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Study of Heterosis and Combining Ability in Barley (*Hordeum vulgare* L.) under Normal and Limited Moisture Condition

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ABSTRACT

The study of heterosis helps the breeder to select the more productive crosses in early generations while combining ability of the parents is essential to recognize better parental combinations that can yield useful cross combinations. 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 heterosis, heterobeltiosis and general and specific combining ability variances and effects. The crosses RD 2035 × RD 2508, RD 2592× RD 2052, DWRB 137 × RD 2052, RD 103 × RD 2035, DWRB 137 ×RD 2035 and RD 2052 × RD 2508 exhibited desirable heterosis and heterobeltiosis for grain yield per spike and its contributing characters in both the environments. An overall evaluation showed that the parent RD 2508, RD 2052 and PL 419 emerged as good general combiners while among the cross DWRB 137 x PL 419 (Normal and limited moisture), PL 419 × RD 103 and RD 103 × RD 2508 (Normal irrigated) emerged as good crosses for grain yield per spike as well as for other yield contributing characters.

Keywords Barley, Drought, Heterosis, Heterobeltiosis, GCA.

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INTRODUCTION

Barley (*Hordeum vulgare* L.) is a preeminent crop which considered as first cereal domesticated for use by man as food and feed (Potla et al. 2013). *Hordeum vulgare* sub sp. Spontaneum (wild ancestor of domesticated barley) is abundant in grasslands and woodlands throughout the fertile crescent area of N-E Africa and Western Asia. In ancient Sanskrit texts of Indo-Aryans, barley is termed as "Yava" and was probably most stable food during vedic period. Barley is grown as irrigated, rainfed crop and under residual soil moisture. Barley can be utilized as animal feed (60%), for malt production (30%), seed production (7%) and for human food (3%). Malt is the second largest use of barley, cultivated for malting and brewing purpose. Malted barley is mostly used for beer, distilled alcohol products and for malt syrup, malted milk and breakfast foods. In India, barley is also used to prepare *'Daliya*' (porridge), *'Sattu'* (flour from the roasted grain), barley pops, *'chapatti'* etc. It is believed to have cooling effect on human body over oat and other cereals particularly during summer. It is used in breads, soups, stews and health products.

The most alternative is to increase the yield per unit area through better crop management practices and increasing the cultivation of high yielding varieties with adequate resistant to biotic and abiotic stresses. Proper choice of parents on the basis of combining ability for putative drought tolerant attributes as well as productive traits and selection in typical target environment will help in combining complex traits, such as, productivity and drought tolerance.

The study of heterosis helps the breeder to select the more productive crosses in early generations. Heterosis in most crops including barley is an important tool in interpreting genetic parameters. Many biometrical procedures have been developed to obtain information on combining ability and diallel analysis is one of them which is widely used to study combining ability of the parents to be choosen for heterosis breeding. It also provides the unique opportunity to test a number of lines in all possible combinations (Mather and Jinks 1971). For this, combining ability analysis provides prerequisite to select the desirable parents for a hybridization program (Kakani *et al.* 2007). General combining ability and specific combining ability are very effective in designing and execution of a breeding program 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.

MATERIALS AND METHODS

The present investigation was carried out during *rabi* 2018-19 and 2019-20 at Research Farm, Rajasthan Agricultural Research Institute (Sri Karan Narendra Agriculture University, Jobner), Durgapura, Jaipur (Rajasthan). Ten diverse parents namely: BH 946, RD 2592, DWRUB 64, DWRB 137, PL 426, PL 419, RD 103, RD 2035, RD 2052 and RD 2508 were selected and crossed in diallel fashion (excluding reciprocals) in all possible combinations during *rabi* 2018-19. In summer 2019, half of the F_1s seed was multiplied during off-season at IARI regional station, Wellington (Tamil Nadu) to advance the generation. In *rabi* 2019-20 ten varieties along with their 45 F_1's and 45 F_2's progenies were evaluated under the limited moisture condition created by giving only three irrigations at the crop stage of 30, 60 and 90 days with three replications in Randomized Block Design. Each replication contained two parts. The parents and F_1s sown in two rows with 3 m row length and F_2s were sown in 4 rows of 3 m in each replication. Row to row and plant to plant distance was kept 30 cm and 10 cm, respectively. Non-experimental rows were planted all around the experiment to eliminate the border effects, if any. All recommended agronomical package of practices were adopted to raise good crop. Observations were recorded days to heading, peduncle length, number of grains per spike, number of spikelets per spike, spike length, biomass per plant and grain yield per spike.

