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DJ Joshi
Department of Genetics and Plant Breeding, C.P.C.A., S.D.A.U., Sardarkrushinagar, Gujarat, India

NB Patel
Department of Genetics and Plant Breeding, C.P.C.A., S.D.A.U., Sardarkrushinagar, Gujarat, India

BK Chaudhary
Department of Genetics and Plant Breeding, C.P.C.A., S.D.A.U., Sardarkrushinagar, Gujarat, India

JM Patel
Cotton Research Station, S. D. Agricultural University, Talod, Gujarat, India

PJ Patel
Seed Spices Research Station, S.D. Agricultural University, Jagudan, Gujarat, India

Corresponding Author:
DJ Joshi
Department of Genetics and Plant Breeding, C.P.C.A., S.D.A.U., Sardarkrushinagar, Gujarat, India

Estimation of combining ability and gene action in feed barley (*Hordeum vulgare* L.) using line × tester analysis

DJ Joshi, NB Patel, BK Chaudhary, JM Patel and PJ Patel

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Abstract
Thirty hybrids generated from crossing ten lines with three testers were studied along with their parents for combining ability and gene action involved in the expression of characters in feed barley to identify suitable parents and desirable hybrid combinations. Observations were recorded for days to heading, days to maturity, plant height (cm), spike length (cm), peduncle length (cm), flag leaf area (cm^2), number of grains per spike, grain yield per plant (g), 1000-grain weight (g), biological yield per plant (g) and harvest index (%). The female parents (lines) *viz.*, PL 842, BH 933, RD 3012 and HUB 272 were found good general combiner for yield and its attributing characters. While for the male parents (tester) K 944 and RD 2552 were found good general combiner for yield contributing traits. The specific combining ability effects of different crosses revealed that none of the crosses showed consistently significant and desirable specific combining ability effects for all the characters. The cross RD 3012 × RD 2552 showed significant and desirable specific combining ability for all the characters *viz.*, days to heading, spike length, peduncle length, flag leaf area, number of grains per spike, grain yield per plant, 1000 grain weight and harvest index and adjudged as auspicious cross. The cross BH 933 × K 944 exhibited significant *sca* effect for all characters *viz.*, days to maturity, spike length, peduncle length, flag leaf area, number of grains per spike, grain yield per plant, 1000 grain weight and harvest index. The ratio of σ^2 gca/σ^2 sca was less than unity for all the characters under study. This showed *sca* variance higher than *gca* variance so, there was preponderance of non-additive gene action. As non-additive gene action was found to be more prominent in the present investigation, so that in addition to conventional breeding methods some non-conventional breeding methods such as diallel selective mating, bi-parental mating in early segregating generations followed by selection or multiple crosses might prove to be effective alternative approach for appreciable progress in grain yield of feed barley.

Keywords: Feed barley (*Hordeum vulgare* L.), combining ability, general combining ability (GCA), specific combining ability (SCA), gene action

