Biological Forum – An International Journal **14(2): 419-428(2022)**

ISSN No. (Print): 0975-1130
ISSN No. (Online): 2249-3239

Combining Ability Analysis for Grain Yield and Its Contributing Traits in Barley (*Hordeum vulgare* L.) Under Normal Irrigated Condition of Rajasthan

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(Received 29 January 2022, Accepted 08 April, 2022)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: In recent years, the malt derived from the germinated barley is the key material for the malting represents the most economically favourable application for beer brewing. The main objective of barley breeding programmes is enriching yield and grain quality. Estimation of combining ability of the parents is essential to recognize better parental combinations that can yield useful cross combinations. It has been recognized from the prior studies that different parental combination perform non-traditionally i.e. superiority of different parental combination differ from cross to cross. Therefore, combining ability analysis is an appropriate way to fulfill this objective. The present research investigation was carried out with 10 parent half diallel set consisting of parents, F_1's and F_2's to estimate the general and specific combining ability variances and effects. Significance of GCA and SCA for all the studied characters in both the generations indicated the importance of both additive and non-additive gene action. An overall assessment showed that the parents RD 2508, RD 2052 and PL 419 appeared as good general combiners and the crosses DWRUB 64 × RD 2508 and RD 2592 × PL 419 appeared as good cross combinations for grain yield per plant and its contributing traits.

Keywords: Barley, combining ability, GCA, SCA, hybrids.

INTRODUCTION

Barley (*Hordeum vulgare* L., 2n = 2x = 14) is the world's fourth most important cereal crop, which is hardy and used for producing malt for brewing industries, as human food and as animal feed. It was one of the first cultivated grains in the fertile crescent of the Near-East as early as 10000 years ago. The total production of barley in the world is 157.82 million tonnes with the productivity of 3010 kg per hectare (Anonymous 2019-20a). In India, barley productivity is below the world average level due to its cultivation under marginal lands, slow varietal replacement rate and minimum input management conditions. Barley production can be increased either by bringing more area under cultivation or by developing new high yielding cultivars. Since area is a limiting factor, new barley varieties with high genetic potential for grain yield needs to be developed. For improvement of yield and quality parameters, better understanding of the genetics and related aspects of a crop is necessary. It requires information about the nature of combining ability of parents to be involved in the hybridization programme and the nature of gene effects also operative in the inheritance of different traits. For this, combining ability analysis provides prerequisite to select the desirable parents for a hybridization programme (Kakani *et al*., 2007). General combining ability and specific combining ability are very effective in designing and execution of a breeding programme and used to test the performance of parents in different cross combinations and also characterize the nature and magnitude of gene effects for expression of yield. Combining ability of parents depends on complex interaction among genes for trait of interest which cannot be adjusted by mere yield and yield adaptation of the parents (Allard and Bradshaw 1964). The presence of additive gene effect is particularly utilized in the development of pure line varieties. Likewise, the dominance and epistatic gene effects (non-additive components) is also valuable for development of hybrid varieties (Munir *et al*., 2007). Several barley breeders have tried to estimate the various gene effects; genetic variance and combining ability through exploiting different mating designs.

MATERIALS AND METHODS

Ten genetically diverse genotypes *viz.,* BH 946, RD 2592, DWRUB 64, DWRB 137, PL 426, PL 419, RD 103, RD 2035, RD 2052 and RD 2508 were selected as parents for present study and crossed in half-diallel mating design (excluding reciprocals) in *rabi* 2018-19. In *summer* 2019, half of the F_1's seed was multiplied during off-season at IARI regional station, Wellington (Tamil Nadu) to advance the generation. The evaluation trial was conducted in *rabi* 2019-20 in which 10 parents along with their 45 F_1's and 45 F_2's progenies were evaluated in a randomized block design with three replications in normal irrigated conditions at Research Farm, Rajasthan Agricultural Research Institute (Sri Karan Narendra Agriculture University, Jobner), Durgapura, Jaipur. First part consisted of 10 parents and 45 F_1's sown in paired two rows plot with 3 meters row length, while the plots of second part consisted of 45 F_2's were sown in four rows of 3 meters. The row to row and plant to plant distance was kept at 30 cm and 10 cm, respectively. Non-experimental rows were planted around the trial to minimize the border effect, if any. Observations were recorded for days to maturity, plant height, number of effective tillers per plant, flag leaf area, 1000-grain weight, grain yield per plant and harvest index on ten randomly selected plants in each parental row and F_1 progenies whereas twenty plants were selected in F_2 progenies from each replication in both the environments.

The pooled analysis of variance indicated significant genotype x environment for most of the characters. Therefore, analysis of variance for combining ability was done following Griffing (1956) method 2 model I. The general mathematical model for analysis as given by Griffing (1956) is:-

$$X_{ijk} = \mu + g_i + g_j + s_{ij} + e_{ijk}/b$$

Where,

X_{ijk} = an observation of the phenotype of a cross between i^{th} and j^{th} parents in k^{th} block

μ = General mean

g_i = General combining ability (GCA) effect of j^{th} parent

s_{ij} = Specific combining ability (SCA) effect for cross between i^{th} and j^{th} parent such that $s_i = s_j$

e_{ijk} = Environmental effects associated with ijk^{th} observation

b = Number of blocks

The usual restriction such as $\Sigma g=0$ and $\Sigma s_{ij} + s_{il} = 0$ are imposed on combining ability effects.

RESULTS AND DISCUSSION

The pooled analysis of variance indicated significant differences for all the studied characters (Table 1). The pooled analysis of variance also indicating that the mean sum of squares due to genotypes together with parents and generations, (F_1's and F_2's) were also found significant for all the studied characters.

Table 1: Analysis of variance for general and specific combining ability under normal irrigated condition for yield and its contributing traits.

