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Study of Combining Ability Analysis in Barley (*Hordeum vulgare* L.)

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A B S T R A C T

9 diverse barley genotypes were selected and crossed in a diallel (without reciprocals) mating design to evaluate combining ability effects to identify promising crosses for 13 quantitative characters including yield and its components. Analysis of variance for diallel revealed highly significant differences for most of the traits investigated. Parent BH 393 has been excellent general combiner for majority of traits *viz.*, days to 50 per cent heading, days to 75 per cent maturity. Another parent BH 959 has good general combiner for plant height, flag leaf area, number of effective tillers per plant, spike length, number of grains per spike, number of spikelets per plant, 1000-grain weight, and grain yield per plant. Followed by Parent RD 2786 has been good general combiner for protein content. Parents RD 2715, BH 959, BH 393 can be utilizing for developing of a variety by exploiting additive gene action. BH 959 and DWRB 64 these both the parents are of higher yielding these both the parent of higher grain yielding crosses *viz.*, RD 2786 × BH 959, RD 2552 × DWRB 64, and RD 2035 × RD 2786. A perusal of specific combining ability effects revealed that positive significant sca effects for grain yield per plant was observed in eleven crosses *viz.*, DWRB 91 × BH 959, RD 2552 × DWRB 64, RD 2035 × RD 2786, RD 2035 × BH 393, DWRB 92 × BH 393 RD 2715 × DWRB 64, RD 2715 × DWRB 91, BH 959 × DWRB 64, RD 2552 × RD 2715, RD 2035 × DWRB 92 and DWRB 91 × DWRB 64 expressed higher positive significant sca effects ranged from 1.17 to 2.50 along with good *per se* performance from 14.44 to 21.07. It is, therefore, the selective parents and crosses could be utilized for developing desirable crosses with high yielding towards exploiting the hybrid vigor or other related traits under crop improvement.

Introduction

Barley (*Hordeum vulgare* L., 2n = 2x =14) is the world's fourth most important cereal crop after Wheat (*Triticum aestivum* L.), Maize (*Zea mays* L.) and Rice (*Oryza sativa* L.). It belongs to family Poaceae. Barley is popularly known as "Jau" in Hindi and one of the most important cereal grain crops in India. It is cultivated as a *rabi* season crop in India and sowing is done from Oct. to Dec. & harvesting from March to May. Barley is most paramount cereal crop and considered as the first cereal domesticated for use by man as food and feed (Potla *et al.*, 2013). This crop requires temperature of 12°C to 16°C at growing stage and about 30°C to 32°C at maturity. It is very susceptible to frost at any stage of its growth and has very good tolerance to drought conditions. It is grown under marginal to sub marginal land and mostly under rained condition. It is an essential crop of North India and among three spp. of barley *Viz.,* Two-row barley (*H. distichum*), four-row barley (*H. tetrastichum*), six-row barley (*H. vulgare*) and husk and huskless barley are available. It is an economically important crop plant, the fourth cereal worldwide in terms of the planting area, utilized almost 60 per cent as animal feed, around 30 per cent for malt production, 7 per cent for seed production and only 3 per cent for human food (Baik *et al.,* 2008). It is produced primarily as animal feed, while it has same nutritive value as corn. It is graining importance in neutraceutical diets and has potential health benefit due to soluble fibre ß-glucan which helps in lowering cholesterol level, improving lipid metabolism (Koulagi *et al.,* 2018). It contains high amounts of carbohydrates, moderate amounts of protein, calcium and phosphorus and it has small amounts of the vitamin B. By- products of the brewing process and malt sprouts are also used as livestock feed. Sometimes barley is grown as a hay crop in some areas and only the smooth varieties or awn less variety are used in hay production. Winter barley also can be used for hay if pasteurized before the stems start to elongate. Barley is also used in liquor industry and breakfast foods.

Since *per se* performance of parents may not reveal their combining ability, so the information on nature of gene actions and their expression in terms of combining ability is necessary. (Patial *et al.,* 2016). The main objectives of this study were to identify of superior parents and crosses combinations from half diallel mating design to obtained high grain yield and better malting quality grains in barley.

