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Combining ability and gene action analysis for yield and yield attributing traits in pearl millet [*Pennisetum glaucum* (L.) R. Br.

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Abstract
A diallel mating design excluding reciprocal was practised among 8 diverse parents and their 28 crosses to access the gene action and combining ability in pearl millet during *kharif* 2019. The statistical results of analysis of variance showed highly significant differences due to genotypes for all the traits under study indicating the parents and their hybrids under study have sufficiently high amount of genetic variability. Moreover, division of mean sum of square due to genotypes showed that the differences among eight parental genotypes were significant for all the yield related attributes. Among the 8 parents, 16317, 15708 and 15851 were considered as good general combiner for character *viz.* grain yield. Apart from grain yield per plant, the parent 16317 was also good combiner for days to flowering, days to maturity, ear head length and ear head girth, harvest index, test weight and protein content. The cross 17548 × 15388 was the finest specific combiner for grain yield per plant followed by 15851 × 15725 and 15725 × 16110**.** An inspection of *per se* performance as well as sca effects of crosses revealed that the 17548 × 15388 and 15851 × 15725 found best crosses for grain yield per plant and its component characters. So, these crosses are advised to further study for commercial exploitation. The proportion of σ^2gca / σ^2sca was below unity for all the traits under study, which suggested considerable action of non-additive genetic variance in the governance of these characters.

Keywords: Pearl millet, Diallel, variability, *Per se* performance, Gene action

Introduction
Pearl millet [*Pennisetum glaucum* (L) R. Br.] is principal cereal food crop after rice and wheat. The chief pearl millet growing Indian states are Gujarat, Rajasthan, Haryana, Maharashtra, Karnataka and Uttar Pradesh in which this crop grown both in summer as well as in *kharif* seasons. Various sources of cytoplasmic genetic male sterility *viz.*, A_1, A_2, A_3, A_4, Aegp and A_5 present in pearl millet which allowed the production and also release of a many hybrids. Pearl millet is cross pollinated in nature and presence of sufficient numbers of male sterile lines in this crop had made of it easy to utilize hybrid vigor on commercial level. The genetic improvement of pearl millet has been carried out through traditional breeding procedures. The study of combining ability supplies important information with regard to the selection of appropriate parents for fruitful hybridization programme and simultaneously explains the nature as well as extent of gene action. As long as, the complexion of gene action differs with genetic constitution of population involved in hybridization programme, it is obligatory to evaluate the parents for their combining ability. The given experiment was performed to study general combining ability of parents as well as specific combining ability of hybrids for different yield attributing characters and also to explore the nature with relative magnitude of gene action for different traits.

Materials and Methods
Plant materials: The experimental material consisted 37 entries having 28 hybrids produced from diallel mating design excluding reciprocals which involved 8 parental lines with a standard check GHB 558.

Field experiments: The above presented experimental material was evaluated in Randomized Block Design with three replications in *kharif*-2019 at Centre for Crop Improvement, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar. Each entry was grown in 2 rows with 4 m in length.

The spacing of 75 cm between the rows and 15 cm between the plant was maintained. All recommended agronomic practices were followed for raising a good pearl millet crop. Different ten observations were recorded on days to flowering, days to maturity, plant height (cm), number of effective tillers per plant, ear head length (cm), ear head girth (cm), grain yield per plant (g), harvest index (%), test weight (g) and protein content (%). The data of observations were recorded from randomly selected 5 plants from each genotype in each replication.

Statistical analysis: The mean performance of each parents and hybrids was subjected to statistical analysis. Analysis of variance to test the significance for each character was carried out as per methodology given by Panse and Sukhatme (1985) [13]. Combining ability analysis for parents and their crosses (Diallel method excluding reciprocals with numerical approach) by Griffing (1956a) [7]and Griffing (1956b) [8].

Results and Discussion

The results of analysis of variance (Table 1) revealed highly significant differences due to genotypes for all the traits under study. This supports that the parents and their hybrids under study possessed sufficiently high amount of genetic variability. Further, partitioning of mean sum of square due to genotypes implied that the differences among parents were significant for all the traits. The significant differences among parents showed greater diversity in the parental lines. In case of hybrids, significant differences were found for all the traits.