Characters	Source of variation							
	GCA (df = 9)		SCA (df = 45)		Error (df =108)		GCA/SCA ratio	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
Days to heading	14.89**	19.83**	5.47**	10.22**	0.51	0.66	0.24	0.17
Days to maturity	50.44**	25.72**	26.09**	15.57**	0.79	0.87	0.16	0.14
Plant height	183.24**	89.74**	46.24**	38.53**	2.18	17.13	0.34	0.28
Effective tillers per plant	3.40**	4.05**	1.77**	1.90**	0.09	0.16	0.16	0.19
Flag leaf area	25.17**	31.77**	9.96**	14.65**	1.28	1.18	0.23	0.19
Peduncle length	19.54**	15.00**	3.70**	4.32**	0.39	0.34	0.48	0.31
Number of grains per spike	35.55**	11.22**	12.26**	12.41**	1.52	3.18	0.26	0.07
Number of spikelets per spike	4.96**	3.09**	1.67**	1.44**	0.12	0.26	0.26	0.20
Spike length	3.74**	1.63**	1.36**	1.05**	0.09	0.07	0.24	0.13
Biomass/ plant	137.89**	151.58**	15.71**	17.43**	1.82	1.20	0.82	0.77
1000- grain weight	18.91**	12.94**	8.24**	8.81**	0.44	0.6	0.20	0.13
Grain yield per spike	0.36**	0.35**	0.09**	0.14**	0.01	0.009	0.36	0.22
Grain yield Per plant	54.33**	65.11**	4.94**	5.75**	0.35	0.31	0.98	0.99
Harvest Index	108.36**	132.86**	18.77**	18.95**	0.89	0.83	0.50	0.61

The significant differences between parents and generations exhibited wide diversity. In addition, the mean sum of squares due to parents vs generations for all studied characters revealed significant differences. For all the studied characters, the G × E interaction was also found significant, which specified a non-linear response of the genotypes to change in the environment (Table 1). This is in compliance with the general assumption that G × E interaction is useful in crop species (Allard and Bradshaw, 1964). Sprague and Federer (1951) suggested that the biasness in estimate of genetic parameters due to G × E interaction is of unknown magnitude and direction and it may not be the same for each parameter.

Analysis of variances for combining ability showed that variances due to general combining ability as well as due to specific combining ability were highly significant for all the studied characters in both the F_1 and F_2 generations(Table 1). Thus, both additive and non-additive gene action played vital role in the genetic control of the characters under this study. This may be possible due to the parental lines included in the present investigation possessed high selection history for these traits. The results are in accordance with earlier findings of Khiabani *et al.* (2015); Eftekhari *et al.* (2016); Rathore and Chauhan (2017); Lal *et al.* (2018); Swati *et al.* (2018); Bouchetat and Aissat (2019); Panwar and Sharma (2019); Kumari *et al.* (2020).

The GCA/SCA variance ratio (predictability ratio) was less than unity for all the characters which clearly showed the predominance of non-additive gene action for all the traits under investigation. The results are in accordance with earlier findings of Lal *et al.* (2018); Swati *et al.* (2018); Bouchetat and Aissat (2019); Parashar (2019); Kumari *et al.* (2020).

In self-pollinated crops like barley, SCA effects have relatively less applicability as they are consequences of non-additive gene effects excepting those arising from complementary gene action or linkage effects and cannot be fixed in the end product i.e. pure line. Jinks and Jones give emphasis to that the superiority of the hybrids might not indicate their ability to yield transgressive segregants, rather SCA would provide satisfactory criteria. However, if a cross combination exhibiting high SCA as well as high *per se* performance having at least one parent as good general combiner for a specific trait, it is expected that this cross combination may provide desirable transgressive segregants in later generations (Table 2 & 3).

The top three cross combinations which were significant and good for two or more characters in F_1 only (Table 4), are as follows: DWRB 137 x RD 2035 for days to heading, days to maturity, plant height, number of effective tillers per plant and number of grains per spike; PL 419 × RD 2508 for plant height and number of effective tillers per plant; RD 103 × RD 2035 for flag leaf area, peduncle length and spike length; RD 2592 × PL 419 for flag leaf area and 1000-grain weight; RD 2592 × DWRB 137 for peduncle length and harvest index; DWRUB 64 × RD 2052 for peduncle length, numbers of grains per spike and spike length; PL 419 × RD 103 for number of spikelets per spike, biomass per plant and grain yield per spike; DWRUB 64 × PL 419 for spike length and biomass per plant; BH 946 × PL 419 for biomass per plant and grain yield per spike; RD 103 × RD 2508 for grain yield per spike and grain yield per plant.

The cross combinations that were significant and good for two or more characters in F_2 only (Table 4) were RD 2592× PL 419 for days to heading, flag leaf area, number of grains per spike, biomass per plant and grain yield per plant; PL 426 × RD 2035 for days to heading and number of grains per spike; RD 2592 × RD 2052 for days to heading and 1000-grain weight; PL 419 × RD 103 for days to maturity and biomass per plant; DWRB 137 × RD 2035 for days to maturity and number of effective tillers per plant; RD 103 x RD 2035 for plant height flag leaf area and grain yield per spike; DWRUB 64 × PL 426 for number of effective tillers per plant and spike length; DWRUB 64 × RD 2035 for peduncle length and 1000-grain weight; DWRB 137 × RD 103 for number of grains per spike and number of spikelets per spike; DWRB 137 × PL 426 for number of spikelets per spike, spike length and 1000-grain weight; DWRB 137 × PL 419 for grain yield per spike and harvest index.

Appraisal of Table 5 recognized an interesting relation between GCA effects of grain yield per plant and other yield contributing characters. Parents, which exhibit desirable GCA effects for grain yield per plant, also slowed desirable GCA effects for one or more yield attributing characters. The parents RD 2508, RD 2052 and PL 419 in both the generations performed as good general combiners for grain yield per plant and some other associated characters. The parents possessing good general combining ability in barley were reported by several researchers such as Potla *et al.* (2013); Madakemohekar *et al.* (2015); Sultan *et al.* (2016); Parashar (2019).

The evaluation of Table 5 established a significant relation between the SCA effect of grain yield per plant and other component characters. The crosses, which exhibited high *per se* performance with desirable SCA effects for grain yield per plant and one or more yield attributing characters and exhibited as good specific cross combinations are as follows: BH 946 ×PL 419 and RD 103 × RD 2508 in F_1 of E_1; RD 2592 × PL 419 and DWRUB 64 × RD 2508 in F_1 of E_2; RD 2592 × PL 419 and DWRB 137 × RD 2052 in F_2 of E_2. The parents BH 946, PL 419, RD 2508, RD 2592 and RD 2052 involved in these cross combinations appeared as good general combiners for grain yield per plant and one or more yield associated characters.

