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Heterosis for grain yield and associated traits in barley (*Hordeum vulgare* L.) genotypes under limited moisture condition of Rajasthan

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Abstract
Heterosis for grain yield and its contributing traits was studied in 10 x 10 half diallel set of ten diverse barley genotypes under limited moisture condition. The analysis of variance showed significant mean squares due to genotypes, parents, generations, F_1, F_2, F_1 vs F_2 progenies and parents vs generations for all the studied characters indicating the sufficient amount of genetic variability present in experimental material. Highly positive and significant heterosis over mid and better parent for grain yield per plant and its contributing traits suggested that there is abundant scope for exploiting heterosis commercially and possibility of isolating desirable segregants. Heterosis ranged between 3.51 (DWRUB 64 x RD 103) to 81.83 (DWRB 137 x RD 2508) for grain yield per plant. Out of 45 crosses, twenty three crosses exhibited positive significant heterosis and heterobeltiosis for grain yield per plant. Among these crosses, cross DWRB 137 x RD 2508, DWRB 137 x RD 2052 and PL 426 x RD 2052 for heterosis; and PL 419 x RD 2052, PL 419 x RD 2508 and PL 426 x RD 2035 for heterobeltiosis were found to be the most promising combinations for grain yield and associated traits like plant height, flag leaf area, 1000-grain weight and harvest index in drought stress environment hence that cross may be exploited in further plant breeding programme or identification of transgressive sergeants from the advanced generation.

Keywords: barley, drought, diallel, heterosis, heterobeltiosis

Introduction
Barley (*Hordeum vulgare* L.) is a self-pollinated valuable cereal crop having chromosome number 2n=2x=14 and a member of grass family (poaceae). It is grown in tropical and temperate climate globally, over a wide range of environment because of its broad ecological adaptation, low input requirement and better adaptability to harsh conditions, i.e. drought, salinity, alkalinity and marginal lands. That is why it has been traditionally considered as poor man's crop throughout the world especially for those people who are dependent on subsistence farming.
Barley can be utilized as animal feed (60%), for malt production (30%), seed production (7%) and for human food (3%) (Baik and Ullrich 2008). The main use of barley grain is as feed for poultry, swine, sheep and cattle. The particular barley varieties used as animal feed are sometimes developed "feed barleys" with attributes such as more protein content that are geared specifically toward this end use. By-products of the brewing process and malt sprouts are also used as livestock feed.
It is considered as the world's fourth most important cereal crop in production after wheat, maize and rice. It is an important winter cereal crop grown in the northern plains of India covering the states of Rajasthan, Uttar Pradesh, Bihar, Haryana, Punjab, Madhya Pradesh, Himachal Pradesh and Uttarakhand that makes about 80% area of total acreage under barley cultivation in India (Madakemohekar *et al.*, 2015) [10]. In India, it is grown over an area of 6.18 lakh hectares and total production of 16.33 lakh tonns with an average grain productivity of 2573 kg per hectare (Anonymous 2019-20) [2]. Whereas in Rajasthan, it is an important *rabi* cereal crop after wheat in both area and production. It is grown over an area of 2.88 lakh hectares and a total production of 8.31 lakh tonns with an average grain productivity of 2884 kg per hectare (Anonymous 2019-20) [2].
It is realized that grain yield plateau have been reached and further needs to increase in yield through the use of systematic breeding approach in desirable directions. The study of heterosis has a direct bearing on the breeding methodology to be applied for varietal improvement and

also provides useful genetic information about usefulness of the parents in breeding programs (Singh *et al.,* 2012). The study of heterosis helps the breeder to select the more productive crosses in early generations. Heterosis in mostly crops including barley is an important tool in interpreting genetic parameters. The nature and magnitude of heterosis could play a vital role for plant breeders in formulating the appropriate breeding procedures.

Drought occurs in all climatic regions and 16.2–41.2% of arable land worldwide considered as drought-prone area (Wang *et al.*, 2014; Kebede *et al*., 2019) [23, 8]. It has been forecasted that presently the drought severity and frequency will increase in dry regions due to climate change (IPCC, 2014) [7]. It has been reported that drought stress could reduce grain yield by 49–87% in barley (Samarah, 2005; Samarah *et al.*, 2009) [17, 18]. Thus, it's production can be enhanced either by increasing cultivated area or by yield per unit area. 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. The objectives of this investigation were to determine the magnitude of the heterosis over mid (average heterosis) and better parents (heterobeltiosis) for grain yield and associated traits in crosses obtained from barley genotypes.