Heterosis over mid parent was calculated by = $[(F_1\text{-MP})/\text{MP}] \times 100$ and heterobeltiosis were calculated by formula proposed by Fonseca and Patterson (1968) i.e., $[(F_1\text{-BP})/\text{BP}] \times 100$. Where F_1= mean values of hybrid, MP = Mean values of mid parents and BP= Mean values of batter parents.

Analysis of variance for combining ability was done for individual environment following Griffing (1956) method 2 model I. The general mathematical model for analysis as given by Griffing (1956).

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

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 ij^{Kth} observation

b = Number of blocks

Table 1. Top three crosses for their heterosis, heterobeltiosis and inbreeding depression estimates under normal irrigated (E_1) and limited moisture (E_2) conditions for yield and associated traits.

Characters	Env	Heterosis	Heterobeltiosis	Inbreeding depression
Days to heading	E_1	RD 2052 x RD 2508	RD 2052 x RD 2508	RD 103 x RD 2508
		DWRUB 64 x RD 103	RD 2592 x RD 2052	BH 946 x RD 2508
		PL 426 x RD 2035	RD 2592 x PL 419	PL 426 x RD 2052
	E_2	RD 2035 x RD 2508	PL 419 x RD 2508	RD 2592 x PL 419
		BH 946 x RD 2035	BH 946 x PL 419	BH 946 x PL 426
		RD 103 x RD 2035	RD 103 x RD 2035	PL 419 x RD 2035
Peduncle length	E_1	DWRUB 64 x RD 2052	RD 103 x RD 2035	RD 103 x RD 2035
		DWRUB 64 x RD 2508	PL 419 x RD 2052	PL 419 x RD 2052
		RD 103 x RD 2035	PL 419 x RD 2508	PL 419 x RD 2508
	E_2	BH 946 x RD 2508	BH 946 x PL 419	PL 426 x RD 2508
		BH 946 x RD 2052	RD 2592 x RD 2035	PL 419 x RD 2052
		DWRUB 64 x RD 2052	PL 419 x RD 2052	PL 419 x RD 2035
Number of grains per spike	E_1	DWRUB 64 x RD 2508	DWRB 137 x RD 2035	DWRB 137 x RD 2035
		DWRUB 64 x RD 2052	DWRUB 64 x RD 2508	DWRUB 64 x RD 2508
		DWRB 137 x PL 419	RD 103 x RD 2035	RD 103 x RD 2035
	E_2	DWRB 137 x RD 103	DWRB 137 x RD 103	DWRB 137 x RD 2052
		BH 946 x PL 419	DWRB 137 x RD 2035	BH 946 x DWRB 137
		DWRB 137 x RD 2035	BH 946 x RD 2035	DWRB 137 x PL 419
Number of spikelets per spike	E_1	RD 2592 x RD 2052	RD 2592 x DWRB 137	DWRUB 64 x DWRB 137
		RD 2592 x RD 2508	RD 103 x RD 2508	RD 103 x RD 2052
		RD 2592 x DWRB 137	RD 2592 x RD 2052	PL 426 X RD 2052
	E_2	RD 2592 x RD 2052	DWRB 137 x RD 2035	DWRB 137 x PL 426
		DWRB 137 x RD 2035	RD 2592 x RD 2052	DWRUB 64 x PL 426
		RD 2592 x PL 426	RD 2592 x PL 426	DWRUB 64 x RD 2052
Spike length	E_1	DWRUB 64 x RD 2508	BH 946 x RD 2508	PL 419 x RD 2035
		DWRUB 64 x RD 2052	BH 946 x DWRB 137	DWRUB 64 x PL 426
		BH 946 x RD 2508	DWRUB 64 x RD 2508	DWRUB 64 x DWRB 137
	E_2	RD 103 x RD 2508	RD 103 x RD 2508	PL 426 x RD 2508
		RD 2052 x RD 2508	RD 2052 x RD 2508	RD 2592 x PL 426
		PL 419 x RD 103	PL 419 x RD 103	DWRB 137 x PL 419
Biomass per plant	E_1	RD 2035 x RD 2052	PL 419 x RD 2052	PL 419 x RD 2052
		RD 2035 x RD 2508	BH 946 x PL 419	BH 946 x PL 419
		RD 103 x RD 2508	PL 419 x RD 2508	PL 419 x RD 2508
	E_2	PL 426 x RD 2052	PL 419 x RD 2052	RD 2052 x RD 2508
		DWRB 137 x RD 2052	PL 419 x RD 2508	RD 2592 x RD 2508
		PL 419 x RD 2052	BH 946 x PL 419	DWRUB 64 x PL 426
Grain yield per spike	E_1	RD 2035 x RD 2508	RD 103 x RD 2035	RD 103 x RD 2035
		RD 103 x RD 2508	DWRB 137 x RD 2035	RD 2592 x PL 426
		DWRB 137 x RD 2508	RD 2052 x RD 2508	BH 946 x RD 103
	E_2	RD 2592 x RD 2052	DWRB 137 x RD 2035	PL 419 x RD 2035
		DWRB 137 x RD 2035	RD 2052 x RD 2508	PL 426 x RD 2035
		DWRB 137 x RD 2052	BH 946 x RD 103	RD 2592 x DWRB 137