Table 2: Estimates of general and specific combining ability effects for yield and its contributing traits under normal irrigated condition.

Parents / Crosses	Days to heading		Days to maturity		Plant Height		No. of effective tillers per plant		Flag leaf area		Peduncle length		Number of grains per spike	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
BH 946	-0.43*	-1.08**	-2.23**	-1.27**	-2.32**	-2.39*	0.21*	0.04	1.88**	2.13**	-0.62**	-0.44**	2.12**	1.54**
RD 2592	-0.54**	-0.31	-0.81**	-2.61**	-7.50**	-5.56**	0.18*	-0.01	1.26**	1.13**	0.78**	0.92**	-0.66	-0.39
DWRUB 64	0.68**	0.61**	2.41**	2.48**	4.24**	2.96*	0.17*	0.36**	-0.79*	-1.34**	-1.51**	-1.50**	-2.62**	-1.23*
DWRB 137	0.98**	0.81**	0.80**	0.64*	3.55**	1.33	-0.34**	-0.45**	-1.51**	-1.49**	-2.06**	-1.48**	-1.52**	-0.55
PL 426	-0.13	1.53**	2.61**	1.23**	4.64**	3.65**	-1.27**	-1.33**	-0.74*	-0.91**	-1.38**	-1.43**	-1.79**	-1.60**
PL 419	-1.02**	-1.00**	-2.12**	-0.83**	-1.94**	-0.23	0.32**	0.24*	0.95**	1.37**	0.96**	0.60**	1.85**	0.17
RD 103	2.04**	1.28**	2.11**	1.31**	3.47**	1.02	-0.25**	-0.23*	-1.06**	-1.44**	0.57**	0.58**	-0.89**	0.18
RD 2035	0.93**	1.42**	1.27**	-0.47	-0.22	-2.04	0.03	0.23*	-2.32**	-2.24**	0.55**	0.53**	0.54	0.22
RD 2052	-1.10**	-2.03**	-2.39**	-0.05	-2.33**	0.06	0.25**	0.33**	1.43**	1.80**	1.23**	0.76**	1.00**	0.94
RD 2508	-1.41**	-1.22**	-1.64**	-0.44	-1.58**	1.21	0.70**	0.82**	0.91**	0.99**	1.48**	1.46**	1.96**	0.71
SE (gi) ±	0.20	0.22	0.24	0.26	0.40	1.13	0.08	0.11	0.31	0.30	0.17	0.16	0.34	0.49
SE (gi-gj)±	0.29	0.33	0.36	0.38	0.60	1.69	0.12	0.16	0.46	0.44	0.25	0.24	0.50	0.73
SCA effects														
BH 946 × RD 2592	-3.07**	-3.04**	-7.15**	1.52	-6.11**	5.91	0.27	0.46	2.10*	2.98**	2.08**	1.84**	3.53**	-1.23
BH 946 × DWRUB 64	4.71**	2.05**	-1.37	0.77	2.92*	0.71	0.19	-0.64	4.07**	5.74**	-3.20**	-2.44**	-2.95*	2.46
BH 946 × DWRB 137	5.40**	3.52**	1.24	-4.06**	14.47**	1.78	1.46**	0.81*	0.65	-0.12	-1.29*	-0.86	1.21	-0.79
BH 946 × PL 426	0.51	5.80**	8.43**	6.69**	7.91**	0.79	-0.98**	-0.49	1.04	2.55*	-0.73	-0.51	-2.78*	-2.88
BH 946 × PL 419	-1.93**	-2.01**	-6.84**	-0.26	-0.04	7.51	0.50	-0.25	1.66	0.93	1.43*	1.49**	1.91	-0.28
BH 946 × RD 103	0.35	-1.29	8.27**	-1.06	4.89**	7.33	-0.72**	-0.59	-3.43**	-4.34**	1.36*	1.21*	2.32*	4.61**
BH 946 ×RD 2035	-1.21	-0.76	-3.57**	-5.95**	9.07**	2.35	-1.68**	-0.61	-4.65**	-5.62**	0.44	-0.31	2.02	-1.87
BH 946 × RD 2052	-3.18**	-2.98**	-0.90	1.96*	-10.92**	-2.61	0.74**	0.59	3.22**	2.96**	1.12	2.43**	2.36*	4.81**
BH 946 × RD 2508	0.12	-2.79**	-1.32	-0.65	1.94	-2.42	1.92**	2.17**	-1.75	-0.43	1.64**	1.33*	-0.03	-1.05
RD 2592 × DWRUB 64	1.48*	0.94	4.88**	-0.90	10.91**	-3.35	-1.40**	-1.26**	0.91	-1.73	-1.86**	-1.37*	-2.30*	1.08
RD 2592 × DWRB 137	-0.15	-1.26	7.16**	2.27**	0.22	0.05	0.59*	0.48	-3.56**	-1.59	2.72**	3.54**	-0.64	1.60
RD 2592 × PL 426	0.96	6.35**	4.35**	-4.31**	0.76	-2.50	-0.11	-1.31**	4.39**	5.48**	-1.45*	-1.34*	-1.16	0.02
RD 2592 × PL 419	-2.82**	-5.45**	-0.26	-2.92**	-4.40**	8.65*	0.66*	1.26**	4.31**	6.22**	0.54	0.89	1.66	6.04**
RD 2592 × RD 103	3.12**	3.27**	1.52	-0.06	4.60**	2.56	-0.96**	-0.48	-3.63**	-3.36**	-0.04	0.52	-1.40	-5.90**
RD 2592 ×RD 2035	1.23	3.46**	-5.32**	0.38	-4.51**	-0.41	0.39	-0.33	0.55	-5.19**	-0.01	1.39*	-0.67	-0.28
RD 2592 × RD 2052	-2.74**	-4.76**	-4.98**	-5.04**	-3.74**	-3.94	1.00**	1.30**	0.50	1.97	0.56	-0.16	4.28**	4.14*
RD 2592 × RD 2508	-1.43*	-2.56**	-3.73**	-3.31**	-7.28**	-11.24**	1.12**	1.01**	0.36	1.43	0.95	-0.60	2.22	-0.36
DWRUB 64 × DWRB 137	-1.04	-1.17	-1.73*	-0.81	-7.32**	-11.52**	-1.34**	0.45	2.54*	-0.68	-1.03	-0.66	0.65	4.25*
DWRUB 64 × PL 426	-1.60*	1.10	-2.54**	-1.40	-1.91	4.80	2.80**	3.12**	-1.08	-2.23*	0.10	-1.82**	-1.97	0.56
DWRUB 64 × PL 419	-1.04	-1.04	6.18**	0.66	3.47*	3.85	-0.06	-0.24	-3.85**	-3.50**	1.86**	3.25**	-3.55**	-2.01
DWRUB 64 × RD 103	-4.77**	-3.65**	-2.70**	2.85**	1.46	-1.23	0.52	0.76*	1.53	2.68**	0.08	-2.26**	1.02	-2.42
DWRUB 64 ×RD 2035	-1.32*	-4.45**	0.13	0.30	-8.18**	0.13	1.43**	0.94*	2.79**	3.67**	2.24**	3.59**	2.92*	4.51**
DWRUB 64 × RD 2052	0.37	1.66*	-2.87**	-1.45	1.96	1.20	-1.59**	-1.24**	0.42	1.59	2.52**	2.73**	6.17**	-3.21
DWRUB 64 × RD 2508	1.35*	1.85*	-1.95*	-3.40**	6.82**	7.97*	-1.44**	-1.69**	0.12	0.52	2.37**	2.73	6.34**	5.12**
DWRB 137 × PL 426	-0.90	-2.76**	-6.59**	-3.56**	-9.55**	-8.20*	0.17	-0.73*	2.32*	2.11*	-0.29	0.36	2.89*	-1.25
DWRB 137 × PL 419	0.98	2.77**	-3.87**	1.16	9.96**	-5.68	0.65*	0.97**	2.57*	0.29	1.77**	1.46**	4.25**	-2.32
DWRB 137 × RD 103	-1.74**	-0.84	-3.09**	-2.31**	-1.45	4.33	1.05**	-0.43	1.21	4.57**	0.76	0.48	-1.22	5.57**
DWRB 137 × RD 2035	-3.29**	-3.65**	-7.59**	-6.20**	-11.33**	-4.08	1.97**	2.12**	-0.78	3.00**	1.88**	0.86	4.52**	-0.64
DWRB 137 × RD 2052	0.73	2.46**	-0.93	0.71	2.35	6.49	-0.15	-0.06	0.10	1.44	-2.97**	-1.73**	-6.30**	-2.43
DWRB 137 × RD 2508	-0.63	-1.01	0.99	-3.90**	1.57	4.40	-1.53**	-0.81*	-2.42*	-5.53**	-0.25	0.80	-0.33	3.41*
PL 426 × PL 419	0.10	-0.95	1.99*	-1.76*	-0.30	-5.10	-0.09	-0.22	-2.83**	0.34	1.03	1.67**	4.52**	-0.71
PL 426 × RD 103	-0.29	-1.56*	-6.90**	-2.23*	-3.44*	-0.72	-0.81**	0.11	2.90**	-0.56	-1.91**	-1.50**	-2.94*	4.21*
PL 426 × RD 2035	-3.18**	-5.37**	-0.07	-2.45**	-1.28	-2.73	1.27**	1.92**	2.62*	5.08**	1.21*	1.08*	2.97*	5.34**
PL 426 × RD 2052	1.18	-2.92**	-2.40**	-2.87**	2.82*	1.01	-1.11**	-0.78*	-2.80**	-4.76**	1.75**	1.45**	2.94*	-1.31
PL 426 × RD 2508	-0.52	2.60**	-1.48	-0.48	1.61	2.82	-1.20**	-1.50**	0.16	-1.2	2.01**	2.78**	-3.82**	-4.04*
PL 419 × RD 103	-1.07	-0.70	-3.51**	-8.84**	-2.80*	-6.67	0.83**	0.92*	-0.68	-4.49**	0.31	0.79	3.22**	2.27
PL 419 × RD 2035	1.37*	3.16**	7.32**	4.60**	4.39**	3.22	-1.52**	-1.44**	-3.03**	1.53	-3.27**	-4.26**	-3.82**	2.80
PL 419 × RD 2052	-2.27**	-2.40**	-5.01**	-2.48**	-6.80**	-1.71	0.83**	0.99**	3.68**	3.17**	1.35*	0.52	1.66	2.22
PL 419 × RD 2508	2.04**	1.46	-6.76**	2.58**	-10.61**	-6.90	2.08**	1.97**	3.81**	3.63**	1.37*	-0.22	0.73	-5.65**