Considering *per se* performance of hybrids, 18 hybrids yielded higher than commercial check GHB 558 for grain yield per plant (table 5), of which two hybrids 17548 × 15388 and 15851 × 15725 yielded significantly higher than GHB 558. Apart from grain yield per plant, the cross 17548 × 15388 also exhibited higher *per se* performance for protein content whereas the cross 15851 × 15725 showed higher *per se* performance for days to maturity, number of effective tillers per plant, earhead length and harvest index. The cross 15851 × 15708 also gave higher *per se* performance for number of effective tillers per plant and test weight.

Among all the parental genotypes under study, 16317, 15708 and 15851 were reported good general combiner for grain yield on the GCA effects (table 3). Apart from the yield, the genotype 16317 was also found good general combiner for days to flowering, days to maturity, ear head length, ear head girth, test weight and protein content.

Specific combining ability effects for each cross are presented in table 4. A significant deviation of crosses from zero would be indicated whether the SCA effects is high or low according to the positive or negative sign. Out of 28 crosses under study, 19 crosses were showed significant and positive SCA for grain yield per plant. The crosses 17548 × 15388, 15851 × 15725, 15708 × 15388, 15725 × 16110 and 15058 × 15388 were considered as good specific combiner on their SCA effects. Therefore, in such crosses desirable transgressive segregants would be expected in the subsequent generation. These results of GCA and SCA were in accordance with Joshi *et al.* (2001a) [9], Joshi *et al.* (2001_b) [10], Sidpara (2002) [18], Rasal and Patil (2003) [16], Lakshmana *et al.* (2003) [12], Dangaria *et al.* (2004) [5], Chotaliya (2005) [4], Yahia Eldie *et al.* (2009) [6], Bhadalia *et al.* (2014) [1], Patel *et al.* (2014) [15], Patel B. C. *et al.* (2016) [14], Reshma M. R. *et al.* (2017) [17], Ladumor *et al.* (2018^b) [11], Amit *et al.* (2019) [2] and Zheelkumar *et al.* (2019) [3].

For days to flowering and days to maturity, number of crosses found significant in desired direction were thirteen and seventeen respectively. Whereas, the crosses, ten, eleven, seventeen, fourteen, thirteen and thirteen showed significant SCA effects in desired direction for number of effective tillers per plant, ear head length, ear head girth, harvest index, test weight and protein content respectively. The crosses found good specific combiner were also reported either good or average specific combiners for it's yield contributing trait.

Based on overall result, it would be concluded that among all the parents genotype 16317, 15708 and 15851 were reported good general combiner for grain yield and it's component traits. This may be useful to used in future breeding programme. The crosses 15851 × 15725 and 15725 × 16110 were found most promising for grain yield and it's components like number of effective tillers per plant, ear head length, ear head girth and harvest index. Based on their mean performance and SCA effects. There would be a chance of getting good transgressive Segregant in future breeding programme.

Table 1: Analysis of variance (Mean square) for parents and hybrids for grain yield and its components characters in pearl Millet

Source of variation	Degree of Freedom	Mean sum of square									
		Days to flowering	Days to maturity	Plant height	No. of effective tillers per plant	Ear head length	Ear head girth	Grain yield per plant	Harvest Index	Test weight	Protein content
Replications	2	0.75	0.62	424.23	0.01	0.38	0.01	22.63	28.53	0.14	0.17
Genotypes	36	45.99**	93.24**	2792.39**	0.43**	33.00**	0.32**	784.92**	208.87**	4.76**	2.58**
Parents (P)	7	49.71**	50.66**	3292.63**	0.52**	19.16**	0.40**	479.30**	308.79**	8.05**	2.71**
Hybrids (H)	27	42.33**	64.39**	2343.24**	0.34**	29.46**	0.23**	615.78**	187.68**	5.01**	2.67**
P × H	1	102.15**	1257.69**	14036.11**	0.54**	255.28**	0.22**	8164.51**	288.78**	21.25**	0.01
Error	72	2.75	7.61	186.44	0.01	2.41	0.01	21.22	10.62	0.12**	0.16
* and** indicates significant at P = 0.05 and P = 0.01 levels, respectively.											