Introductiona

Barley (*Hordeum vulgare* L.) is an important *rabi* cereal crop grown throughout the temperate and tropical regions of the world. It is a most paramount cereal crop and considered as the first cereal domesticated for use by man as food and feed (Potla *et al*. 2013) [12]. It is frequently being described as the most cosmopolitan of the crops and also considered, as poor man's crop because of its low input requirement and better adaptability to problematic and marginal lands. Barley assumes the fourth position in total cereal production in the world after wheat, rice and maize, each of which covers nearly 30 per cent of the world's total cereal production (FAO STAT, 2004) [2]. It belongs to the family *Poaceae*, tribe *triticeae* and genus *Hordeum* which consists of about 32 species including the wild and cultivated one. Barley is a self-pollinating diploid species with 2n=14 chromosomes. In many countries around the world, because of its hardiness, it is often considered the only possible rainfed cereal crop under low input and stressful environment. Barley is rather well-tolerant to drought, salinity and other dehydrative stresses. The major barley growing states in India are Rajasthan, Uttar Pradesh, Haryana, Punjab, Madhya Pradesh, Uttarakhand, Himachal Pradesh, Bihar, Jammu and Kashmir, West Bengal, Chhattisgarh and Sikkim. Rajasthan ranks first in barley production (0.86 mt) followed by Uttar Pradesh (0.43 mt) and Madhya Pradesh (0.30 mt) with the productivity level of 30.46 q/ha, 27.74 q/ha and 22.89 q/ha, respectively, however the highest productivity is in the state of Punjab (35.96 q/ha). Apart from malting, feed and food purposes, it contains β-glucans which is helpful in lowering the risk of cardio-vascular diseases (Kumar *et al*. 2014) [6]. Barley straw provides an important source of roughage for the animal, particularly in the dry areas. Farmers' preference for barley cultivation in hills lies in the varieties which would give high fodder yield for their live stocks and food grain for human consumption. Breeding efforts are very much needed for developing dual purpose barley varieties capable of giving high grain yield even after harvesting the crop for green fodder The Parents are discriminated based on their capability using the general combining ability (GCA), which is primarily a function of additive gene action. The average performance of lines in a series of cross combinations determines the general combining ability (GCA). In segregating generations, the specific combining ability is utilized to identify superior cross-combinations that could lead to promising genotypes. In future barley improvement programs, F_1s that exhibit significant SCA effects in a desired direction may be included. The general and specific combining ability is associated with interaction effects, which may be due to dominance and epistatic components of genetic variation that are non-fixable in nature. The Line × Tester analysis is a common approach for assessing the expression of genetic aspects of traits (Kempthorne, 1957) [5] which provides information about GCA and SCA of parents and at the same time it is helpful in identifying best heterotic crosses. It provides information about genetic mechanism controlling yield and yield components and it is one of the powerful tools accessible to estimate the combining ability effects and aids in selecting desirable parents and crosses for exploitation in pedigree breeding (Rashid *et al*. 2007) [14]. This analysis besides providing reliable information on the combining ability of parents to produce superior progenies, also detect the estimates of additive and non-additive gene effects. The breeding method in any crop depends upon its genetic architecture and the pattern of inheritance of characters. Therefore, a proper understanding of the nature of inheritance of yield and its components by estimation of genetic parameters like combining ability (GCA and SCA) is required to put such a breeding programme on a sound footing. Grain yield is a complex metric trait which is an ultimate product of the action and the interaction of a number of component characters. Thus, the present study was conducted to identify the best combiners and their crosses based on general and specific combining ability effects for grain as well as forge yield and its component traits in feed barley.

Materials and Methods

The experimental material comprised of forty four feed barley genotypes including thirteen parents *viz.*, BH 970, BH 933, RD 2784, RD 3014, RD 3011, RD 3012, HUB 210, HUB 271, HUB 272 and PL 842 as female parents (lines) and K 944, BH 946 and RD 2552 as male parents (testers) and their thirty F_1's developed through line × tester mating design. The experimental material along with the check RD 2552, were grown in a randomized block design with three replications under normal conditions during *rabi* 2022-23 at Centre for Crop Improvement, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar. Sowing was done at the normal date of sowing. The parents, F_1's and check were grown in a plot with row-to-row distance of 22.5 cm and plant to plant distance of 10 cm. All the recommended cultural practices were adopted to raise a good crop. Observations were recorded on five randomly selected plants in each of the parent, F_1's and check. Mean values over selected plants were used for statistical analysis. Observations were recorded on five randomly selected plants in each replication for all the trait under study except days to heading and days to maturity where on plot basis observations were recorded. The data on days to heading, days to maturity, plant height (cm), flag leaf area (cm^2), peduncle length (cm) and spike length (cm), were recorded on the tagged plant when the plants were in the field, while data for characters 1000-grain weight (g), number of grains per spike, biological yield per plant (g), grain yield per plant (g) and harvest index (%) were recorded after harvesting of the randomly selected plants for yield. The experimental data were compiled by taking the mean over selected plants of each treatment for each replication. The mean data was subjected for the following statistical analysis i.e. analysis of variance (Panse and Sukhatme, 1967) [10]. The variation among the hybrids was partitioned further into sources attributable to general and specific combining ability components following the procedure suggested by Kempthorne (1957) [5].