RD 103 × RD 2035	-0.02	0.21	3.43**	1.80*	-8.44**	-13.03**	0.59*	1.02**	6.49**	5.74**	3.23**	2.80**	3.86**	0.19
RD 103 × RD 2052	2.35**	1.99**	2.77**	2.38**	7.36**	-1.99	-2.16**	-3.11**	-6.35**	-5.51**	0.11	1.61**	-1.60	-2.29
RD 103 × RD 2508	-1.02	-4.15**	-4.32**	-1.90*	-2.38	-3.08	0.85**	1.50**	2.41*	4.98**	-0.04	0.94	3.64**	3.44*
RD 2035 × RD 2052	1.46*	-0.15	4.93**	3.83**	5.15**	-6.20	-1.85**	-1.54**	-1.06	-2.72**	0.13	-1.54**	- 4.03**	-2.30
RD 2035 × RD 2508	-0.57	3.38**	6.18**	0.55	-2.36	-6.52	0.93**	0.64	2.91**	1.47	-3.35**	-0.51	1.04	-1.70
RD 2052 × RD 2508	-4.21**	-3.51**	-5.15**	-3.87**	-5.49**	7.48	0.95**	1.27**	3.81**	5.64**	0.89	-1.10*	0.89	5.01**
ES (Sij)±	**0.66**	**0.75**	**0.82**	**0.86**	**1.36**	**3.81**	**0.27**	**0.37**	**1.04**	**1.00**	**0.57**	**0.54**	**1.13**	**1.64**
SE (Sij-Sik)±	**0.97**	**1.10**	**1.20**	**1.26**	**2.00**	**5.60**	**0.40**	**0.54**	**1.53**	**1.47**	**0.84**	**0.79**	**1.67**	**2.41**
SE (Sij-Ski)±	**0.92**	**1.05**	**1.15**	**1.20**	**1.91**	**5.34**	**0.38**	**0.52**	**1.46**	**1.40**	**0.80**	**0.75**	**1.59**	**2.30**

*, ** Significant at 5 and 1 per cent levels, respectively.

