**	4.85**	-3.13**
11.	17715 R	2.83**	3.87**	-7.63**	-0.27**	-0.26**	-2.66**	-0.49**	-0.03	-9.79**	-4.52**	-5.36**
12.	17686 R	1.49**	2.24**	1.69	-0.09**	0.02	-1.69	-0.74	0.10**	-12.17**	-7.38	-4.09*
S.E._±												
	Line	0.21	0.27	0.75	0.01	0.02	0.17	0.11	0.01	0.25	0.18	0.33
	Tester	0.32	0.42	1.17	0.02	0.03	0.25	0.17	0.02	0.39	0.28	

* and ** indicate significance of values at P=0.05 and 0.01, respectively

girth and Fe content. The mean sum of squares due to crosses effects were significant for all the characters. The mean sum of squares due to line x tester interaction effects were found significant for all the characters. The mean sum of squares due to environment x crosses interaction effects were found significant for all the characters except number of nodes per plant and number of effective tillers per plant. The mean sum of squares due to environment x tester interaction effects were found significant for number of nodes per plant and number of effective tillers per plant. The mean sum of squares due to environment x line x tester interaction effects were significant for all the characters.

Days to 50% flowering :

On pooled basis, the female line 00111A (-2.22) has displayed highly significant and negative general

combining ability effects followed by 02888A (-0.75) and 00444A (-0.65) for days to 50% flowering. Among tester parents, three have displayed significant and negative general combining ability effects on pooled basis for days to 50% flowering. The tester parent 15006R (-5.64) has recorded highly significant and negative general combining ability effects followed by 15713R (-3.64) and 15351R (-3.60), respectively. The general combining ability effects are presented in Table 2. Whereas, specific combining ability effects are presented in Table 3.

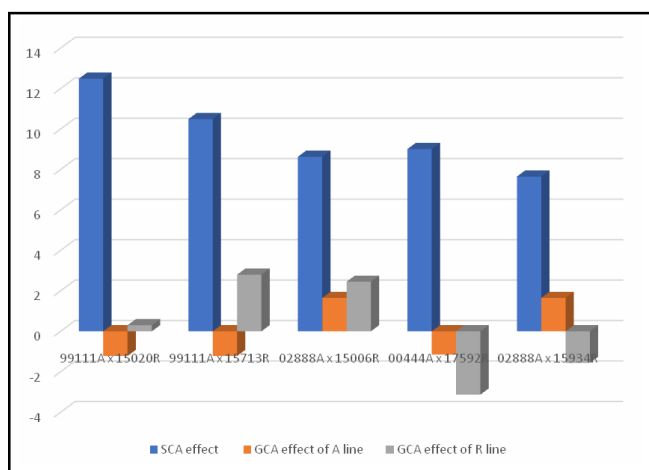
On pooled basis, twenty crosses recorded significant and negative specific combining ability effects (SCA) for days to 50% flowering. The crosses 99111A X 15020R (-8.87) followed by 02333A X 15183R (-7.08), 00444A X 17686R (-6.02), 99111A X 17592R (-5.67), 02888A X 15392R (-5.32) exhibited highly significant and negative specific combining ability effects (SCA) for days to 50%

Table 3 (a): Top ranking parent with respect to *per se* performance and GCA effects and five top ranking hybrids with respect to *per se* performance and SCA effects