Material 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 F1's 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 F1's and 45 F2'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 maturity, plant height, number of effective tillers per plant, flag leaf area, 1000-grain weight, grain yield per plant and harvest index.. 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) [6] 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.

Result and Discussion

The analysis of variance showed significant mean squares due to genotypes, parents and generations for all the studied characters. Similarly F_1 and F_2 generations also showed significant differences for all the studied characters. The occurrence of inbreeding depression was supported by the significance of F_1 vs F_2 for all the studied characters. Mean squares due to F_1 vs F_2 were found significant for all the studied characters. Similarly, the difference among the parents vs generations were significant for all the studied traits. This significant difference between parents vs generations showed the presence of heterosis.

The commercial exploitation of heterosis in crop plant is observed as major breakthrough in the realm of plant breeding. It is a phenomenon of vast practical importance, as its utilization has led to significant yield improvement in several crop plants. The main aim of heterosis in the present investigation was to search out the best combination of parents giving high degree of heterosis and its exploitation to get better transgressive segregants.

The degree of heterosis varied from cross to cross for all the studied characters. High heterosis in certain crosses and low in others shown that nature of gene action varied with the genetic makeup of the individual parents. In the present study, the crosses exhibited obvious heterotic response over mid-parental values for different characters. Though, the measure of relative heterosis is relatively less important than heterobeltiosis and hence, it is better to measure the heterosis in terms of superiority over the better parent rather than mid-parent.

In this study, maximum range of heterosis has been estimated for all the studied characters. An overall appraisal of the investigation shown that heterosis ranged from -12.29 to 13.41 for days to maturity; -24.88 to 23.77 for plant height; -14.38 to 36.60 for number of effective tillers per plant; -24.49 to 47.78 for flag leaf area; -9.86 to 24.65 for 1000-grain weight; 3.51 to 81.83 for grain yield per plant and -8.35 to 45.35 for harvest index. The result for different characters are conformity with the findings obtained by several research such as Daya *et al.* (2009) [5], Abd El-Aty *et al.* (2011) [1], Vishwakarma *et al.* (2011) [22], Shendy (2015) [20], Mansour (2016) [11], Pesarkhlu *et al.* (2016) [13], Ram and Shekhawat (2017c) [15], Lal *et al.* (2018b) [9], Parashar *et al.* (2018) [12] and Bouchetat *et al.* (2020) [4].

A good number of crosses had significant desired heterosis and heterobeltiosis for grain yield and its contributing characters. For days to maturity, seventeen crosses namely BH 946 x RD 2592, BH 946 x RD 2052, RD 2592 x RD 2508, RD 2592 x RD 2052, PL 419 x RD 2052, PL 419 x RD 2508, RD 103 x RD 2508, RD 2052 x RD 2508, RD 2035 x RD 2508, BH 946 x PL 419, BH 946 x PL 426, BH 946 x RD 2508, RD 2592 x PL 426, RD 2592 x PL 419, DWRB 137 x PL 426, PL 426 x RD 103 and PL 426 x RD 2508 revealed negative significant heterosis and heterobeltiosis. Therefore, these crosses were considered the most desirable for days to maturity. For plant height, twenty seven crosses namely PL 419 x RD 2508, RD 2592 x DWRB 137, RD 2052 x RD 2508, RD 2592 x RD 2508, PL 419 x RD 103, BH 946 x RD 2592, BH 946 x PL 426, BH 946 x PL 419, BH 946 x RD 2508, RD 2592 x PL 426, RD 2592 x PL 419, RD 2592 x RD 2052, DWRUB 64 x RD 103, DWRUB 64 x RD 2508, DWRB 137 x PL 426, DWRB 137 x RD 103, DWRB 137 x RD 2035, DWRB 137 x RD 2052, DWRB 137 x RD 2508, PL 426 x PL 419, PL 426 x RD 103, PL 419 x RD 2035, PL 419 x RD 2052, RD 103 x RD 2035, RD 103 x RD 2508, RD 2035 x RD 2052 and RD 2035 x RD 2508 revealed negative significant heterosis and heterobeltiosis. Therefore, these crosses were considered the most desirable for plant height.