Table 3: Estimates of general and specific combining ability effects for yield and its contributing traits under normal irrigated condition.

Parents / Crosses	**No. of spikelets per spike**		Spike Length		Biomass per plant		1000-Grain Weight		Grain Yield per spike		Grain Yield Per Plant		Harvest Index	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
BH 946	0.78**	0.53**	0.22**	0.05	0.77*	1.04**	1.98**	0.97**	0.09**	0.07**	0.49**	0.73**	0.80**	1.24**
RD 2592	-0.05	-0.43**	0.18*	0.23**	0.65	-0.01	-0.28	-1.12**	-0.04	-0.02	1.61**	1.26**	4.37**	4.00**
DWRUB 64	-0.63**	-0.42**	-0.75**	-0.62**	-1.98**	-2.20**	0.46*	0.37	-0.14**	-0.13**	-0.64**	-0.62**	0.50	0.56*
DWRB 137	-0.70**	-0.61**	-0.75**	-0.36**	-3.63**	-4.02**	-2.02**	-1.49**	-0.21**	-0.19**	-1.90**	-2.05**	-1.61**	-1.62**
PL 426	-0.78**	-0.25	-0.41**	-0.39**	-4.74**	-4.59**	-0.47*	-0.23	-0.03	-0.04	-3.28**	-3.43**	-4.86**	-5.24**
PL 419	-0.22*	-0.34*	0.31**	-0.01	4.01**	3.81**	1.83**	1.35**	0.20**	0.14**	2.03**	2.13**	1.76**	2.23**
RD 103	-0.27**	-0.14	-0.33**	-0.08	-2.14**	-2.01**	-1.47**	-1.47**	-0.24**	-0.23**	-1.65**	-1.92**	-2.71**	-3.46**
RD 2035	1.10**	0.79**	-0.03	0.32**	-1.70**	-1.78**	-0.33	0.16	-0.06*	-0.09**	-1.69**	-1.94**	-3.20**	-3.71**
RD 2052	0.35**	0.67**	0.72**	0.31**	3.70**	4.13**	0.24	0.91**	0.17**	0.20**	1.84**	2.16**	1.45**	1.79**
RD 2508	0.41**	0.19	0.84**	0.54**	5.06**	5.63**	0.05	0.55*	0.25**	0.28**	3.17**	3.70**	3.49**	4.22**
SE (gi) ±	**0.09**	**0.14**	**0.08**	**0.07**	**0.37**	**0.30**	**0.18**	**0.21**	**0.03**	**0.03**	**0.16**	**0.15**	**0.26**	**0.25**
SE (gi-gj)±	**0.14**	**0.21**	**0.12**	**0.11**	**0.55**	**0.45**	**0.27**	**0.32**	**0.04**	**0.04**	**0.24**	**0.23**	**0.39**	**0.37**
SCA effects														
BH 946 × RD 2592	0.73*	0.58	1.21**	1.24**	2.13	2.25*	2.00**	2.74**	0.19*	0.21*	0.54	0.79	-1.16	-0.50
BH 946 × DWRUB 64	-1.12**	-0.37	-0.76**	-0.45	-1.13	-2.87**	-0.81	-2.38**	-0.45**	-0.24**	-0.88	-1.20*	-1.07	0.18
BH 946 × DWRB 137	-0.39	-0.10	1.16**	0.42	3.69**	1.40	1.27*	-1.89**	-0.34**	-0.08	-0.25	-0.64	-4.22**	-3.12**
BH 946 × PL 426	-0.51	-0.47	-0.17	-0.67**	0.36	2.50*	-2.81**	1.35	0.05	-0.07	-1.87**	-0.80	-6.19**	-4.68**
BH 946 × PL 419	-1.47**	-0.80	0.30	0.58*	5.36**	5.16**	0.02	0.78	0.11	0.22*	2.59**	2.34**	1.02	0.40
BH 946 × RD 103	0.58	0.46	-0.12	0.05	-0.27	0.92	-4.11**	-4.94**	-0.18	0.16	0.36	0.76	2.04*	1.66*
BH 946 ×RD 2035	0.18	-0.27	1.37**	0.53*	-0.19	1.39	4.19**	1.19	0.18	-0.58**	-0.04	0.25	0.40	-0.34
BH 946 × RD 2052	1.03**	-0.49	0.43	1.46**	1.23	2.38*	0.52	2.01**	0.31**	0.29**	2.13**	2.35**	4.18**	3.29**
BH 946 × RD 2508	-0.49	-0.71	0.67*	-0.12	-0.74	-0.79	2.07**	-0.23	0.13	0.11	0.65	0.99	2.42**	3.08**
RD 2592 × DWRUB 64	0.81*	0.76	-0.41	0.77**	-5.89**	-3.97**	2.18**	2.48**	0.15	-0.45**	0.53	0.73	11.45**	8.90**
RD 2592 × DWRB 137	1.24**	-0.35	-0.76**	-0.45	-0.85	-0.08	0.30	-0.34	-0.21*	0.04	1.97**	1.41**	7.94**	5.31**
RD 2592 × PL 426	-0.41	0.46	1.33**	0.51*	-2.64*	-1.72	0.91	0.64	-0.53**	-0.21*	-3.03**	-3.07**	-7.23**	-8.19**
RD 2592 × PL 419	1.26**	1.05*	-0.71*	-0.34	4.13**	5.47**	4.35**	1.97**	0.24*	0.28**	1.72**	2.79**	-0.70	0.54
RD 2592 × RD 103	-0.65*	0.55	-0.08	0.29	-1.34	-1.59	0.11	-2.69**	-0.29**	-0.48**	0.72	1.04*	4.35**	5.61**
RD 2592 ×RD 2035	0.41	-0.48	-1.77**	-2.10**	4.78**	1.54	-5.09**	-4.48**	0.11	0.14	2.80**	1.83**	2.80**	3.91**
RD 2592 × RD 2052	1.69**	0.81	0.44	-1.15**	2.50*	0.43	3.18**	4.30**	0.17	0.25**	1.29*	0.68	0.09	0.94
RD 2592 × RD 2508	1.07**	1.55**	0.32	0.67**	3.25*	1.99	3.53	3.86**	0.09	0.30**	1.08*	0.70	-1.42	-1.07
DWRUB 64 × DWRB 137	-0.41	1.24**	-0.16	0.80**	-0.68	-1.48	-5.04**	-2.95**	0.02	0.22*	-1.65**	-2.42**	-4.99**	-6.45**
DWRUB 64 × PL 426	-0.43	0.18	0.37	1.92**	2.36	2.50*	-1.23*	-3.84**	-0.06	0.14	0.77	0.91	-0.33	0.25
DWRUB 64 × PL 419	-0.89**	-0.96*	1.58**	-0.12	5.51**	4.81**	0.04	-0.52	0.17	0.26**	2.24**	2.29**	0.32	1.21
DWRUB 64 × RD 103	0.99**	0.54	-1.45**	-0.96**	-1.82	-0.41	2.01**	2.50**	0.15	0.33**	-0.15	0.73	1.88*	3.24**
DWRUB 64 ×RD 2035	1.46**	0.31	1.23**	0.15	0.70	-0.94	1.44*	4.13**	-0.06	-0.01	1.09*	-0.23	2.82**	0.60