The combining ability provide information of the nature of gene action involved in the inheritance of various characters and there by breeding methodology to be used. The nature of gene action would help in predicting the efficiency of selection in population. A distinct type of gene action, its magnitude and constitution of genetic architecture are of fundamental importance to plant breeder.

Materials and Methods

For the present experiment 9 parents were crossed in diallel (without reciprocals) mating design to obtain 36 crosses during *rabi* 2017-18. The experimental material thus consisted of 9 parents 36 crosses and two checks *viz.,* RD 2899 and BH 946. Nine genetically diverse parents namely RD 2035, RD 2552, RD 2786, RD 2715, DWRB 91, BH 959, DWRB 92, DWRB 64, and BH 393. Experiment was evaluated in randomized block design (RBD) in 3 replications. The experiment carried out at the research farm, Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology, Udaipur (Rajasthan) during *rabi* 2018-2019. The observations recorded for thirteen characters *viz.,* days to 50 per cent heading, days to 75 per cent maturity, plant height, flag leaf area, number of effective tillers per plant, spike length, number of grains per spike, number of spikelets per plant, 1000-grain weight, grain yield per plant, biological yield per plant, harvest index and protein content.

The data obtained were subjected to statistical analysis to get information on significance of differences and combining ability (Griffing B. *et al.,* 1956 method 2, Model I).

The statistical model used for said analysis was:

$$X_{ij} = \mu + g_i + g_j + s_{ij} + \frac{1}{r}\sum_{b} e_{ijb} \quad \{i, j = 1,\ldots\ldots p \text{ and } b = 1,\ldots\ldots r\}$$

Where,

X_{ij} = Mean value of experimental genotype,

μ = Population mean,

g_i (g_j) = General combining ability (GCA) effect for i^{th} (j^{th}) parent,

s_{ij} = Specific combining ability (SCA) effect for cross between i^{th} and j^{th} parent assuming s_{ij} = s_{ji}

e_{ijb} = Error component pertaining to i^{jth} observation in b^{th} replication,

p = Number of parents and

r = Number of replications.

Results and Discussion

The analysis of variance revealed that while, mean squares due to general combining ability (GCA) was significant for all the traits. Specific combining ability (SCA) effects were significant for all the traits, expect for days to 75 per cent maturity. Table 1

Parents RD 2715, BH 959, BH 393 can be utilizing for developing of a variety by exploiting additive gene action.

Perusal of Table 2 Out of 36 crosses, five crosses *viz.,* RD 2786 × BH 959 (21.07), BH 959 × DWRB 64 (20.23), DWRB 91 × BH 959 (20.22), RD 2035 × RD 2786 (20.06) and RD 2715 × BH 959 (19.97) exhibited higher *per se* performance for grain yield per plant.

3 crosses *viz.,* DWRB 91 × BH 959, RD 2035× RD 2786 and BH 959 × DWRB 64 expressed higher significant sca effects for grain yield per plant. The significant specific combining ability effects (SCA) might be due to the occurrence of inter-allelic interaction and can be easily exploited in cross pollinated crops and in self-pollinated crops where commercial hybrid seed production is possible.

Parent BH 393 has been excellent general combiner for majority of traits *viz.,* days to 50 per cent heading, days to 75 per cent maturity. Another parent BH 959 has good general combiner for plant height, flag leaf area, number of effective tillers per plant, spike length, number of grains per spike, number of spikelets per plant, 1000-grain weight, and grain yield per plant.

Followed by Parent RD 2786 has been good general combiner for protein content. BH 959 and DWRB 64 these both the parents are of higher yielding these both the parent of higher grain yielding crosses *viz.,* RD 2786 × BH 959, RD 2552 × DWRB 64, and RD 2035 × RD 2786.

Among the parents, 4 parents expressed positive significant gca effects in positive direction with the magnitude varied from 0.56 (RD 2715) to 1.74 (BH 959). The positive significant sca effects for grain yield per plant were exhibited by 11 crosses with the magnitude ranged from 1.17 (DWRB 91 × DWRB 64) to 2.50 (DWRB 91 × BH 959). These results are in similar to the finding of Amer *et al.,* (2012), Potla *et al.,* (2013), Sultan *et al.,* (2016), Rathore *et al.,* (2017), Ram *et al.,* (2017) and Patial *et al.,* (2016).