Sr. No.	Characters	Best general combiners	Best performing hybrid	Hybrids with high SCA effects	GCA of the parents	SCA effects
1.	Days to 50% flowering	00111A	00111A X 15351R	99111A X 15020R	Poor X Good	(-8.87)
		02888A	02888A X 15006R	02333A X 15183R 00444A	Average X Good	(-7.08)
		15006R	00444A X 15006R	X 17686R 99111A X	Good X Poor	(-6.02)
		15351R	99111A X 15020R	17592R 02888A X 15392R	Poor X Average	(-5.67)
		15713R	02333A X 15223R		Good X Poor	(-5.32)
2.	Days to maturity	00111A	00111A X 15713R	99111A X 15020R 02888A	Poor X Good	(-9.18)
		15006R	02333A X 15006R	X 15392R 99111A X	Average X Poor	(-8.02)
		15020R	02888A X 15351R	15223R 02333A X 15183R	Poor X Average	(-6.81)
		15713R	99111A X 15713R	99111A X 15713R	Average X Poor	(-6.74)
3.	Earhead length	00111A	00111A X 15713R	99111A X 15020R 02888A	Average X	(6.70)
		02888A	02333A X 15183R	X 15934R 02333A X	Average	(5.91)
		15006R	02888A X 15006R	15183R 00444A X 15006R	Good X Poor	(5.77)
		15351R	00444A X 15006R	99111A X 15713R	Good X Average	(5.66)
		15713R	00444A X 15351R		Poor X Good	(5.40)
4.	Earhead girth	00111A	00111A X 15351R	00444A X 15006R	Poor X Good	(1.75)
		02888A	00111A X 15713R	99111A X 15020R 02888A	Poor X Poor	(1.56)
		15006R	02333A X 15351R	X 15934R 99111A X	Good X Good	(1.40)
		15351R	02888A X 15006R	15223R 00111A X 17715R	Poor X Good	(1.38)
		15713R	02888A X 15351R		Average X Poor	(1.22)
5.	Number of nodes	02333A	02333A X 15392R	00111A X 17715R 02333A	Poor X Average	(1.57)
		15006R	02333A X 15351R	X 15706R 99111A X	Good X Poor	(1.52)
		15351R	02333A X 15706R	15223R 02888A X 15934R	Poor X Poor	(1.27)
		15392R	02333A X 15006R	99111A X 15020R	Poor X Good	(1.17)
		15713R	00444A X 15713R		Poor X Poor	(1.15)

Table 3 (b): Top ranking parent with respect to *per se* performance and GCA effects and five top ranking hybrids with respect to *per se* performance and SCA effects

Sr. No.	Characters	Best general combiners	Best performing hybrid	Hybrids with high SCA effects	GCA of the parents	SCA effects
6.	Total number of tillers per plant	00111A	99111A X 15392R	99111A X 15020R 00111A	Good X Good	(1.46)
		02888A	00444A X 15351R	X 17715R 02888A X	Good X Poor	(1.34)
		15006R	99111A X 15020R	15934R 00444A X 17592R	Good X Poor	(1.17)
		15351R	02888A X 15006R	02333A X 15934R	Poor X Good	(1.14)
		15392R	00444A X 15392R		Poor X Poor	(1.07)
7.	Number of effective tillers per plant	00111A	02888A X 15934R	00444A X 17592R 99111A	Poor X Average	(0.84)
		02888A	00444A X 15351R	X 15020R 99111A X	Poor X Average	(0.75)
		15006R	02888A X 15006R	15713R 02888A X 15934R	Poor X Average	(0.74)
		15351R	99111A X 15020R	00444A X 15351R	Good X Average	(0.66)
		15392R	99111A X 15713R		Poor X Good	(0.61)
8.	Plant height	02333A	00111A X 15392R	99111A X 15223R 00444A	Poor X Average	(25.55)
		02888A	99111A X 15183R	X 15351R 99111A X	Poor X Average	(22.99)
		15006R	02333A X 15392R	15183R 00111A X 15392R	Poor X Good	(22.08)
		15183R	02333A X 15934R	00111A X 17715R	Good X Good	(16.61)
		15706R	02333A X 15006R		Good X Poor	(16.55)
9.	Fe content and	02333A	02888A X 15006R	99111A X 15020R 02888A	Good X Good	(33.06)
		99111A	02333A X 15351R	X 15006R 99111A X	Good X Good	(29.64)
		15006R	00444A X 15351R	15713R 00444A X 15351R	Good X Good	(26.16)
		15351R	00111A X 15351R	00111A X 17592R	Average X Good	(18.77)
		15713R	99111A X 15020R		Poor X Good	(16.30)
10.	Zn content	02333A	02333A X 15351R	99111A X 15020R 00111A	Poor X Good	(22.12)
		15020R	99111A X 15020R	X 15706R 02333A X	Average X Poor	(18.27)
		15351R	02333A X 15020R	15351R 02888A X 15183R	Good X Good	(15.21)
		15713R	00111A X 17592R	00111A X 17592R	Poor X Poor	(13.54)
		17592R	00111A X 15706R		Average X Good	(11.97)
11.	Grain yield per plant	02333A	02888A X 15006R	99111A X 15020R 99111A	Poor X Average	(12.49)
		02888A	99111A X 15713R	X 15713R 00444A X	Poor X Good	(10.49)
		15006R	99111A X 15020R	15792R 02888A X 15006R	Poor X Poor	(9.01)
		15351R	02333A X 15351R	00111A X 15713R	Good X Good	(8.63)
		15713R	02333A X 15006R		Poor X Good	(8.18)