DWRUB 64 × RD 2052	-1.10**	-0.24	1.61**	0.53*	3.62**	5.14**	2.10**	1.55*	0.27**	0.36**	1.97**	3.29**	1.64	3.49**
DWRUB 64 × RD 2508	0.99**	-0.03	1.35**	0.94**	4.08**	3.98**	1.69**	1.38	0.26**	-0.05	2.52**	3.05**	2.43**	3.79**
DWRB 137 × PL 426	1.50**	1.84**	0.60*	1.47**	3.29**	1.79	3.15**	4.38**	-0.09	-0.27**	2.33**	1.60**	3.76**	2.73**
DWRB 137 × PL 419	-0.46	-0.73	-0.83**	-0.61*	-5.29**	-6.29**	2.99**	2.84**	0.31**	0.58**	0.57	0.45	8.99**	10.40**
DWRB 137 × RD 103	0.89**	2.10**	-1.16**	-1.67**	2.29	2.09*	0.15	2.42**	0.05	-0.21*	0.32	0.08	-1.48	-2.22**
DWRB 137 × RD 2035	1.29**	0.40	0.80**	1.03**	0.50	2.25*	-1.45*	-0.41	0.21*	-0.12	-0.44	0.80	-2.20*	0.00
DWRB 137 × RD 2052	-0.66*	-0.94*	-0.13	-0.79**	0.41	1.02	0.38	-0.73	0.31**	0.29**	0.73	1.34*	2.13*	3.33**
DWRB 137 × RD 2508	-1.98**	-1.80**	-0.59*	-0.09	0.90	2.87**	-1.56*	-0.63	0.33**	0.31**	0.29	1.30*	0.57	1.30
PL 426 × PL 419	-0.61	-0.23	-0.03	-0.05	-2.54*	-4.91**	-2.09**	-0.32	-0.17	-0.64**	-0.16	-0.88	3.07**	3.54**
PL 426 × RD 103	-1.26**	-1.70**	-2.26**	-2.08**	2.14	3.38**	-5.83**	-5.70**	-0.13	-0.03	1.13*	1.15*	1.05	-0.18
PL 426 × RD 2035	0.81*	1.27**	0.25	0.81**	1.61	0.07	3.60**	0.97	0.03	0.13	1.27*	0.66	2.12*	1.24
PL 426 × RD 2052	-0.38	0.36	1.37**	0.07	1.06	2.08*	-1.10	-1.35	0.29**	0.30**	0.32	0.67	0.65	0.76
PL 426 × RD 2508	0.04	-0.53	0.61*	-0.17	-2.66*	-1.26	-0.08	-0.32	0.08	0.16	-2.68**	-2.12**	-4.11**	-3.38**
PL 419 × RD 103	1.98**	0.80	1.38**	0.97**	5.18**	5.31**	2.27**	0.82	0.51**	0.09	1.42*	1.28*	-0.45	-0.97
PL 419 × RD 2035	-2.29**	-1.53**	-2.04**	0.01	-5.60**	-4.15**	-1.53*	-0.98	0.20*	0.38**	-3.14**	-2.51**	-3.17**	-2.63**
PL 419 × RD 2052	1.79**	2.29**	0.48	-0.73**	4.30**	4.89**	0.67	0.27	-0.20*	-0.24**	1.72**	2.19**	-0.15	0.13
PL 419 × RD 2508	0.37	-0.43	-0.38	-1.58**	1.16	1.99	1.46*	1.74*	-0.25**	-0.16	1.62**	1.67**	2.19*	1.17
RD 103 × RD 2035	1.13**	0.70	1.45**	0.64**	0.73	2.54*	2.00**	1.97**	0.27**	0.76**	0.42	0.42	0.75	-1.10
RD 103 × RD 2052	-2.02**	-0.65	-0.59*	0.49*	-4.96**	-6.38**	0.80	0.99	-0.27**	-0.54**	-3.03**	-3.54**	-3.45**	-3.35**
RD 103 × RD 2508	1.49**	1.16*	0.75**	0.87**	4.85**	2.29*	1.12	3.52**	0.39**	0.52**	3.57**	2.40**	4.86**	4.68**
RD 2035 × RD 2052	0.47	0.82	-1.85**	-0.71**	5.13**	4.45**	0.47	2.66**	-0.07	0.19*	1.09*	0.41	-1.06	-1.96*
RD 2035 × RD 2508	0.49	1.77**	0.49	0.62*	3.74**	4.79**	0.29	1.22	0.25**	0.24**	1.00	2.05**	-0.12	1.39
RD 2052 × RD 2508	1.07**	1.49**	0.45	1.00**	1.17	3.04**	1.65**	2.00**	0.15	0.25**	1.50**	2.26**	2.02*	1.58
ES (Sij)±	0.31	0.47	0.28	0.24	1.24	1.01	0.61	0.71	0.09	0.09	0.54	0.51	0.87	0.84
SE (Sij-Sik)±	0.46	0.69	0.41	0.36	1.83	1.48	0.90	1.05	0.14	0.13	0.80	0.75	1.28	1.23
SE (Sij-Ski)±	0.44	0.66	0.39	0.34	1.74	1.41	0.86	1.00	0.13	0.12	0.76	0.72	1.22	1.18

Table 4: Best three parents, F_1's and F_2's for their mean values, GCA and SCA effects under normal irrigated condition for yield and associated traits.