Table 2: Analysis of variance (Mean square) for combining ability and estimates of components of variance for various characters in pearl millet

Source of variation	Degree of Freedom	Mean sum of square									
		Days to flowering	Days to maturity	Plant height	No. of effective tillers per plant	Ear head length	Ear head girth	Grain yield per plant	Harvest Index	Test weight	Protein content
Parents (P)	7	51.71**	59.57**	883.98**	0.11**	14.94**	0.15**	60.86**	35.76**	2.07**	1.47**
Hybrids(H)	28	6.04**	25.00**	973.67**	0.14**	10.37**	0.10**	319.86**	80.55**	2.02**	0.81**
Error	70	0.93	2.57	62.15	0.01	0.82	0.01	7.07	3.62	0.04	0.08
Estimates of components of genetic variance and related parameters											
σ^2gca		5.07	5.7	82.17	0.01	2.94	0.01	5.37	6.69	0.29	0.11
σ^2sca		5.10	22.43	911.54	0.12	5.71	0.09	312.77	68.23	1.19	0.73

σ^2gca / σ^2sca	0.99	0.25	0.09	0.08	0.51	0.11	0.02	0.09	0.24	0.15
* and** indicates significant at P = 0.05 and P = 0.01 levels, respectively.										

Table 3: Estimation of general combining ability (*gca*) effects of parents for various characters in pearl millet

Source of variation		Days to flowering	Days to maturity	Plant height (cm)	No. of effective tillers per plant	Ear head length (cm)	Ear head girth (cm)	Grain yield per plant (g)	Harvest index (%)	Test weight (g)	Protein content (%)
15058		-1.14**	-0.80	0.82	-0.15**	-2.79**	-0.25**	-1.65*	-2.63**	-1.22**	0.02
15851		-1.81**	-1.47**	13.32**	-0.03	3.16**	0.12**	2.43**	-1.12*	-0.12	-0.70**
15708		2.49**	2.97**	9.26**	0.23**	0.51	-0.03	3.15**	3.61**	0.54**	-0.20**
15725		2.76**	2.30**	-12.72**	-0.06**	-0.78**	-0.02	-2.66**	-3.05**	-0.19**	0.17*
17548		-2.14**	-2.73**	-11.37**	-0.02	0.93**	0.01	-1.97*	2.32**	0.29**	-0.08
15388		2.86**	3.27**	0.19	0.07**	-0.79**	0.02	-1.05	-2.49**	0.31**	0.27**
16110		-1.01**	-1.3**	-5.40*	-0.05**	-0.85**	0.10**	-1.41	0.76	0.32**	0.07
16317		-2.01**	-2.23**	5.90*	-0.02	0.60*	0.05**	3.16**	2.59**	0.06**	0.44**
Range	Min.	-2.14	-2.73	-12.72	-0.15	-0.25	-0.25	-2.66	-3.05	-1.22	0.70
	Max.	2.86	3.27	13.32	0.23	0.12	0.12	3.16	3.61	0.54	0.44
S.Em.±		0.28	0.47	2.33	0.01	0.26	0.10	0.78	0.56	0.06	0.06
Positive		3	3	5	2	4	5	3	4	5	5
Positive significant		3	3	3	2	3	3	3	3	5	3
Negative		5	5	3	6	4	3	5	4	3	3
Negative Significant		5	4	3	3	4	1	3	4	1	2
* and** indicates significant at P = 0.05 and P = 0.01 levels, respectively.											

Table 4: Estimation of Specific Combining Ability (*sca*) for various characters in pearl millet