Results and Discussion

The mean squares were obtained in the analysis of variance for combining ability and estimated components of genetic variance for various characters presented in Table 1. The mean squares due to replications were significant for days to maturity, number of grains per spike, grain yield per plant, biological yield per plant and harvest index. While, the mean squares due to hybrids were significant for all the characters except plant height. The mean squares due to males were significant for the characters *viz.*, days to heading, plant height, peduncle length, flag leaf area, number of grains per spike and 1000-grain weight. This indicated the importance of males for their contribution towards general combining ability variance components for these traits. The mean squares due to females were significant for the most of the characters except for plant height. It signifies sufficient variation is present in and among the lines under study. The line × tester mean squares exhibited significance for all plant characters under study except for plant height character. This signified the contribution of hybrids for specific combining ability variance components.

General combining ability effects varied from one parent to another giving negative or positive value (Table 2). The parental line PL 842 was found good general combiner for one and more characters *viz.*, days to heading, days to maturity, spike length, peduncle length, flag leaf area, number grain per spike, grain yield per plant, 1000 grain weight. On the other hand, HUB 272 was also adjudged as good general combiner for days to heading, days to maturity, peduncle length, number grain per spike and harvest index. While, the parent RD 3012 had good general combining ability effect for days to maturity, spike length, peduncle length, number grain per spike and grain yield per plant and biological yield per plant (Table-2). Thus, parents PL 842, RD 3012 and HUB 272 exhibited positive general combining ability for yield and its contributing traits. The parental lines *viz.*, BH 933 for days to heading, spike length and 1000 grain weight; RD 3011 for grain yield per plant; HUB 271 for biological yield per plant; RD 2784 and HUB 210 for harvest index; RD 2552 for 1000 grain weight.

All crosses exhibited significant and desirable SCA effects for one or more characters. The best cross combination namely BH 933 × K 944 expressed maximum *sca* effects along with *per se* performance for most of the characters *viz.*, days to maturity, spike length, peduncle length, flag leaf area, number grain per spike, grain yield per plant and harvest index. The cross BH 970 × BH 946 deserved significant *sca* effects for days to maturity, number grain per spike, grain yield per plant and biological yield per plant. The specific combining ability (*sca*) effects of the crosses for various characters are depicted in table 3. The crosses namely PL 842 × K 944, RD 3012 × RD 2552 and BH 933 × K 944 were common crosses found significant positive *sca* effects and per *se* performance. The cross RD 3012 × RD 2552 showed significant and desirable specific combining ability for all the characters *viz*., days to heading, spike length, peduncle length, flag leaf area, number of grains per spike, grain yield per plant, 1000 grain weight and harvest index. The cross BH 933 × K 944 exhibited significant *sca* effect for all characters *viz*., days to maturity, spike length, peduncle length, flag leaf area, number of grains per spike, grain yield per plant, 1000 grain weight and harvest index. The cross showing high *sca* effects for grain yield per plant also exhibited high or average *sca* effects for yield components. This indicated that, yield is a complex character depends upon the number of component characters.

Similar findings for one and more characters were also reported in feed barley by Pesaraklu *et al.* (2016) [11], Madakemohekar *et al.* (2018) [8], Mustafa, Kumari *et al.* (2020) [7], Katiyar, *et al.* (2021) [4] and Joshi *et al*. (2023) [3].

The variance for general combining ability and specific combining ability along with the gene action for different characters in feed barley is described in table 4.