Out of 36 crosses only two crosses *viz.,* DWRB 91× BH 959 and RD 2552 × DWRB 64 exhibited higher sca effects for grain yield per plant. As well as yield attributing traits, viz., number of grains per spike. with respect to protein content maximum sca effects for protein content were expressed by cross RD 2552 × RD 2786 (1.20) followed by DWRB 91× BH 959 and RD 2035 × RD 2786. Table 3-4

Table.1 Combining ability mean square and EMS for thirteen characters in Barley (*Hordeum vulgare* L.)

SN.	Characters	Source			Var Model I	
		GCA	SCA	Error	GCA	SCA
		[8]	[36]	[88]		
1	Days to 50 per cent heading	15.14**	5.67*	3.27	8.63	86.28
2	Days to 75 per cent maturity	22.44**	6.17	6.07	11.90	3.37
3	Plant height (cm)	29.00**	15.08**	4.60	17.74	377.21
4	Flag leaf area (cm^2)	55.58**	8.85**	0.38	40.14	304.76
5	Number of effective tillers per plant	11.64**	1.70**	0.26	8.27	51.77
6	Spike length (cm)	6.94**	2.78**	0.55	4.65	80.31
7	Number of grains per spike	1064.71**	99.81**	1.72	773.08	3531.40
8	Number of spikelets per plant	4146.58**	744.47**	39.99	2986.61	25361.53
9	1000-Grain weight (g)	11.40**	2.15**	1.02	7.56	40.74
10	Grain yield per plant (g)	11.80**	1.99**	0.31	8.35	60.53
11	Biological yield per plant (g)	10.74*	13.30**	4.16	4.79	329.20
12	Harvest index %	14.82**	6.79**	1.61	9.61	186.33
13	Protein content %	0.79**	0.37**	0.02	0.56	12.45

*, ** Significant at 5% and 1% level of significance, respectively.

Table.2 Identified on the basis of *per se* performance, for grain yield and protein content as well as sca/gca in Barley

S. No.	Crosses	***Per se* performance for grain yield per plant (g)**	Sca/gca effects for grain yield per plant	Sca/gca effects for protein content
1.	RD 2786 × BH 959	21.07	0.94	0.39**
2.	BH 959 × DWRB 64	20.23	1.51*	-0.43**
3.	DWRB 91 × BH959	20.22	2.50**	1.14**
4.	RD 2035 × RD 2786	20.06	1.97**	1.13**
5.	RD 2715 × BH 959	19.97	0.16	0.70**
6.	RD 2035	15.27	-0.30	-0.07
7.	RD 2786	20.21	0.87**	-0.07
8.	RD 2715	17.46	0.56**	0.05
9.	DWRB 91	13.73	-1.54**	0.13**
10.	BH 959	19.94	1.74**	0.59**
11.	DWRB 64	15.67	-0.54**	-0.31**
7.	BH 946	19.36		

Best check- BH 946
*, ** Significant at 5 % and 1 % level of significance respectively.

Table.3 GCA and SCA effects for Days to 50 per cent heading, Days to 75 per cent maturity, Plant height, Flag leaf area, Number of effective tillers per plant, Spike length and Number of grains per spike