Sr. No.	Source of variation	Days to flowering	Days to maturity	Plant height	No. of effective tiller per plant	Ear head length
1	15058 × 15851	-0.02	-4.14**	-5.22	0.16**	0.90*
2	15058 × 15708	-2.99**	-2.91**	9.25**	0.37**	-1.98**
3	15058 × 15725	1.41**	-0.24	31.36**	-0.67**	-1.10**
4	15058 × 17548	0.31	-2.21**	-21.32**	0.05	2.54**
5	15058 × 15388	-3.36**	-4.21**	34.18**	0.39**	-0.34
6	15058 × 16110	-0.49	-3.64**	34.50**	-0.08**	-1.33**
7	15058 × 16317	0.51	-0.37	14.41**	0.02	-0.12
8	15851 × 15708	-1.66**	-5.57**	8.68**	0.25**	-0.14
9	15851 × 15725	-0.26	-7.24**	25.25**	0.14**	2.62**
10	15851 × 17548	0.31	-4.54**	-41.63**	-0.14**	-1.96**
11	15851 × 15388	-2.02**	2.46**	18.21**	-0.19**	2.10**
12	15851 × 16110	-0.49	-0.97	-29.34**	0.40**	1.92**
13	15851 × 16317	0.84*	1.63*	1.50	-0.03	0.63
14	15708 × 15725	5.44**	4.33**	-20.35**	0.35**	5.58**
15	15708 × 17548	-1.99**	2.69**	25.37**	-0.39**	-1.77**
16	15708 × 15388	3.01**	-1.64*	-42.59**	-0.05	0.30
17	15708 × 16110	-1.46**	-3.07**	30.93**	-0.25**	-3.23**
18	15708 × 16317	-1.79**	-1.81**	14.04**	-0.69**	1.52**
19	15725 × 17548	-1.59**	-4.64**	14.01**	-0.24**	-0.59
20	15725 × 15388	2.41**	5.03**	-36.42**	0.04	-3.08**
21	15725 × 16110	-2.06**	-4.41**	34.90**	-0.03	1.25**
22	15725 × 16317	-2.39**	-4.81**	19.74**	0.33**	0.14
23	17548 × 15388	-4.02**	-3.94**	62.90**	-0.04	-5.09**
24	17548 × 16110	-0.49	0.29	-23.38**	0.75**	1.25**
25	17548 × 16317	2.18**	0.23	-6.20*	-0.15**	2.57**
26	15388 × 16110	-0.49	-1.71**	35.06**	-0.50**	-2.33**
27	15388 × 16317	-2.16**	-4.77**	-12.43**	-0.13**	3.19**
28	16110 × 16317	-1.29**	-0.87	-4.78	0.59**	-1.52**
S.Em.±		0.37	0.63	3.10	0.02	0.30
Range		-4.02 to 5.44	-7.24 to 5.03	-42.59 to 62.90	-0.69 to 0.75	-5.09 to 5.58
No. of significant		19	22	25	21	21
No. of +ve significant		6	5	16	10	11
No. of -ve significant		13	17	9	11	10
* and** indicates significant at P = 0.05 and P = 0.01 levels, respectively.						

Table 4: Continued.

Sr. No.	Source of variation	Ear head girth	Grain yield per plant	Harvest index	Test wt.	Protein content
1	15058 × 15851	-0.34**	-3.39**	9.27**	0.87**	-0.76**
2	15058 × 15708	0.20**	17.45**	-0.53**	0.75**	0.82**
3	15058 × 15725	-0.76**	4.57**	-18.27**	-3.42**	-0.90**
4	15058 × 17548	0.40**	-6.01**	7.73*	0.70**	0.76**
5	15058 × 15388	0.04*	17.90**	-5.52**	-0.47**	-0.34**
6	15058 × 16110	0.15**	15.58**	-1.87**	1.27**	1.41**
7	15058 × 16317	0.10**	7.81**	2.37**	-0.19*	-1.21**
8	15851 × 15708	0.10**	16.47**	6.10**	-2.53**	-0.08
9	15851 × 15725	0.18**	27.68**	4.18**	1.17**	-0.73**
10	15851 × 17548	-0.04	-21.9**	-7.80**	0.82**	-0.34**
11	15851 × 15388	0.18**	10.58**	2.96**	0.21*	-0.72**
12	15851 × 16110	0.20**	-14.46**	-3.47**	-0.47**	0.17
13	15851 × 16317	-0.23**	-11.72**	1.88	-0.13	1.45**
14	15708 × 15725	0.15**	-12.88**	15.74**	0.02	-1.08**
15	15708 × 17548	-0.35**	6.75**	-5.97**	-0.42**	0.70**
16	15708 × 15388	0.13**	21.96**	4.14**	-0.17*	0.41**
17	15708 × 16110	-0.37**	4.53**	-14.59**	0.36**	0.73**
18	15708 × 16317	0.18**	1.94	-13.62**	0.22**	0.82**
19	15725 × 17548	0.48**	16.91**	-3.83**	-1.47**	0.89**
20	15725 × 15388	-0.19**	-12.31**	5.54**	0.63**	0.88**
21	15725 × 16110	0.34**	20.50**	1.63*	0.79**	0.40**
22	15725 × 16317	0.32**	5.26**	-5.04**	-0.35**	0.65**
23	17548 × 15388	-0.80**	31.12**	-10.87**	0.56**	-0.98**
24	17548 × 16110	0.01	-13.44**	2.76**	0.51**	-0.43**
25	17548 × 16317	0.10**	10.25**	-2.94**	-0.66**	0.15**
26	15388 × 16110	0.00	4.78**	6.09**	0.02	-0.12
27	15388 × 16317	0.14**	15.3**	4.49**	-0.61**	-1.39**
28	16110 × 16317	-0.31**	12.83**	13.77**	-0.69**	-0.06
S.Em.±		0.01	1.04	0.75	0.08	0.09
Range		-0.80 to 0.48	-21.96 to 31.12	-18.27 to 15.74	-3.42 to 1.27	-1.39 to 1.45
No. of significant		25	27	27	25	24
No. of +ve significant		17	19	14	13	13
No. of -ve significant		8	8	13	12	11
* and** indicates significant at P = 0.05 and P = 0.01 levels, respectively.						