The ratio of σ^2gca/ σ^2sca was less than unity for all the characters under study. This showed *sca* variance higher than *gca* variance so, there had a preponderance non-additive gene action. As non-additive gene action was found to be more prominent in the present investigation, so that in addition to conventional breeding methods some non-conventional breeding methods such as diallel selective mating, bi-parental mating in early segregating generations followed by selection or multiple crosses might prove to be effective alternative approach for appreciable progress in grain yield of barley. The relative contribution of lines × tester component was higher than the lines and testers for all the characters and again confirming predominant role of non-additive gene effects in the inheritance of all the characters under studied. Similar findings were also reported by Deniz *et al.* (2015) [1] and Ram and Shekawat (2017) [13]. Top three of the parents and hybrids for per *se* performance, combining ability effect are described in table: 5.

With the due respect of per *se* performance and combining ability, female parents *viz*., PL 842, BH 933, RD 3012 and HUB 272 were found good general combiner for yield and its attributing characters and forage yield prospects. While, male parents K 944 and RD 2552 were found good general combiner for grain yield contributing traits *viz.*, 1000-grain weight and number of grains per spike. In particular, using these parents in a structured crossing scheme may enhance barley even more productive in relation to yield. Based on combining ability for grain yield and its contributing characters, the superior cross combination (RD 3012 × RD 2552) was determined. This combination may be used to develop a superior line for yield and component traits in barley by utilizing potential transgressive segregates in advance generation.

Table 1: Analysis of variance for combining ability for yield and yield contributing characters in feed barley

Source of variation	d. f.	Days to heading	Days to maturity	Plant height	Spike length	Peduncle length	Flag leaf area	Number of grains per spike	Grain yield per plant	1000 grain weight	Biological yield per plant	Harvest index
Replications	2	3.42	26.22**	101.92	0.11	0.15	3.60	79.98**	19.21**	4.01	33.23*	58.20*
Hybrids	29	29.44**	40.01**	55.61	4.34**	6.15**	53.68**	148.85**	3.27*	40.97**	55.33**	42.32**
Females (Line)	9	55.01**	66.32**	27.55	5.96**	8.17**	86.08**	102.12**	4.25**	47.57**	46.99**	43.75**
Males (Tester)	2	29.56**	3.88	117.24*	0.51	2.24**	67.57**	388.42**	0.89	36.53**	10.45	5.07
Lines × Testers	18	16.65**	30.86**	62.79	3.95**	5.58**	35.94**	145.59**	3.04*	38.16**	64.48**	45.75**
Error	58	1.48	4.66	35.22	0.64	0.28	4.64	8.68	1.38	2.85	7.36	14.28
σ^2gca		1.31	0.21	0.49	-0.03	-0.01	2.09	5.11	-0.02	0.19	-1.83	-1.09
σ^2sca		5.05	8.73	9.19	1.10	1.76	10.43	45.63	0.55	11.76	19.04	10.48
σ^2gca/ σ^2sca		0.26	0.02	0.05	-0.03	-0.0a1	0.20	0.11	-0.04	0.01	-0.09	-0.10

* Significant at 5% level; ** Significant at 1% level

Table 2: Estimation of general combining ability (*gca*) effects of parents for various characters in feed barley

Sr. No.	Source of variation	Days to heading	Days to maturity	Plant height	Spike length	Peduncle length	Flag leaf area	Number of grains per spike	Grain yield per plant	1000 grain weight	Biological yield per plant	Harvest index
Lines												
1	BH 970	1.68**	0.33	-2.12	-1.16**	-0.66**	4.32**	0.69	-1.00*	0.21	-0.16	-2.94*
2	BH 933	-1.60**	0.84	-0.60	0.55*	0.07	-2.57**	0.42	0.09	1.90**	0.79	0.77
3	RD 2784	1.68**	-0.89	-0.12	0.11	-0.12	-0.60	-0.86	-0.59	-1.22*	-3.97**	3.63**
4	RD 3014	1.06*	0.46	0.96	-1.18**	0.13	-1.75*	-2.41*	-1.07**	-2.08**	-1.52	-1.18
5	RD 3011	2.66**	5.48**	-0.89	-0.04	-0.99**	1.13	-6.08**	0.57*	-1.16*	0.76	-0.33
6	RD 3012	0.59	-3.31**	2.32	0.76**	1.11**	-1.33	5.07**	0.53*	0.59	1.26*	0.25
7	HUB 210	1.37**	-0.40	1.41	-0.20	-1.77**	-3.99**	-1.24	-0.01	1.10*	-3.15**	2.48*
8	HUB 271	0.01	2.90**	-3.25*	-0.58*	0.40*	-2.81**	-2.46*	0.05	-3.87**	2.82**	-2.70*
9	HUB 272	-1.69**	-2.53**	1.54	0.44	0.42*	3.01**	4.07**	0.48*	0.04	0.33	1.77*
10	PL 842	-5.78**	-2.89**	0.74	1.31**	1.40**	4.59**	2.81**	0.93*	4.48**	2.83**	-1.75
Testers												
1	K 944	0.32	-0.11	0.77	-0.13	0.17	1.57**	2.20**	0.19	-0.43	0.34	0.43
2	BH 946	0.79**	0.40	-2.24*	0.12	-0.31**	-0.16	-4.15**	-0.09	-0.81*	0.33	-0.05
3	RD 2552	-1.11**	-0.29	1.47	0.08	0.14	-1.41**	1.94**	-0.10	1.25**	-0.68	-0.38