RESULTS AND DISCUSSION

The superiority of hybrids particularly over better parent is more important an useful in determining the feasibility of commercial exploitation of heterosis and also indicating the parental combinations capable of producing the highest level of transgressive segregants.

In the present study, the maximum range of heterosis has been estimated for all studied characters. An overall appraisal of the investigation shown that heterosis ranged from -9.63 to 7.80 in E_1 and -11.73 to 5.57 in E_2 for days to heading, -9.22 to 23.40 in E_1 and -7.45 to 28.29 in E_2 for peduncle length, -6.83 to 21.61 in E_1 and -8.09 to 20.07 in E_2 for number of grains per spike, -14.47 to 35.13 in E_1 and -17.59 to 43.95 in E_2 for number of spikelets per spike, -20.85 to 38.40 in E_1 and -20.18 to 30.54 in E_2 for spike length, -8.98 to 38.83 in E_1 and -6.80 to 31.62 in E_2 for biomass per plant; -16.47 to 25.00 in E_1 and -13.10 to 25.61 in E_2 for grain yield per spike. The result in both the environments for different characters are in conformity with the findings of several researchers such as Shendy (2015), Pesarkhlu *et al*. (2016), Ram and Shekhawat (2017), Lal *et al*. (2018a), Parashar *et al*. (2019) and Bouchetat *et al*. (2020). The superiority of hybrids over better parent (heterobeltiosis) is more important and useful in determining the practicability of commercial exploitation of heterosis and also indicating the parental combination capable of producing the utmost level of transgressive segregants.

Three best heterotic and heterobeltiotic crosses for grain yield per spike are presented in Table 1. Perusal of this table indicated that the crosses RD 2035 x RD 2508, RD 103 x RD 2508 and DWRB 137 x RD 2508 in E_1 and RD 2592 x RD 2052, DWRB 137 x RD 2035 and DWRB 137 x RD 2052 in E_2 exhibited desirable heterosis. Whereas, crosses RD103 x RD 2035, DWRB 137 x RD 2035 and RD 2052 x RD 2508 in E_1 and DWRB 137 x RD 2035, RD 2052 x RD 2508 and BH 946 x RD 103 in E_2 exhibited desirable heterobeltiosis for grain yield per spike. Among top three crosses for grain yield per spike in both the environments, the crosses RD 2035 x RD 2508, RD 2592 x RD 2052, DWRB 137 x RD 2052, RD 103 x RD 2035, DWRB 137 x RD 2035 and RD 2052 x RD 2508 showed desirable heterosis and heterobeltiosis for one or more characters in both the environments. Hence, these crosses may be considered as promising type for tangible advancement of barley yield under normal irrigated and limited moisture condition.