Table 5: Comparative study of most promising hybrids in relation to *per se* value and sca effects for grain yield per plant with useful component characters showing desirable sca effects.

Sr. No.	Hybrid	Grain yield per plant (g)	SCA effects for grain yield	Significant SCA for component trait in desirable direction
1	17548 × 15388	66.97	31.12**	Days to flowering, Days to maturity and Test weight.
2	15851 × 15725	66.33	27.68**	Days to maturity, No. of effective tiller per plant, Ear head length, Ear head girth, Harvest index and Test weight.
3	15708 × 15388	45.14	21.96**	Ear head girth, Harvest index and Protein content.
4	15725 × 16110	55.30	20.50**	Days to flowering, Days to maturity, Ear head length, Ear head girth, Harvest index, Test weight and Protein content.
5	15058 × 15388	54.08	17.90**	Days to flowering, Days to maturity, No. of effective tiller per plant and Ear head girth.
* and** indicates significant at P = 0.05 and P = 0.01 levels, respectively.				

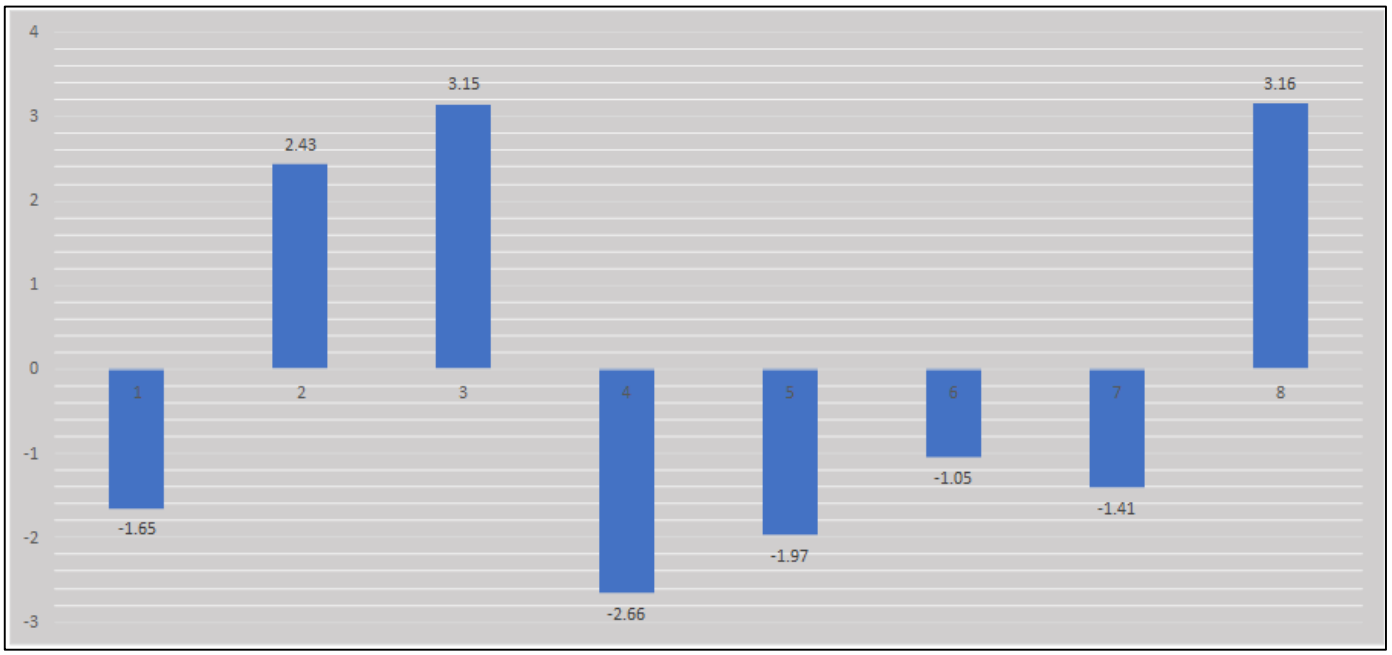

Fig 1: Diagrammatically representation of general combining ability of restorer parents for grain yield per plant