* Significant at 5% level; ** Significant at 1% level

Table 3: Estimation of specific combining ability (*sca*) effects of the crosses for various characters in feed barley

Sr. No.	Hybrids	Days to heading	Days to maturity	Plant height	Spike length	Peduncle length	Flag leaf area	No. of grain per spike	Grain yield per plant	1000 grain weight	Biological yield per plant	Harvest index
1	BH 970 X K 944	-0.23	5.15**	2.29	-1.05*	0.30	1.37	-5.85**	-1.44*	-2.15*	-7.96**	7.20**
2	BH 970 X BH 946	-1.04	-3.82**	1.38	0.22	-0.55	-1.72	6.24**	1.78*	2.70**	4.90**	-1.09
3	BH 970 X RD 2552	1.27	-1.33	-3.67	0.84	0.26	0.34	-0.39	-0.34	-0.55	3.05	-6.11**
4	BH 933 X K 944	-0.81	-5.35**	6.45	1.81**	2.56**	3.47**	10.28**	0.99*	6.96**	-3.28*	3.89*
5	BH 933 X BH 946	-0.15	-0.14	-3.53	-1.26**	-0.95**	1.14	-11.42**	-1.38*	-4.13**	2.54	-1.73
6	BH 933 X RD 2552	0.96	5.49**	-2.92	-0.55	-1.61**	-4.61**	1.14	0.40	-2.83**	0.74	-2.15
7	RD 2784 X K 944	0.04	0.04	1.56	0.08	-0.10	0.86	-0.36	0.83*	-1.95*	6.72**	-4.91*
8	RD 2784 X BH 946	1.62*	-2.86*	2.25	0.59	0.38	-0.50	-0.06	0.54	2.06*	-2.54	3.23
9	RD 2784 X RD 2552	-1.66*	2.82*	-3.81	-0.67	-0.28	-0.36	0.42	-1.36*	-0.10	-4.18**	1.68
10	RD 3014 X K 944	-2.40**	-1.38	-0.33	0.83	-0.63*	1.44	1.53	1.32*	-1.64	6.84**	-3.33
11	RD 3014 X BH 946	-0.22	0.04	2.29	-0.26	1.84**	-0.44	-2.45	-1.31	3.76**	-8.94**	5.50*
12	RD 3014 X RD 2552	2.62**	1.34	-1.96	-0.57	-1.21**	-1.00	0.92	-0.01	-2.13*	2.11	-2.18
13	RD 3011 X K 944	-1.14	-0.13	-6.73	0.18	0.23	-4.43**	-5.34**	-0.12	-1.79	0.08	-0.39
14	RD 3011 X BH 946	-0.75	1.75	4.89	0.90*	1.11**	-1.30	13.61**	0.14	2.77**	-1.13	0.57
15	RD 3011 X RD 2552	1.89**	-1.62	1.84	-1.08*	-1.34**	5.73**	-8.27**	-0.02	-0.99	1.05	-0.18
16	RD 3012 X K 944	0.66	2.00	-4.35	-0.60	-0.88**	-6.12**	-5.89**	-0.34	-4.62**	-1.70	1.61
17	RD 3012 X BH 946	1.32	0.22	-4.13	-0.74	-0.53	2.46*	0.53	-0.40	-1.88	3.72*	-5.14*
18	RD 3012 X RD 2552	-1.97**	-2.22	8.48*	1.34**	1.41**	3.66**	5.36**	0.74*	6.50**	-2.02	3.54*