For number of effective tillers per plant, twenty one crosses namely DWRUB 64 x RD 2508, BH 946 x RD 2508, PL 426 x RD 2508, RD 2592 x RD 2562, PL 419 x RD 2508, BH 946 x RD 2052, PL 419 x RD 2052, RD 2052 x RD 2508, RD 2592 x PL 419, BH 946 x RD 2592, BH 946 x PL 426, BH 946 x PL 419, RD 2592 x RD 103, RD 2592 x RD 2052, DWRUB 64 x PL 419, DWRUB 64 x RD 2035, DWRUB 64 x RD 2052, DWRB 137 x RD 2052, DWRB 137 x RD 2508, PL 426 x PL 419 and PL 426 x RD 2052 revealed positive significant heterosis and heterobeltiosis. Therefore, these crosses were considered the most desirable for number of effective tillers per plant. For flag leaf area, fifteen crosses namely RD 2052 x RD 2508, RD 2592 x RD 2052, DWRB 137 x RD 2052, DWRUB 64 x RD 2052, PL 419 x RD 2052, RD 103 x RD 2035, RD 2592 x RD 2508, RD 2035 x RD 2508, PL 419 x RD 103, DWRUB 64 x PL 419, RD 2592 x PL 419, DWRUB 64 x RD 2508, DWRB 137 x RD 2508, PL 419 x RD 2508 and RD 103 x RD 2508 revealed positive significant heterosis and heterobeltiosis. Therefore, these crosses were considered the most desirable for flag leaf area.

For 1000-grain weight, twenty one crosses namely DWRB 137 x RD 2508, BH 946 x RD 2508, PL 426 x RD 2508, RD 2592 x RD 2508, PL 419 x RD 2508, BH 946 x RD 2052, RD 2592 x RD 2052, RD 2592 x PL 419, BH 946 x RD 2592, DWRB 137 x RD 2508, PL 419 x RD 2052, RD 2052 x RD 2508, PL 426 x RD 2052, PL 426 x PL 419, DWRB 137 x RD 2052, DWRUB 64 x RD 2052, DWRUB 64 x RD 2035, BH 946 x PL 419, RD 2592 x RD 103, DWRUB 64 x PL 419 and BH 946 X PL 426 revealed positive significant heterosis and heterobeltiosis. Therefore, these crosses were considered the most desirable for 1000-grain weight. For grain yield per plant, twenty three crosses namely DWRB 137 x RD 2508, DWRB 137 x RD 2052, PL 426 x RD 2052, DWRUB 64 x PL 419, PL 426 x RD 2035, PL 419 x RD 103, RD 103 x RD 2508, PL 419 x RD 2052, PL 419 X RD 2508, RD 2035 x RD 2508, RD 2592 x PL 419, BH 946 x PL 419, RD 2052 x RD 2508, PL 426 x RD 103, DWRUB 64 x RD 2508, DWRUB 64 x RD 2052, DWRB 137 x PL 426, RD 2592 x RD 2052, RD 2592 x RD 2508, RD 2592 x RD 2035, BH 946 x RD 2508, BH 946 x RD 2052 and BH 946 x RD 2592 revealed positive significant heterosis and heterobeltiosis. Therefore, these crosses were considered the most desirable for grain yield per plant.

For harvest index, twenty four crosses namely DWRB 137 x RD 2508, DWRB 137 x RD 2052, DWRB 137 x PL 419, PL 426 x RD 103, RD 103 x RD 2508, PL 426 x RD 2035, DWRUB 64 x RD 2052, DWRB 137 x PL 426, DWRB 137 x RD 103, DWRUB 64 x PL 419, RD 2592 x PL 419, BH 946 x RD 2052, BH 946 x RD 2508, BH 946 x RD 103, DWRUB 64 x RD 2508, PL 419 x RD 2508, PL 419 x RD 2052, PL 426 x RD 103, RD 2035 x RD 2508, BH 946 x RD 2592, BH 946 x PL 419, RD 2592 x RD 2052, RD 2592 x RD 2508 and RD 2052 x RD 2508 revealed positive significant heterosis and heterobeltiosis. Therefore, these crosses were considered the most desirable for harvest index.

An overall appraisal of table 2 revealed that the twenty three crosses found heterotic and heterobeltiotic for grain yield per plant, also exhibited desirable heterosis or heterobeltiosis for other yield related characters.

The table 3 shows a significant relation between heterosis and heterobeltiosis for grain yield and its contributing characters i.e. crosses which exhibited desirable heterosis and heterobeltiosis for grain yield have shown desirable heterosis and heterobeltiosis for at least three or more yield contributing characters. For instance plant height, flag leaf area, 1000-grain weight and harvest index mainly contributed to heterosis and heterobeltiosis for grain yield per plant. Though, the crosses exhibiting heterotic expressions for grain yield per plant were not heterotic for all the characters. It was also observed that the expression of heterosis and heterobeltiosis was influenced by the environment for most of the traits due to significant G x E interactions. These results are in accordance with earlier reports of Sharma *et al.* (2002), Daya *et al.* (2009) [5], Abd El-Aty *et al.* (2011) [1], Vishwakarma *et al.* (2011) [22], Potla *et al.* (2013) [14], Saad *et al.* (2013) [16], Shendy (2015) [20], Mansour (2016) [11], Ram and Shekhawat (2017) [15], Lal *et al.* (2018) [9], Parashar *et al.* (2018) [12] and Bouchetat *et al.* (2020) [4].