Assessment of Table 2 divulged an interesting relation between heterosis and heterobeltiosis of grain yield per spike and other yield attributing traits. The parents, which, showed desirable heterosis and heterobeltiosis for grain yield per spike, also exhibited desirable heterosis and heterobeltiosis at least for one or more yield attributing traits. Such as, heterosis for grain yield per spike was mainly contributed by days to heading, number of grains per spike length and biomass per plant in both the environments, while heterobeltiosis by number of grains per spike and number of spikelets per spike in both the environments. Findings of this investigation supported the contentions of Grafius (1959), who suggested that there could be no separate gene system for yield *per se* as yield is an end product of the multiplicative interactions among its various contributing attributes. Thus, heterobeltiosis for various yield contributing characters might be result in the expression of heterobeltiosis for grain yield. However, the crosses showing heterotic expression for grain yield per spike were not heterotic for all the characters. It was also noted that the expression of heterosis and heterobeltiosis was influenced by the environments for almost all the characters. This was because of significant G × E interaction.

Table 2. Best crosses exhibiting high heterosis and heterobeltiosis for grain yield per spike along with desirable (+) heterotic expression for other characters under normal irrigated (E_1) and limited moisture (E_2) conditions.

Particulars	Heterosis						Heterobeltiosis					
Environment	E_1			E_2			E_1			E_2		
Crosses possessing high heterosis and heterobeltiosis for grain yield per spike	RD 2035 ×RD 2508	RD 103 × RD 2508	DWRB 137 ×RD 2508	RD 2592 × RD 2052	DWRB 137 x RD 2035	DWRB 137 × RD 2052	RD 103 × RD 2035	DWRB 137 × RD 2035	RD 2052× RD 2508	DWRB 137 x RD 2035	RD 2052 × RD 2508	BH 946 × RD 103
Days to heading	+	+	+	+	+	-	-	+	+	-	+	-
Peduncle length	-	+	-	+	+	-	+	-	+	-	+	-
Number of grains per spike	+	+	+	+	+	-	+	+	+	+	+	-
Number of spikelets per spike	+	+	-	+	+	-	+	+	+	+	+	-
Spike length	+	+	-	+	-	+	-	-	+	-	+	-
Biomass per plant	+	+	+	+	-	+	+	+	+	-	+	-

Table 3. Analysis of variance for general and specific combining ability under normal irrigated and limited moisture conditions for yield and its contributing traits.

Characters	Env	GCA (df = 9) F_1	GCA (df = 9) F_2	SCA (df = 45) F_1	SCA (df = 45) F_2	Error (df =108) F_1	Error (df =108) F_2	GCA/SCA ratio F_1	GCA/SCA ratio F_2
Days to heading	E_1	14.89**	19.83**	5.47**	10.22**	0.51	0.66	0.24	0.17
	E_2	23.76**	11.71**	7.65**	9.90**	0.57	0.66	0.27	0.10
Peduncle length	E_1	19.54**	15.00**	3.70**	4.32**	0.39	0.34	0.48	0.31
	E_2	20.00**	19.95**	2.71**	3.51**	0.40	0.40	0.71	0.52
Number of grains per spike	E_1	35.55**	11.22**	12.26**	12.41**	1.52	3.18	0.26	0.07
	E_2	13.80**	16.81**	8.93**	11.95**	0.67	2.35	0.13	0.13
Number of spikelets per spike	E_1	4.96**	3.09**	1.67**	1.44**	0.12	0.26	0.26	0.20
	E_2	2.51**	0.45**	0.94**	1.18**	0.10	0.10	0.24	0.03
Spike length	E_1	3.74**	1.63**	1.36**	1.05**	0.09	0.07	0.24	0.13
	E_2	1.80**	1.20**	0.54**	0.67**	0.08	0.04	0.31	0.15
Biomass/ plant	E_1	137.89**	151.58**	15.71**	17.43**	1.82	1.20	0.82	0.77
	E_2	59.71**	72.86**	5.76**	8.27**	0.62	0.55	0.96	0.78
Grain yield per spike	E_1	0.36**	0.35**	0.09**	0.14**	0.01	0.009	0.36	0.22
	E_2	0.37**	0.22**	0.09**	0.07**	0.01	0.01	0.38	0.29