Characters	High mean			GCA		SCA	
	Parents	F_1	F_2	F_1	F_2	F_1	F_2
Days to heading	BH 946	RD 2052 x RD 2508	RD 2592 x RD 2052	RD 2508	RD 2052	DWRUB 64 x RD 103	RD 2592 x PL 419
	RD 2508	BH 946 x RD 2052	RD 2592 x PL 419	RD 2052	RD 2508	RD 2052 x RD 2508	PL 426 x RD 2035
	PL 419	RD 2592 x PL 419	RD 2052 x RD 2508	PL 419	BH 946	DWRB 137 x RD 2035	RD 2592 x RD 2052
Days to maturity	BH 946	BH 946 x PL 419	PL 419 x RD 103	RD 2052	RD 2592	DWRB 137 x RD 2035	PL 419 x RD 103
	RD 2035	PL 419 x RD 2508	BH 946 x RD 2035	BH 946	BH 946	BH 946 x RD 2592	DWRB 137 x RD 2035
	RD 2592	BH 946 x RD 2592	DWRB 137 x RD 2035	PL 419	PL 419	PL 426 x RD 103	BH 946 x RD 2035
Plant height	BH 946	RD 2592 x RD 2508	RD 2592 x RD 2508	RD 2592	RD 2592	DWRB 137 x RD 2035	RD 103 x RD 2035
	RD 2592	BH 946 x RD 2592	RD 103 x RD 2035	RD 2052	BH 946	BH 946 x RD 2052	DWRUB 64 x DWRB 137
	RD 2052	BH 946 x RD 2052	RD 2035 x RD 2052	BH 946	-	PL 419 x RD 2508	RD 2592 x RD 2508
Number of effective tillers per plant	RD 2052	PL 419 x RD 2508	BH 946 x RD 2508	RD 2508	RD 2508	DWRUB 64 x PL 426	DWRUB 64 x PL 426
	DWRUB 64	BH 946 x RD 2508	PL 419 x RD 2508	PL 419	DWRUB 64	PL 419 x RD 2508	BH 946 x RD 2508
	RD 103	RD 2592 x RD 2508	RD 2052 x RD 2508	RD 2052	RD 2052	DWRB 137 x RD 2035	DWRB 137 x RD 2035

Flag leaf area	BH 946	BH 946 x RD 2052	RD 2592 x PL 419	BH 946	BH 946	RD 103 x RD 2035	RD 2592 x PL 419
	RD 2052	RD 2592 x PL 419	RD 2052 x RD 2508	RD 2052	RD 2052	RD 2592 x PL 426	BH 946 x DWRUB 64
	RD 2592	RD 2592 x PL 426	BH 946 x DWRUB 64	RD 2592	PL 419	RD 2592 x PL 419	RD 103 x RD 2035
Peduncle length	RD 2508	RD 103 x RD 2035	RD 103 x RD 2035	RD 2508	RD 2508	RD 103 x RD 2035	DWRUB 64 x RD 2035
	RD 2035	PL 419 x RD 2508	RD 2592 x DWRB 137	RD 2052	RD 2592	RD 2592 x DWRB 137	RD 2592 x DWRB 137
	RD 2592	RD 2052 x RD 2508	RD 103 x RD 2508	PL 419	RD 2052	DWRUB 64 x RD 2052	DWRUB 64 x PL 419
Number of grains per spike	BH 946	BH 946 x PL 419	BH 946 x RD 2052	BH 946	BH 946	DWRUB 64 x RD 2508	RD 2592 x PL 419
	RD 2052	DWRUB 64 x RD 2508	RD 2052 x RD 2508	RD 2508	-	DWRUB 64 x RD 2052	DWRB 137 x RD 103
	RD 2508	BH 946 x RD 2052	BH 946 x RD 103	PL 419	-	DWRB 137 x RD 2035	PL 426 x RD 2035
Number of spikelets per spike	BH 946	BH 946 x RD 2052	RD 2035 x RD 2508	RD 2035	RD 2052	PL 419 x RD 103	PL 419 x RD 2052
	RD 2035	RD 2592 x RD 2052	PL 419 x RD 2035	BH 946	RD 2508	PL 419 x RD 2052	DWRB 137 x RD 103
	RD 2052	PL 419 x RD 2052	RD 2052 x RD 2508	RD 2508	BH 946	RD 2592 x RD 2052	DWRB 137 x PL 426
Spike length	PL 419	RD 2052 x RD 2508	RD 2052 x RD 2508	RD 2508	RD 2508	DWRUB 64 x RD 2052	DWRUB 64 x PL 426
	RD 2592	BH 946 x RD 2508	BH 946 x RD 2052	RD 2052	RD 2035	DWRUB 64 x PL 419	DWRB 137 x PL 426
	RD 103	DWRUB 64 x RD 2052	BH 946 x RD 2592	PL 419	RD 2052	RD 103 x RD 2035	BH 946 x RD 2052
Biomass per plant	RD 2508	PL 419 x RD 2052	PL 419 x RD 2052	RD 2508	RD 2508	DWRUB 64 x PL 419	RD 2592 x PL 419
	PL 419	PL 419 x RD 2508	RD 2052 x RD 2508	PL 419	RD 2052	BH 946 x PL 419	PL 419 x RD 103
	RD 2052	BH 946 x PL 419	PL 419 x RD 2508	RD 2052	PL 419	PL 419 x RD 103	BH 946 x PL 419
1000-grain weight	BH 946	RD 2592 x PL 419	DWRUB 64 x RD 2035	BH 946	PL 419	RD 2592 x PL 419	DWRB 137 x PL 426
	PL 426	BH 946 x RD 2035	RD 2592 x RD 2052	PL 419	BH 946	BH 946 x RD 2035	RD 2592 x RD 2052
	DWRUB 64	BH 946 x RD 2508	BH 946 x RD 2052	DWRUB 64	RD 2052	PL 426 x RD 2035	DWRUB 64 x RD 2035
Grain yield per spike	PL 426	BH 946 x RD 2052	RD 2052 x RD 2508	RD 2508	RD 2508	PL 419 x RD 103	RD 103 x RD 2035
	BH 946	RD 2052 x RD 2508	BH 946 x RD 2052	PL 419	RD 2052	RD 103 x RD 2508	DWRB 137 x PL 419
	RD 2592	PL 419 x RD 103	RD 103 x RD 2508	RD 2052	PL 419	DWRB 137 x RD 2508	RD 103 x RD 2508
Grain yield per plant	RD 2508	PL 419 x RD 2508	RD 2052 x RD 2508	RD 2508	RD 2508	RD 103 x RD 2508	DWRUB 64 x RD 2052
	RD 2052	BH 946 x PL 419	RD 2592 x PL 419	PL 419	RD 2052	RD 2592 x RD 2035	DWRUB 64 x RD 2508
	PL 419	RD 103 x RD 2508	DWRUB 64 x RD 2508	RD 2052	PL 419	BH 946 x PL 419	RD 2592 x PL 419
Harvest index	BH 946	RD 2592 x DWRUB 64	RD 2592 x DWRUB 64	RD 2592	RD 2508	RD 2592 x DWRUB 64	DWRB 137 x PL 419
	RD 2508	RD 2592 x DWRB 137	DWRB 137 x PL 419	RD 2508	RD 2592	DWRB 137 x PL 419	RD 2592 x DWRUB 64
	RD 2592	DWRB 137 x PL 419	DWRUB 64 x RD 2508	PL 419	PL 419	RD 2592 x DWRB 137	RD 2592 x RD 103