The cross DWRB 137 x RD 2508, DWRB 137 x RD 2052 and PL 426 x RD 2052 for heterosis; and PL 419 x RD 2052, PL 419 x RD 2508 and PL 426 x RD 2035 for heterobeltiosis were found to be the most promising combinations for grain yield and also exhibited desirable heterosis and/or heterobeltiosis for most of the yield related traits in drought stress environment, hence these six crosses can be further used in further plant breeding programme.

Table 1: Crosses showing significant heterosis and heterobeltiosis for grain yield and associated traits.

S. No.	Crosses	Grain yield per plant		Days to maturity		Plant height		Number of effective tillers per plant	
		H	HB	H	HB	H	HB	H	HB
1	BH 946 × RD 2592	37.35**	25.31**	-12.29**	-11.78**	-9.61**	-13.78**	19.39**	18.78**
2	BH 946 × PL 419	41.31**	36.27**	-8.28**	-5.49**	-7.93**	-11.20**	6.99	1.02
3	BH 946 × RD 2052	38.48**	36.42**	-12.05**	-11.14**	12.49**	8.69**	30.61**	29.95*
4	BH 946 × RD 2508	39.17**	30.25**	-4.73	-4.60**	-14.64**	-21.95**	24.39**	19.72**
5	RD 2592 × PL 419	41.59**	33.65**	-10.00**	-6.71**	-16.31**	-17.26**	25.41**	18.97**
6	RD 2592 ×RD 2035	34.65**	12.26*	0.86	1.73	6.08*	-0.34	3.05	2.01
7	RD 2592 × RD 2052	38.22**	27.84**	-9.38**	-7.92**	-10.01**	-11.21**	30.77**	30.77**
8	RD 2592 × RD 2508	26.70**	23.27**	-9.56**	-9.17**	-20.00**	-23.48**	27.45**	22.07**
9	DWRUB 64 × PL 419	46.39**	28.93**	5.33**	8.39**	4.26	-0.64	-6.06	-15.84**
10	DWRUB 64 × RD 2052	45.41**	25.70**	-3.53**	1.29	-1.03	-5.85*	-7.21	-12.67*
11	DWRUB 64 × RD 2508	51.00**	36.74**	-2.88*	3.23*	-7.29**	-8.00**	0.92	-0.90
12	DWRB 137 × PL 426	38.00**	26.43*	-6.98**	-5.04**	-14.46**	-15.69**	22.49**	2.99
13	DWRB 137 × RD 2052	68.98**	19.34**	-1.18	-0.59	-6.15**	-10.20**	1.52	0.00
14	DWRB 137 × RD 2508	81.83**	32.65**	2.62*	4.45**	-14.39**	-15.56**	-2.90	-5.63
15	PL 426 × RD 103	37.59**	24.22**	-4.60**	-2.56*	-13.07**	-16.20**	-14.38*	-25.14**
16	PL 426 × RD 2035	46.81**	37.54**	3.01**	3.76**	0.78	-9.24**	-12.50	-26.13**
17	PL 426 × RD 2052	50.01**	12.18*	4.34**	5.87**	12.24**	5.91*	5.42	-10.26
18	PL 419 × RD 103	46.50**	20.33**	-6.05**	-0.61	-18.04**	-25.14**	27.93**	25.14**

19	PL 419 × RD 2052	45.13**	42.01**	-9.12**	-7.32**	-12.04**	-12.21**	30.27**	23.59**
20	PL 419 × RD 2508	44.19**	39.78**	-9.01**	-6.10**	-24.88**	-28.93**	36.60**	24.41**
21	RD 103 × RD 2508	46.15**	23.10**	-8.53**	-6.30**	-7.13**	-10.53**	16.67**	8.45
22	RD 2035 × RD 2508	42.83**	16.50**	-8.20**	-7.80**	-7.70**	-16.82**	27.67**	23.47**
23	RD 2052 × RD 2508	35.36**	28.49**	-8.41**	-7.33**	-21.21**	-25.60**	29.41**	23.94**