**Fig 1: Promising crosses for specific combining ability effects along with general combining ability effects of parents**

flowering. These crosses exhibited highly significant and negative specific combining ability effects (SCA) in all the environments for days to 50% flowering. Similar kind of results were observed by Haussmann *et al.* (2006), Khandagale *et al.* (2014), Patel *et al.* (2016) and Gavali *et al.* (2018).

Days to maturity :

On pooled basis, the female line 00111A (-2.46) has displayed significant and negative general combining ability effects for days to maturity. The line 02888A has recorded significant and negative GCA effects in E_3 environment (-2.43) only. With respect to tester parents, four have displayed significant and negative general combining ability effects on pooled basis for days to maturity. The tester parent 15006R (-3.32) has recorded

highly significant and negative general combining ability effects followed by 15020R (-2.88), 15713R (-2.72) and 17592R (-0.88), respectively.

On pooled basis, sixteen crosses recorded significant and negative specific combining ability effects (SCA) for days to maturity. The crosses with highly significant and negative specific combining ability effects (SCA) were 99111A X 15020R (-9.18) followed by 02888A X 15392R (-8.02), 99111A X 15223R (-6.81), 02333A X 15183R (-6.74), 99111A X 15713R (-4.58). These crosses exhibited highly significant and negative specific combining ability effects (SCA) in rest of the environments for days to maturity. The results are in accordance with the findings of Patel *et al.* (2008), Khandagale *et al.* (2014) and Patel *et al.* (2016).

Plant height :

On pooled basis, the female line 02333A (5.06) has displayed significant and positive general combining ability effects followed by 00111A (2.01) and 02888A (1.52) for plant height. Among tester parents, three have exhibited significant and positive general combining ability effects on pooled basis for plant height. The tester parent 15392R (8.29) has recorded highly significant and positive general combining ability effects followed by 15183R (5.49) and 15006R (4.23), respectively. On pooled basis twenty crosses recorded significant and positive specific combining ability effects (SCA) for plant height. The crosses which exhibited highly significant and negative specific combining ability effects (SCA) were 99111A X 15223R (25.55) followed by 00444A X 15351R (22.99), 99111A X 15183R (22.08), 00111A X 15392R (16.61) and 00111A X 17715R (16.55). These crosses exhibited highly significant and positive specific combining ability effects (SCA) in rest of the environments for plant height. Similar results were reported by Khandagale *et al.* (2014) and Patel *et al.* (2016).

Total number of tillers per plant :

On pooled basis, the female line 00111A (0.28) has displayed significant and positive general combining ability effects followed by 02888A (0.24) for total number of tillers per plant. Whereas, among tester parents, four have exhibited significant and positive general combining ability effects on pooled basis for total number of tillers per plant. The tester parent 15392R (0.77) has recorded highly significant and positive general combining ability effects followed by 15351R (0.64) and 15006R (0.37), respectively.

On pooled basis, twenty-seven crosses recorded significant and positive specific combining ability effects (SCA) for total number of tillers per plant. The crosses with highly significant and negative specific combining ability effects (SCA) were 99111A X 15020R (1.46) followed by 00111A X 17715R (1.34), 02888A X 15934R (1.17), 00444A X 17592R (1.14), 02333A X 15934R (1.07). These crosses exhibited highly significant and positive specific combining ability effects (SCA) in rest of the environments for total number of tillers per plant. The findings are in agreement with the results of Haussmann *et al.* (2006), Singh and Sharma (2014) and Patel *et al.* (2016).