S N.	Genotype	Days to 50 per cent heading	Days to 75 per cent maturity	Plant height	Flag leaf area	Number of effective tillers per plant	Spike length	Number of grains per spike
1	RD 2035	-0.97	0.40	-1.38*	2.73**	1.03**	0.69**	5.81**
2	RD 2552	0.70	2.67**	0.80	-3.19**	-0.39**	-0.36	-1.69**
3	RD 2786	-1.15*	0.58	0.72	-0.61**	0.54**	0.65**	1.96**
4	RD 2715	1.34*	-1.18	2.89**	1.74**	0.19	0.24	5.05**
5	DWRB 91	-0.91	-1.72*	-0.69	-1.56**	-0.18	-1.16**	-12.54**
6	BH 959	-0.21	-1.36	-1.61**	2.59**	1.43**	1.14**	9.99**
7	DWRB 92	-0.21	1.07	1.68**	-2.31**	-1.85**	0.11	-19.72**
8	DWRB 64	-0.81	0.55	-1.88**	-1.24**	0.36*	-1.13**	5.34**
9	BH 393	2.22**	-1.02	-0.54	1.84**	-1.14**	-0.18	5.81**
10	RD 2035 × RD 2552	-0.70	-3.67	-1.46	-2.68**	-1.36**	1.44*	-2.01
11	RD 2035 × RD 2786	-2.52	-4.24	-4.59*	5.50**	1.93**	1.79**	8.73**
12	RD 2035 × RD 2715	3.00	2.18	6.53**	1.67**	-2.05**	0.58	5.44**
13	RD 2035 × DWRB 91	-0.09	3.06	-0.78	-3.36**	-1.02*	0.10	-16.86**
14	RD 2035 × BH 959	1.55	1.36	2.80	-6.72**	2.59**	-0.47	3.18**
15	RD 2035 × DWRB 92	2.55	0.27	-2.72	-3.35**	-1.65**	-1.70*	-10.34**
16	RD 2035 × DWRB 64	2.48	2.79	0.81	2.05**	-2.18**	-1.43*	8.09**
17	RD 2035 × BH 393	-2.21	1.03	0.22	-0.82	-1.01*	-0.08	-4.61**
18	RD 2552 × RD 2786	-1.52	1.82	1.77	-1.19*	-0.07	-0.42	2.13
19	RD 2552 × RD 2715	-3.33*	-0.09	0.45	-3.04**	-0.65	-0.91	2.01
20	RD 2552 × DWRB 91	-0.76	1.12	1.84	-0.82	1.04*	-3.05**	-8.50**
21	RD 2552 × BH 959	2.21	1.09	0.33	-1.93**	0.11	-0.54	-0.59
22	RD 2552 × DWRB 92	5.55**	-1.00	-6.41**	4.53**	0.38	1.28	-4.61**
23	RD 2552 × DWRB 64	-0.18	1.52	0.45	-1.17*	-0.42	0.61	4.42**
24	RD 2552 × BH 393	2.12	1.76	-0.02	4.79**	0.64	-0.36	1.72
25	RD 2786 × RD 2715	-1.15	-0.33	1.80	-0.76	-0.19	1.06	2.29
26	RD 2786 × DWRB 91	1.42	1.21	0.22	-3.44**	0.55	-2.51**	-9.38**
27	RD 2786 × BH 959	3.73*	-2.82	1.02	4.83**	-0.60	2.81**	-1.01
28	RD 2786 × DWRB 92	-0.61	0.76	-2.07	0.21	-0.43	-2.33**	-4.00**
29	RD 2786 × DWRB 64	0.33	-1.39	2.27	2.18**	0.15	-1.93**	-3.33**
30	RD 2786 × BH 393	-1.03	4.52*	-1.81	-3.68**	0.66	-0.81	-1.73
31	RD 2715 × DWRB 91	4.27*	1.30	-1.29	-1.10	0.27	-1.61*	-19.44**
32	RD 2715 × BH 959	-0.76	-1.73	-7.23**	2.12**	2.66**	0.68	6.80**
33	RD 2715 × DWRB 92	-0.76	-0.82	1.28	-1.20*	-0.80	-0.03	-8.06**
34	RD 2715 × DWRB 64	-1.48	-4.30	-2.10	-0.85	0.87	-0.93	-5.49**
35	RD 2715 × BH 393	0.15	2.94	1.36	-1.09	-0.08	-0.19	-3.82**
36	DWRB 91 × BH 959	-4.18*	-2.85	-5.57**	4.81**	1.06*	2.09**	23.26**
37	DWRB 91 × DWRB 92	0.15	2.06	6.90**	-0.85	-0.02	2.84**	5.21**
38	DWRB 91 × DWRB 64	-1.24	-2.09	0.47	0.18	-0.67	1.76*	13.18**
39	DWRB 91 × BH 393	2.73	-0.85	-0.05	-0.92	-0.53	0.67	10.74**
40	BH 959 × DWRB 92	-1.21	4.03	4.33*	1.01	-1.58**	-0.93	-16.22**
41	BH 959 × DWRB 64	0.39	0.88	-5.37**	-4.15**	-0.94*	-4.15**	-14.29**
42	BH 959 × BH 393	-0.64	-0.21	2.71	-1.04	-0.37	-0.17	-2.59*
43	DWRB 64 × DWRB 92	0.06	2.12	11.45**	-0.10	2.81**	2.38**	-8.17**
44	DWRB 92 × BH 393	-3.97*	-4.64*	-1.72	1.96**	-0.01	0.43	20.09**
45	DWRB 64 × BH 393	-3.03	2.55	0.53	1.56**	0.59	1.53*	-3.94**
	Standard error							
	Gi	0.51	0.70	0.61	0.18	0.14	0.21	0.37
	Gi-Gj	0.77	1.05	0.91	0.26	0.22	0.32	0.56
	Sii	1.46	1.99	1.74	0.50	0.41	0.60	1.06
	Sij	1.65	2.25	1.96	0.57	0.46	0.68	1.20
	Sij-ik	2.44	3.32	2.89	0.84	0.69	1.00	1.77
	Sij-Skl	2.31	3.15	2.74	0.79	0.65	0.95	1.68