Higher grain yield per spike is a desirable character in barley associated with negative magnitude of inbreeding depression. Thirty three crosses in E_1 and twenty crosses in E_2 were inclined towards negative magnitudes, of which seven crosses in E_1 and two crosses in E_2 showed negative significant inbreeding depression, which indicated that grain yield per spike in F_2 generation was higher than F_1 generation. The negative inbreeding depression may result from the advantage of population buffering, which may occur in F_2 generation due to the segregation of genes or sometimes because of formation of superior gene combinations, such a situation is valuable in conventional breeding program.

Analysis of variances for combining ability showed that variances due to general combining ability (GCA) as well as due to specific combining ability (SCA) were highly significant for all the studied characters in both the environment in both the F_1 and F_2 generations (Table 3). Thus, both additive and non-additive gene action played vital role in the genetic control of the characters under this study. The results are in accordance with earlier findings of Rathore and Chauhan (2017), Lal *et al.* (2018b), Bouchetat and Aissat (2019) and Anju kumari *et al.* (2020).

The GCA/SCA variance ratio (predictability ratio) was less than unity in both the environments 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 Rathore and Chauhan (2017), Parashar *et al.* (2019), Bouchetat and Aissat (2019) and Anju kumari *et al.* (2020).

The cross combinations that were significant and good for two or more characters in F_1 of E_1 only (Table 4) were DWRB 137 x RD 2035 for days to heading and number of grains per spike; RD 103 x RD 2035 for peduncle length and spike length; DWRUB 64 x RD 2052 for peduncle length, numbers of grains per spike and spike length; PL 419 x RD 103 for number of spikelets per spike, biomass per plant and grain yield per spike; DWRUB 64 x PL 419 for spike length and biomass per plant; BH 946 x PL 419 for biomass per plant and grain yield per spike.

The cross combinations that were significant and good for two or more characters in F1 of E2 only (Table 4) were BH 946 x RD 2052 for days to heading and number of spikelets per spike; DWRUB 64 x RD 2508 for peduncle length and grain yield per spike; DWRB 137 x RD 2035 for number of spikelets per spike and grain yield per spike.

The cross combinations that were significant

Table 4. Best three parents, F_1's and F_2's for their mean values, GCA and SCA effects under normal irrigated (E_1) and limited moisture (E_2) conditions for yield and associated traits.