Number of effective tillers per plant :

On pooled basis, the female line 02888A (0.22) has recorded significant and positive general combining ability effects followed by 00111A (0.13) for number of effective tillers per plant. Whereas, among testers, three have exhibited significant and positive general combining ability effects on pooled basis for number of effective tillers per plant. The tester parent 15351R (0.40) has recorded highly significant and positive general combining ability effects followed by 15392R (0.30) and 15006R (0.24), respectively.

On pooled basis, twenty-three crosses recorded significant and positive specific combining ability effects (SCA) for number of effective tillers per plant. The crosses with highly significant and negative specific combining ability effects (SCA) were 00444A X 17592R (0.84) followed by 99111A X 15020R (0.75), 99111A X 15713R (0.74), 02888A X 15934R (0.66), 00444A X 15351R (0.61). These crosses exhibited highly significant and positive specific combining ability effects (SCA) in rest of the environments for number of effective tillers per plant. Similar findings were reported by Yadav *et al.* (2002), Rathore *et al.* (2004) and Shanmugnathan *et al.* (2005).

Earhead length :

On pooled basis, the female line 02333A (1.29) has displayed significant and positive general combining ability effects followed by 02888A (0.86) for earhead length. Among tester parents, three have exhibited significant and positive general combining ability effects on pooled basis for earhead length. The tester parent 15351R (4.47) has recorded highly significant and positive general combining ability effects followed by 15006R (2.47) and 15713R (2.37), respectively.

On pooled basis, sixteen crosses recorded significant and positive specific combining ability effects (SCA) for earhead length. The crosses which exhibited highly significant and positive specific combining ability effects (SCA) were 99111A X 15020R (6.70) followed by 02888A X 15934R (5.91), 02333A X 15183R (5.77), 00444A X 15006R (5.66), 99111A X 15713R (5.40). These crosses exhibited highly significant and positive specific combining ability effects (SCA) in rest of the environments for earhead length. The results are in agreement with Haussmann *et al.* (2006), Singh and Sharma (2014) and Patel *et al.* (2016).

Earhead girth :

On pooled basis, the female line 02888A (0.42) has displayed significant and positive general combining ability effects followed by 02333A (0.33) for earhead girth. Whereas, among testers three have exhibited significant and positive general combining ability effects on pooled basis for earhead girth. The tester 15351R (1.52) has recorded highly significant and positive general combining ability effects followed by 15006R (0.61) and 15713R (0.45), respectively. On pooled basis, ten crosses recorded significant and positive specific combining ability effects (SCA) for earhead girth. The crosses which recorded highly significant and negative specific combining ability effects (SCA) were 00444A X 15006R (1.75) followed by 99111A X 15020R (1.56), 02888A X 15934R (1.40), 99111A X 15223R (1.38), 00111A X 17715R (1.22). These crosses exhibited highly significant and positive specific combining ability effects (SCA) in rest of the environments for earhead girth. The results are in agreement with Haussmann *et al.* (2006), Singh and Sharma (2014) and Patel *et al.* (2016).

Number of nodes per plant :

On pooled basis, the female line 02333A (0.89) has displayed significant and positive general combining ability effects for number of nodes per plant. The female line 00444A has recorded significant and positive GCA effects in environment E_2 (0.10) only. Whereas, among tester parents, six have exhibited significant and positive general combining ability effects on pooled basis for number of nodes per plant. The tester parent 15392R (0.44) has recorded highly significant and positive general combining ability effects followed by 15006R (0.41), 15713R (0.29), 15351R (0.18) and 15934R (0.15), respectively.

On pooled basis, twenty-four crosses recorded significant and positive specific combining ability effects (SCA) for number of nodes per plant. The crosses which recorded highly significant and negative specific combining ability effects (SCA) were 00111A X 17715R (1.57) followed by 02333A X 15706R (1.52), 99111A X 15223R (1.27), 02888A X 15934R (1.17), 99111A X 15020R (1.15). These crosses exhibited highly significant and positive specific combining ability effects (SCA) in rest of the environments for number of nodes per plant. Similar kind of results were reported by Badwal (1970), Kushwaha and Singh (1992) and Singh and Sharma (2014).