19	HUB 210 X K 944	-0.32	0.49	0.09	-1.70**	-0.39	1.61	-1.19	-0.88	0.45	-3.81*	0.20
20	HUB 210 X BH 946	-2.06**	-2.16	1.51	0.57	0.96**	-0.48	3.37	0.42	0.07	4.00*	-3.00
21	HUB 210 X RD 2552	2.38**	1.67	-1.61	1.13*	-0.57	-1.12	-2.19	0.46	-0.52	-0.19	2.80
22	HUB 271 X K 944	2.23**	0.78	1.49	0.83	-0.10	2.87*	1.10	0.04	1.13	-1.04	0.24
23	HUB 271 X BH 946	-2.17**	2.26	0.98	0.68	-1.15**	-4.46**	3.00	0.53	0.00	0.89	-0.38
24	HUB 271 X RD 2552	-0.06	-3.04*	-2.47	-1.50**	1.25**	1.59	-4.09*	-0.57	-1.14	0.15	0.13
25	HUB 272 X K 944	0.08	0.22	-3.17	-0.83	-1.59**	-1.21	-0.03	-0.55	0.31	1.66	-3.27
26	HUB 272 X BH 946	-0.13	3.04*	-2.69	-0.06	-0.04	3.39**	-3.14	-0.16	-2.61**	-1.04	1.64
27	HUB 272 X RD 2552	0.05	-3.26*	5.86	0.89	1.63**	-2.19	3.17	0.71	2.30*	-0.62	1.63
28	PL 842 X K 944	1.90**	-1.82	2.69	0.47	0.62*	0.13	5.75**	0.16	3.32**	2.47	-1.24
29	PL 842 X BH 946	3.56**	1.66	-2.95	-0.63	-1.08**	1.91	-9.68**	-0.17	-2.76**	-2.39	0.40
30	PL 842 X RD 2552	-5.46**	0.16	0.26	0.17	0.46	-2.04	3.93*	0.05	-0.56	-0.08	0.84
S.E.±		0.70	1.25	3.43	0.46	0.31	1.24	1.70	0.68	0.98	1.57	2.18
Range	Minimum	-5.46	-5.35	-6.73	-1.70	-1.61	-6.12	-11.42	-1.44	-4.62	-8.94	-6.11
	Maximum	3.56	5.49	8.48	1.81	2.56	5.73	13.61	1.78	6.96	6.84	7.20

* Significant at 5% level; ** Significant at 1% level.

Table 4: Variance for general combining ability and specific combining ability along with the gene action for different characters in feed barley

Sr. No	Traits	σ^2 gca	σ^2 sca	σ^2 gca/ σ^2 sca	Gene action
1	Days to heading	1.31	5.05	0.26	Non-additive
2	Days to maturity	0.21	8.73	0.02	Non-additive
3	Plant height (cm)	0.49	9.19	0.05	Non-additive
4	Spike length (cm)	-0.03	1.10	-0.03	Non-additive
5	Peduncle length	-0.01	1.76	-0.01	Non-additive
6	Flag leaf area	2.09	10.43	0.20	Non-additive
7	Number of grains per spike	5.11	45.63	0.11	Non-additive
8	Grain yield per plant	-0.02	0.55	-0.04	Non-additive
9	1000 grain weight	0.19	11.76	0.01	Non-additive
10	Biological yield per plant	-1.83	19.04	-0.09	Non-additive
11	Harvest index	-1.09	10.48	-0.10	Non-additive