S. No.	Crosses	Flag leaf area		1000-grain weight		Harvest index	
		H	HB	H	HB	H	HB
1	BH 946 × RD 2592	13.65**	5.25	15.46**	9.07**	12.92**	7.20*
2	BH 946 × PL 419	9.21	-0.61	9.49**	8.88**	16.48**	11.71**
3	BH 946 × RD 2052	33.81**	4.58	17.50**	12.00**	14.87**	11.59**
4	BH 946 × RD 2508	17.80**	5.39	23.19**	10.96**	13.50**	10.02**
5	RD 2592 × PL 419	21.60**	19.32*	16.86**	9.81**	16.61**	15.37**
6	RD 2592 ×RD 2035	21.88**	6.61	2.80	-4.30	17.91**	4.85
7	RD 2592 × RD 2052	47.34**	22.34**	16.53**	15.43**	14.67**	11.98**
8	RD 2592 × RD 2508	34.05**	29.10**	20.29**	14.35**	10.18**	7.84*
9	DWRUB 64 × PL 419	18.17**	17.85*	7.66**	5.07*	19.89**	12.54**
10	DWRUB 64 × RD 2052	42.39**	20.34*	7.04**	5.52*	20.55**	11.78**
11	DWRUB 64 × RD 2508	24.91**	22.89**	24.65**	9.34**	29.27**	20.11**
12	DWRB 137 × PL 426	-7.72	-15.47*	7.91**	0.54	22.31**	13.51**
13	DWRB 137 × RD 2052	42.69**	26.15**	7.84**	7.61**	35.26**	7.26*
14	DWRB 137 × RD 2508	20.60**	16.30*	15.81**	9.32**	45.35**	15.44**
15	PL 426 × RD 103	6.96	-1.89	-9.32**	-12.03**	26.03**	7.31*
16	PL 426 × RD 2035	1.35	-12.95	4.28*	3.62	21.94**	17.21**
17	PL 426 × RD 2052	23.92**	1.56	13.51**	5.97*	17.44**	-1.09
18	PL 419 × RD 103	22.17**	15.84**	1.04	-0.37	22.99**	4.89
19	PL 419 × RD 2052	41.58**	19.39*	15.43**	9.44**	12.16**	10.69**
20	PL 419 × RD 2508	22.78**	20.46**	19.81**	7.38**	12.73**	11.50**
21	RD 103 × RD 2508	25.19**	20.90*	15.25**	4.62	27.33**	7.61*
22	RD 2035 × RD 2508	31.48**	18.41*	11.03**	-1.37	22.77**	7.13*
23	RD 2052 × RD 2508	47.78**	26.60**	12.67**	6.15*	8.83**	8.59**

Table 2: Top three promising hybrids for their heterosis and heterobeltiosis for seed yield and associated traits

Characters	Days to maturity	Plant height	Number of effective tillers per plant	Flag leaf area
Heterotic crosses	BH 946 x RD 2592	PL 419 x RD 2508	PL 419 x RD 2508	RD 2052 x RD 2508
	BH 946 x RD 2052	RD 2592 x DWRB 137	RD 2592 x RD 2052	RD 2592 x RD 2052
	RD 2592 x RD 2508	RD 2052 x RD 2508	BH 946 x RD 2052	DWRB 137 x RD 2052
Heterobeltiotic crosses	BH 946 x RD 2592	PL 419 x RD 2508	RD 2592 x RD 2052	RD 2592 x RD 2508
	BH 946 x RD 2052	RD 2052 x RD 2508	BH 946 x RD 2052	RD 2052 x RD 2508
	RD 2592 x RD 2508	PL 419 x RD 103	PL 419 x RD 103	DWRB 137 x RD 2052

Characters	1000-grain weight	Grain yield per plant	Harvest index
Heterotic crosses	DWRUB 64 x RD 2508	DWRB 137 x RD 2508	DWRB 137 x RD 2508
	BH 946 x RD 2508	DWRB 137 x RD 2052	DWRB 137 x RD 2052
	PL 426 x RD 2508	PL 426 x RD 2052	DWRB 137 x PL 419
Heterobeltiotic crosses	RD 2592 x RD 2052	PL 419 x RD 2052	PL 426 x RD 103
	RD 2592 x RD 2508	PL 419 x RD 2508	DWRUB 64 x RD 2508
	BH 946 x RD 2052	PL 426 x RD 2035	PL 426 x RD 2035

Conclusion

The cross DWRB 137 x RD 2508, DWRB 137 x RD 2052 and PL 426 x RD 2052 for heterosis; and PL 419 x RD 2052, PL 419 x RD 2508 and PL 426 x RD 2035 for heterobeltiosis were found to be the most promising combinations for grain yield and associated traits like plant height, flag leaf area, 1000-grain weight and harvest index in drought stress environment hence that cross may be exploited in further plant breeding programme or identification of transgressive sergeants from the advanced generation.

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