Grain yield per plant :

On pooled basis two female lines have exhibited highly significant and positive general combining ability effects for grain yield per plant. The female line 02888A (1.65) has exhibited significant and positive general combining ability effects followed by 02333A (1.30) for grain yield per plant. On pooled basis, five testers has exhibited significant and positive general combining ability effects for grain yield per plant. The tester parent 15351R (7.55) has recorded highly significant and positive general combining ability effects followed by 15713 (2.80), 15183R (2.56), 15392R (2.53) and 15006R (2.45), respectively.

On pooled basis, twenty crosses recorded highly significant and positive specific combining ability effects (SCA) for grain yield per plant. The crosses with highly significant and negative specific combining ability effects (SCA) were 99111A X 15020R (12.49) followed by 99111A X 15713R (10.49), 00444A X 15792R (9.01), 02888A X 15006R (8.63), 00111A X 15713R (8.18). These crosses exhibited highly significant and positive specific combining ability effects (SCA) in rest of the environments for grain yield per plant. The high yielding crosses have at least one of the parents as good or average general combiner for grain yield. The fascinating thing is parents with either poor x average, poor x good, good x good, poor x poor and good x poor general combining ability effects (GCA) exhibited highly significant and positive heterosis for grain yield. The crosses showing high *per se* performance have resulted from the parents with good, average and good X poor general combining parents. The results are in accordance with the findings of Nandniya *et al.* (2016), Patel *et al.* (2016), Solanki *et al.* (2017) and Gavali *et al.* (2018).

Fe content :

Three female parents have exhibited highly significant and positive general combining ability effects for Fe content. The female line 02333A (2.24) has displayed significant and positive general combining ability effects for Fe content followed by 99111A (1.58) and 02888A (1.31). On pooled basis, five tester parents has exhibited significant and positive general combining ability effects for Fe content. The tester parent 15351R (27.82) has recorded highly significant and positive general combining ability effects followed by 15006R (13.32), 15713R (7.52) 17592R (4.62) and 15020R (3.65), respectively.

On pooled basis, twenty-six crosses recorded significant and positive specific combining ability effects (SCA) for Fe content. The crosses with highly significant and positive specific combining ability effects (SCA) were 99111A X 15020R (33.06) followed by 02888A X 15006R (29.64), 99111A X 15713R (26.16), 00444A X 15351R (18.77), 00111A X 17592R (16.30). These crosses exhibited highly significant and positive specific combining ability effects (SCA) in rest of the environments for Fe content. The findings are in accordance with the results of Velu *et al.* (2011), Rai *et al.* (2012), Govindraj *et al.* (2013), Solanki *et al.* (2017) and Gavali *et al.* (2018).

Zn content :

One female parent has recorded highly significant and positive general combining ability effects for Zn content. The female parent 02333A (4.69) has displayed significant and positive general combining ability effects for Zn content. On pooled basis, five testers has exhibited significant and positive general combining ability effects for Zn content. The tester parent 15351R (8.46) has recorded highly significant and positive general combining ability effects followed by 15020R (7.33), 15713R (5.57), 17592R (4.85) and 15006R (2.32), respectively. On pooled basis, twenty-five crosses recorded significant and positive specific combining ability effects (SCA) for Zn content. The crosses with highly significant and negative specific combining ability effects (SCA) were 99111A X 15020R (22.12) followed by 00111A X 15706R (18.27), 02333A X 15351R (15.21), 02888A X 15183R (13.54) and 00111A X 17592R (11.97). These crosses exhibited highly significant and positive specific combining ability effects (SCA) in rest of the environments for Zn content. Similar findings were reported by Velu *et al.* (2011), Rai *et al.* (2012), Govindraj *et al.* (2013) and

Solanki *et al.* (2017).

Conclusion :

The female parents 02333A, 02888A along with male parents 15006R, 15183R, 15351R, 15392R and 15713R were found good general combiners for grain yield per plant and other characters. The hybrids 02888A x 15006R, 99111A x 15020R, 99111A x 15183R were found best specific combinations for grain yield per plant. These hybrids were found to record high specific combining ability effects for other characters. Hence, the hybrids 02888A x 15006R, 99111A x 15020R, 99111A x 15183R can be considered for exploitation of heterosis for grain yield with multiseason testing.

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