Table 5: Top three of the parents and hybrids for per se performance, combining ability effect

Characters	*Per se* performance		Status of the parents	Combining ability	
	Parents	Hybrids		GCA	SCA
Days to heading	PL 842	PL 842 × RD 2552	G × G	PL 842	PL 842 × RD 2552
	K 944	PL 842 × K 944	G × A	HUB 272	RD 3014× K 944
	HUB 271	HUB 272 × RD 2552	G × G	BH 933	HUB 271 × BH 946
Days to maturity	K 944	HUB 272 × RD 2552	G × A	RD 3012	BH 933 × K 944
	HUB 272	RD 3012 × RD 2552	G × A	PL 842	BH 970 × BH 946
	PL 842	PL 842 × K 944	G × A	HUB 272	HUB 271 × RD 2552
Plant height	HUB 210	RD 3011 × K 944	A × A	BH 946	-
	RD 3011	BH 933 ×BH 946	A × G	HUB 271	-
	BH 970	HUB 271 ×BH 946	G × G	-	-
Spike length	RD 2552	BH 933 × K944	G × P	PL 842	BH 933 × K 944
	K 944	RD 3012 × RD 2552	G × A	RD 3012	RD 3012× RD 2552
	HUB 272	PL 842 × K 944	G × P	BH 933	HUB 210 × RD 2552
Peduncle length	BH 933	BH 933 × K 944	A × A	PL 842	BH 933 × K 944
	HUB 272	RD 3012 × RD 2552	G × A	RD 3012	RD 3014 × BH 946
	RD 2552	PL 842 × K 944	G × A	HUB 272	HUB 272 × RD 2552
Flag leaf area	BH 946	BH 970 × K 944	G × G	PL 842	RD 3011 × RD 2552
	HUB 210	PL 842 × BH 946	G × P	HUB 272	RD 3012 × RD 2552
	PL 842	PL 842 × K 944	G × G	BH 970	BH 933 × K 944
Number grain per spike	HUB 272	BH 933 × K 944	A × G	RD 3012	RD 3011 × BH 946
	K 944	RD 3012 × RD 2552	P × G	HUB 272	BH 933 × K 944
	RD 2552	PL 842 × K 944	G × G	PL 842	BH 970 × BH 946
Grain yield per plant	K 944	PL 842 × K 944	G × G	PL 842	BH 970 × BH 946
	RD 2552	BH 933 × K 944	A × A	RD 3011	BH 933 × K 944
	HUB 272	RD 3012 × RD 2552	A × P	RD 3012	RD 3012 × RD 2552
1000 grain weight	HUB 272	BH 933 × K 944	G × P	PL 842	BH 933 × K 944
	PL 842	RD 3012 × RD 2552	A × G	BH 933	RD 3012 × RD 2552
	RD 2552	PL 842 × K 944	G × P	RD 2552	RD 3014 × BH 946
Biological yield per plant	RD 2784	RD 3014 × K 944	P × A	PL 842	RD 3014 × K 944
	HUB 210	PL 842 × K 944	G × A	HUB 271	RD 2784 × K 944
	HUB 271	RD 3012 ×BH 946	G × A	RD 3012	BH 970 × BH 946
Harvest index	BH 946	RD 2784 × BH 946	G × P	RD 2784	BH 970 × K 944
	RD 3011	BH 933 × K 944	A × A	HUB 210	RD 3014 × BH 946
	PL 842	RD 2784 ×RD 2552	G × P	HUB 272	BH 933 × K 944

Conclusion
In conclusion, the study revealed significant genetic variability in barley for traits related to grain yield and its components, with a predominance of non-additive gene action. The general combining ability (GCA) and specific combining ability (SCA) effects indicated that the selected parental lines, such as PL 842, RD 3012, and HUB 272, were strong combiners for several yield traits. The cross RD 3012 × RD 2552 emerged as the most promising, showing desirable SCA effects for all studied traits. Non-conventional breeding methods, such as diallel selective mating, may be effective in improving grain yield through these crosses.

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