Characters	Env.	Parents	High mean F_1	High mean F_2	GCA F_1	GCA F_2	SCA F_1	SCA F_2
Days to heading	E_1	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
	E_2	DWRB 137	PL 419 x RD 2052	BH 946 x PL 419	RD 2052	RD 2508	DWRUB 64 x RD 103	DWRUB 64 x RD 103
		RD 2052	BH 946 x RD 2052	RD 2592 x RD 2508	RD 2508	DWRB 137	BH 946 x RD 2052	BH 946 x RD 2035
		PL 426	PL 419 x RD 2508	BH 946 x RD 2052	DWRB 137	PL 419	PL 419 x RD 2052	BH 946 x PL 419
				DWRUB 64 x RD 103				
Peduncle length	E_1	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 2592xDWRB 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
	E_2	RD 103	RD 103 x RD 2508	PL 419 x RD 2052	RD 2508	RD 2508	DWRUB 64 x RD 2052	PL 419 x RD 2052
		RD 2508	RD 103 x RD 2035	RD 2052 x RD 2508	RD 103	RD 2052	BH 946 x RD 2508	BH 946 x RD 2592
		RD 2052	PL 419 x RD 103	PL 419 x RD 103	RD 2052	RD 103	DWRUB 64 x RD 2508	PL 419 x RD 103
Number of grains per spike	E_1	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
	E_2	PL 419	BH 946 x PL 419	RD 2592 x PL 419	PL 419	PL 419	DWRB 137 x RD 103	DWRUB 64 x PL 426
		RD 2592	PL 419 x RD 2052	PL 419 x RD 2052	RD 2592	RD 2052	BH 946 x PL 419	DWRB 137 x RD 2035
		RD 2508	RD 2592 x PL 419	RD 2592 x RD 2508	RD 2035	-	DWRUB 64 x PL 419	BH 946 x PL 419
Number of spikelets per spike	E_1	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
	E_2	PL 419	RD 2592 x PL 419	DWRUB 64 x PL 426	BH 946	BH 946	DWRB 137 x RD 2035	DWRUB 64 x PL 426
		BH 946	BH 946 x RD 2592	BH 946 x DWRB 137	RD 2592	-	BH 946 x RD 2052	RD 103 x RD 2035
		RD 103	BH 946 x RD 2052	RD 103 x RD 2035	RD 2508	-	RD 2592 x RD 2052	DWRUB 64 x RD 2052
Spike length	E_1	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 64xRD 2052	BH 946 x RD 2592	PL 419	RD 2052	RD 103xRD 2035	BH 946 x RD 2052
	E_2	PL 419	RD 103 x RD 2508	RD 2592 x PL 426	RD 2508	RD 2508	PL 419 x RD 103	BH 946 x RD 2035
		RD 2035	PL 419 x RD 103	BH 946 x RD 2035	RD 2052	PL 419	RD 103 x RD 2508	RD 2592 x PL 426
		RD 103	RD 2052 x RD 2508	DWRUB 64 x RD 103	PL 419	RD 103	DWRB 137 x PL 426	DWRUB 64 x RD 103
Biomass per plant	E_1	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
	E_2	RD 2052	PL 419 x RD 2052	RD 2052 x RD 2508	RD 2052	RD 2052	DWRB 137 x RD 2052	DWRB 137 x RD 2052
		PL 419	PL 419 x RD 2508	PL 419 x RD 2052	PL 419	PL 419	DWRB 137 x RD 2508	RD 2052 x RD 2508
		BH 946	PL 426 x RD 2052	PL 419 x RD 2508	BH 946	RD 2508	PL 426 x RD 2052	DWRUB 64 x PL 419
Grain yield per spike	E_1	PL 419	BH 946 x RD 2052	DWRB 137 x PL 419	RD 2508	RD 2508	PL 419 x RD 103	RD 103 x RD 2035
		RD 2508	DWRB 137 x RD 2508	BH 946 x RD 2052	PL 419	RD 2052	RD 103 x RD 2508	DWRB 137 x PL 419
		RD 2052	PL 419 x RD 103	RD 103 x RD 2508	RD 2052	PL 419	DWRB 137 x RD 2508	RD 103 x RD 2508
	E2	DWRUB 64	BH 946 x RD 103	RD 2052 x RD 2508	RD 2508	RD 2508	BH 946 x RD 103	DWRB 137 x PL 426
		PL 419	DWRUB 64 x RD 2052	RD 103 x RD 2508	PL 419	RD 2052	DWRB 137 x RD 2035	RD 2592 x RD 2052
		RD 2508	DWRB 137 x PL 419	RD 2592 x RD 2052	RD 2052	PL 419	DWRB 137 x PL 419	RD 103 x RD 2508

and good for two or more characters in F_2 of E_1 only (Table 4) were RD 2592 x PL 419 for days to heading, number of grains per spike and biomass per plant; PL 426 x RD 2035 for days to heading and number of grains per spike; DWRB 137 x RD 103 for number of grains per spike and number of spikelets per spike; DWRB 137 x PL 426 for number of spikelets per spike and spike length.