*, ** Significant at 5% and 1% level of significance respectively.

Table.4 GCA and SCA effects for Number of spikelets per plant, 1000-Grain weight, Grain yield per plant, Biological yield per plant, Harvest index, and Protein content

SN.	Genotype	Number of spikelets per plant	1000-Grain weight	Grain yield per plant	Biological yield per plant	Harvest index	Protein content
1	RD 2035	22.22**	0.15	-0.30	-0.76	0.10	-0.07
2	RD 2552	-15.05**	-0.90**	-0.56**	0.53	-1.09**	0.07
3	RD 2786	8.88**	1.06**	0.87**	0.86	0.48	-0.07
4	RD 2715	5.04**	-0.14	0.56**	0.54	0.60	0.05
5	DWRB 91	4.57*	-1.61**	-1.54**	-0.60	-1.72**	0.13**
6	BH 959	25.83**	1.60**	1.74**	-0.05	2.20**	0.59**
7	DWRB 92	-23.29**	-0.81**	-0.95**	-0.45	-1.03**	-0.31**
8	DWRB 64	2.68	-0.05	-0.54**	-1.68**	0.32	-0.31**
9	BH 393	-30.88**	0.69*	0.72**	1.59**	0.13	-0.07
10	RD 2035 × RD 2552	-24.03**	0.30	-0.87	-0.23	-1.02	-0.46**
11	RD 2035 × RD 2786	59.84**	-0.21	1.97**	-1.49	3.18**	1.13**
12	RD 2035 × RD 2715	-41.37**	-0.44	-0.82	0.82	-1.78	-0.13
13	RD 2035 × DWRB 91	-18.81**	1.39	0.51	-1.31	1.32	0.28*
14	RD 2035 × BH 959	38.65**	1.44	0.11	2.13	-1.21	-0.24
15	RD 2035 × DWRB 92	-27.89**	-0.02	1.22*	2.50	0.15	0.77**
16	RD 2035 × DWRB 64	-44.07**	2.06*	-0.57	0.21	-0.85	0.32*
17	RD 2035 × BH 393	-28.54**	-0.86	1.75**	10.03**	-2.89*	-0.00
18	RD 2552 × RD 2786	26.51**	-0.86	-0.44	-0.44	-0.04	1.20**
19	RD 2552 × RD 2715	-25.79**	1.85*	1.30*	0.40	1.17	-0.02
20	RD 2552 × DWRB 91	20.54**	1.23	-1.96**	-1.12	-1.99	0.16
21	RD 2552 × BH 959	3.71	-1.53	-0.52	1.28	-1.32	-0.89**
22	RD 2552 × DWRB 92	-10.37	1.70	0.26	0.37	0.25	-0.78**
23	RD 2552 × DWRB 64	11.64*	1.18	1.98**	2.95	0.79	0.07
24	RD 2552 × BH 393	4.45	-1.51	-0.05	-1.96	0.98	0.24
25	RD 2786 × RD 2715	-17.11**	-0.58	-0.40	-0.07	-0.64	-0.91**
26	RD 2786 × DWRB 91	-0.18	-2.34*	-1.42**	-0.04	-1.56	-0.38**
27	RD 2786 × BH 959	-25.82**	2.69**	0.94	3.20	-0.80	0.39**
28	RD 2786 × DWRB 92	12.17*	-0.25	0.81	-1.56	2.08	-0.21
29	RD 2786 × DWRB 64	-12.28*	-1.39	-3.42**	1.10	-4.92**	0.15
30	RD 2786 × BH 393	25.00**	-1.46	0.07	-0.24	0.16	-0.52**
31	RD 2715 × DWRB 91	15.29**	-1.51	1.54**	0.12	1.70	0.15
32	RD 2715 × BH 959	60.07**	0.94	0.16	-13.72**	9.68**	0.70**
33	RD 2715 × DWRB 92	8.36	-1.81	-0.69	-0.12	-0.98	-0.69**