1. 15058 2. 15851 3. 15708 4. 15725 5.17548 6.15388 7.16110 8.16317

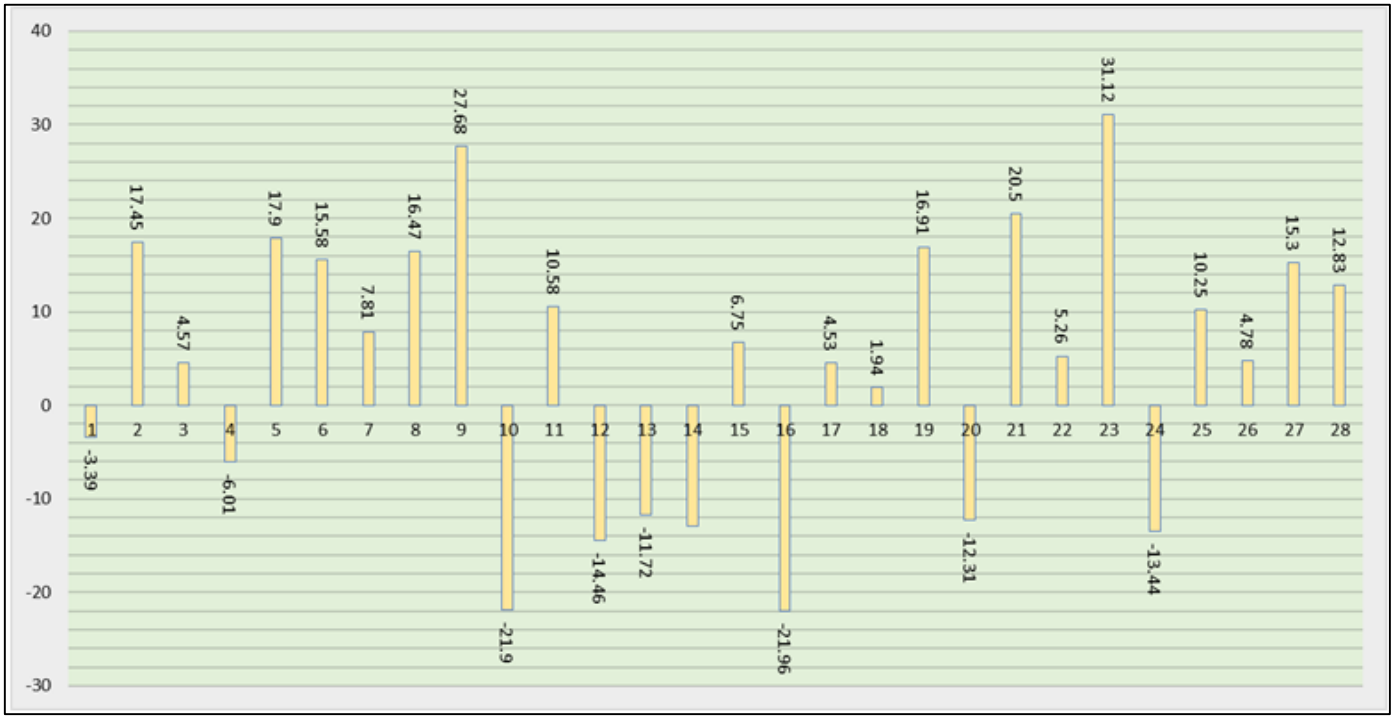

Fig 2: Graphical representation of specific combining ability effects of hybrids for grain yield per plant in pearl millet

1. 15058 × 15851 2. 15058 × 15708 3. 15058 × 15725 4. 15058 × 17548 5. 15058 × 15388 6. 15058 × 16110 7. 15058 × 16317 8. 15851 × 15708 9. 15851 × 15725 10. 15851 × 17548 11. 15851 × 15388 12. 15851 × 16110 13. 15851 × 16317 14. 15708 × 15725 15. 15708 × 17548 16. 15708 × 15388 17. 15708 × 16110 18. 15708 × 16317 19. 15725 × 17548 20. 15725 × 15388 21. 15725 × 16110 22. 15725 × 16317 23. 17548 × 15388 24. 17548 × 16110 25. 17548 × 16317 26. 15388 × 16110 27. 15388 × 16317 28. 16110 × 16317

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