Table 5: Best parents possessing high GCA effects and SCA effects along with their *per se* performance for grain yield per plant and significant desirable (+) GCA effects and SCA effects for other characters under normal irrigated condition in F_1 and F_2 generation.

Generation in which exhibited high GCA effects and *per se* performance	F_1			F_2				Generation in which exhibited high SCA effects and *per se* performance	F_1	
Best parents based on desirable GCA effects and *per se* performance for grain yield per plant	**RD 2508**	**RD 2052**	**PL 419**	**RD 2508**	**RD 2052**	**PL 419**		**Best crosses based on desirable SCA effects and *per se* performance for grain yield per plant**	**BH 946 X PL 419**	**RD103 x RD 2508**
Days to heading	+	+	+	+	+	+		Days to heading	+	-
Days to maturity	+	+	+	-	-	+		Days to maturity	+	+
Plant height	+	+	+	-	-	-		Plant height	-	-
Number of effective tillers per plant	+	+	+	+	+	+		Number of effective tillers per plant	-	+
Flag leaf area	+	+	+	+	+	+		Flag leaf area	-	+
Peduncle length	+	+	+	+	+	+		Peduncle length	+	-
Number of grains per spike	+	+	+	-	-	-		Number of grains per spike	-	+
Number of spikelets per spike	+	+	-	-	+	-		Number of spikelets per spike	-	+
Spike length	+	+	+	+	+	-		Spike length	-	+
Biomass per plant	+	+	+	+	+	+		Biomass per plant	+	+
1000-grain weight	-	-	+	+	+	+		1000-grain weight	-	-
Grain yield per spike	+	+	+	+	+	+		Grain yield per spike	-	+
Harvest index	+	+	+	+	+	+		Harvest index	-	+

This is fascinating that SCA effects of the best crosses and GCA effects of their parents indicated that good specific cross combinations were result from the cross between good × good, good × poor and poor x poor combiners. However, in the present study, appraisal of SCA effects of these crosses and GCA effects of their parents revealed that these crosses generally included one parent with good GCA effect. Hence, the involvement of at least one good general combiner parent appeared to be desirable for obtaining the better hybrids. Biparental progeny selection proposed by Andrus (1963) may be used to get some transgressive segregants from the crosses involving good × good and good × poor combiners. These findings are in partial conformity with results of Madic *et al.* (2014); Ram and Shekhawat (2017); Lal *et al.* (2018); Parashar (2019).

Conclusively, an overall evaluation showed that the parent RD 2508, RD 2052 and PL 419 emerged as good general combiners while among the cross DWRUB 64 × RD 2508, RD 2592 × PL 419 and BH 946 × PL 419 emerged as good crosses for grain yield per plant as well as for other yield contributing characters. The additive gene action has been exploited more in barley, while the non-additive variance which is result of dominance and epistasis gene interaction remains to be used, which can be exploited for further improvement of barley crop through systematic breeding programme for the targeted environment. Overall evaluation of the results in the present investigation, suggested that appreciable improvement in barley production in forthcoming years would be realized through restricted recurrent selection (Hull, 1945), diallel selective mating (Jensen, 1970), use of the multiple crosses and bi-parental mating may be effective and alternative approaches for tangible advancement of barley yield in the coming years.

CONCLUSION

An overall evaluation showed that the parent RD 2508, RD 2052 and PL 419 emerged as good general combiners while among the cross DWRUB 64 × RD 2508, RD 2592 × PL 419 and BH 946 × PL 419 emerged as good crosses for grain yield per plant as well as for other yield contributing characters. The additive gene action has been exploited more in barley, while the non-additive variance which is result of dominance and epistasis gene interaction remains to be used, which can be exploited for further improvement of barley crop through systematic breeding programme for the targeted environment. Overall evaluation of the results in the present investigation, suggested that appreciable improvement in barley production in forthcoming years would be realized through restricted recurrent selection (Hull, 1945), diallel selective mating (Jensen, 1970), use of the multiple crosses and bi-parental mating may be effective and alternative approaches for tangible advancement of barley yield in the coming years.

Acknowledgments. The author acknowledges support from staff of division of Plant Breeding and Genetics of Rajasthan Agricultural Research Institute Durgapura, Jaipur.
Conflict of Interest. None.

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How to cite this article: Madhu Yadav, Ved Prakash, Madhu Choudhary, S.S. Rajput, Sonu Get, Sarfraz Ahmad, Khushwant B. Choudhary and Shravan Kumar Sharma (2022). Combining Ability Analysis for Grain Yield and Its Contributing Traits in Barley (*Hordeum vulgare* L.) Under Normal Irrigated Condition of Rajasthan. *Biological Forum – An International Journal, 14*(2): 419-428.