34	RD 2715 × DWRB 64	2.89	-0.51	1.65**	2.40	0.33	-0.15
35	RD 2715 × BH 393	-4.36	-0.03	-0.41	2.29	-1.95	-0.64**
36	DWRB 91 × BH 959	29.44**	1.79	2.50**	0.49	2.72*	1.14**
37	DWRB 91 × DWRB 92	-11.74*	0.97	0.71	0.06	0.91	0.18
38	DWRB 91 × DWRB 64	-7.82	-0.44	1.17*	1.00	0.94	-0.37*
39	DWRB 91 × BH 393	-11.48	0.85	-1.64**	-1.62	-1.21	0.08
40	BH 959 × DWRB 92	-24.83**	0.95	-1.92**	-0.71	-2.03	0.60**
41	BH 959 × DWRB 64	-15.53**	-1.44	1.51**	2.61	0.04	-0.43**
42	BH 959 × BH 393	-0.72	-1.10	-0.67	0.00	-1.15	0.18
43	DWRB 64 × DWRB 92	27.58**	0.11	0.38	0.79	-0.03	0.28
44	DWRB 92 × BH 393	-6.37	0.67	1.67**	-0.72	2.30	0.56**
45	DWRB 64 × BH 393	16.04**	-0.15	-1.15*	1.16	-2.27	-0.13
	Standard error						
	Gi	1.80	0.29	0.16	0.58	0.36	0.04
	Gi-Gj	2.70	0.43	0.24	0.87	0.54	0.07
	Sii	5.12	0.82	0.45	1.65	1.03	0.13
	Sij	5.78	0.92	0.51	1.87	1.16	0.14
	Sij-ik	8.53	1.36	0.75	2.75	1.71	0.21
	Sij-Skl	8.09	1.29	0.71	2.61	1.62	0.20

*, ** Significant at 5% and 1% level of significance respectively.

The study under presents were revealed that some of the parents *viz.*, BH 959 and RD 2786 used in present analysis can be preferred for the successful development of variety through pedigree method.

Parents were noted as good sources of encouraging genes for increasing grain yield and exploit of these parents would be more gratifying for boosting grain yield in Barley.

A perusal of specific combining ability effects revealed that positive significant sca effects for grain yield per plant was observed in eleven crosses *viz.*, DWRB 91 × BH 959, RD 2552 × DWRB 64, RD 2035 × RD 2786, RD 2035 × BH 393, DWRB 92 × BH 393 RD 2715 × DWRB 64, RD 2715 × DWRB 91, BH 959 × DWRB 64, RD 2552 × RD 2715, RD 2035 × DWRB 92 and DWRB 91 × DWRB 64 expressed higher positive significant sca effects ranged from 1.17 to 2.50 along with good *per se* performance from 14.44 to 21.07.

Table 4 In general a close association between sca effects and per se performance for grain yields per plant and protein content was recorded amongst the five promising crosses.

These five crosses appear to be very capable combination and could be recommended for multi-location trial.

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