The cross combination that were significant and good for two or more characters in F_2 of E_2 only (Table 4) were DWRUB 64 x RD 103 for days to

Table 5. Best parents possessing high GCA effects along with their per se performance for grain yield per spike and significant desirable (+) GCA effects for other characters under normal irrigated (E_1) and limited moisture (E_2) conditions in F_1 and F_2 generation.

Environment	E_1						E_2			
Generation in which exhibited high GCA effects and per se performance	F_1			F_2			F_1		F_2	
Best parents based on desirable GCA effects and per se performance for grain yield per spike	RD 2508	RD 2052	PL 419	RD 2508	RD 2052	PL 419	RD 2052	PL 419	RD 2052	PL 419
Days to heading	+	+	+	+	+	+	+	-	+	+
Peduncle length	+	+	+	+	+	+	+	-	+	-
Number of grains per spike	+	+	+	-	-	-	-	+	+	+
Number of spikelets per spike	+	+	-	-	+	-	-	+	-	-
Spike length	+	+	+	+	+	-	+	+	+	+
Biomass per plant	+	+	+	+	+	+	+	+	+	+

heading and spike length; BH 946 x RD 2035 for days to heading and spike length; BH 946 x PL 419 for days to heading and number of grains per spike; DWRUB 64 x PL 426 for number of grains per spike and number of spikelets per spike.

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 Sultan *et al.* (2016) and Parashar *et al.* (2019).

The evaluation of Table 6 established a significant relation between the SCA effect of grain yield per spike and other component characters. The crosses, which exhibited high *per se* performance with desirable SCA effects for grain yield per spike and one or more yield attributing characters and exhibited as good specific cross combinations are as follows: PL 419 x RD 103 and DWRB 137 x PL 419 in F_1 of E_1; DWRB 137 x PL 419 and RD 103 x RD 2508 in F_2 of E_1; BH 946 x RD 103 and DWRB 137 x PL 419 in F_1 of E_2; RD 2592 x RD 2052 in F_2 of E_2. The parents

Table 6. Best crosses possessing high SCA effects along with their *per se* performance for grain yield per spike and significant desirable (+) SCA effects for other characters under normal irrigated (E_1) and limited moisture (E_2) conditions in F_1 and F_2 generation.

Environment	E_1				E_2		
Generation in which exhibited high SCA effects and *per se* performance	F_1		F_2		F_1		F2
Best crosses based on desirable SCA effects and *per se* performance for grain yield per spike	PL 419× RD 103	DWRB 137× RD 2508	DWRB 137 × PL 419	RD 103 × RD 2508	BH 946 × RD 103	DWRB 137 × PL 419	RD 2592 × RD 2052
Days to heading	-	+	-	+	-	+	+
Peduncle length	+	-	+	-	+	-	-
Number of grains per spike	+	-	+	+	+	+	-
Number of spikelets per spike	+	+	-	+	-	-	+
Spike length	+	-	+	+	+	+	-
Biomass per plant	+	+	-	+	-	+	+

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 spike and one or more yield associated characters.

Conclusively, Among top three crosses for grain yield per spike in both the environments, the crosses RD 2035 x RD 2508, RD 2592 x RD 2052, DWRB 137 x RD 2052, RD 103 x RD 2035, DWRB 137 x RD 2035 and RD 2052 x RD 2508 showed desirable heterosis and heterobeltiosis for one or more characters in both the environments. Hence, progeny of these crosses may have potential for high grain yield and progeny of heterotic crosses may provide transgressive segregants. Likewise, the degree of heterosis is essential for deciding the direction of future breeding program. An overall evaluation showed that the parent RD 2508, RD 2052 and PL 419 emerged as good general combiners while among the cross DWRB 137 x PL 419(Normal and limited moisture), PL 419 x RD 103 and RD 103 x RD 2508 (Normal irrigated) emerged as good crosses for grain yield per spike as well as for other yield contributing characters. It is 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.

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