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Heterosis investigation in six rowed barley (*Hordeum vulgare* L.)

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Abstract
The present investigation carried out by the assess the heterosis for grain yield and its contributing characters under three different environmental conditions using eight diverse barley parents along with their 28 F_1. Heterosis for grain yield per plant range from -11.48 per cent to 18.93 per cent in E_1, -8.38 per cent to 14.91 per cent in E_2 and -18.13 per cent to 18.5 per cent in E_3. Seven crosses in E_1, eleven crosses in E_2 and E_3 each exhibited positive significant heterosis while four crosses in E_1, six crosses in E_2 and nine in E_3 exhibited positive significant heterobeltiosis. The crosses BH902 × RD2904, BH902 × DWR143 (except E_1 both heterosis and HB), RD2904 × RD2909 (except E_1 and E_2 in HB), and DWR143 × DWR137 (except HB in E_1 and E_2) in all the environments exhibited positive significant heterosis. Hence, these crosses were considered to be most desirable for grain yield per plant. The heterosis over better parent varied from -15.92 (RD2909 x HUB242) to 11.54 (BH902 x DWR143) in E_1, -12.83 (UPB1059 x DWR137) to 10.43 (BH902 x RD2904) in E_2 and -21.13 (RD2909 x BH959) to 17.97 (HUB242 x BH959) in E_3, respectively. For heterotic effects of grain yield, four hybrids in E_1, six hybrids in E_2, nine hybrids in E_3 and four crosses in pooled analysis gave high amount of heterotic effects.

Keywords: Heterosis, heterobeltiosis, six rowed barley, grain yield

1. Introduction
Barley (*Hordeum vulgare* L. 2n =2x = 14) is the worlds' fourth most important cereal crop after wheat, maize and rice. 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). The major use of barley grains is in the production of malt, which is used in breweries to make beer industrial alcohol, whisky, malt syrups, malted milk and vinegar. The spend malt after brewing is used as a feed. Barley is believed to have cooling effect on human system and in several regions it is preferred over wheat and other cereals particularly during summer.

2. Material and Methods
Crosses among the eight genotypes were made in diallel fashion excluding reciprocals, during *Rabi* season 2015-16. A number of plant were randomly selected in the parent crossed with a number of selected plants from other plants. In *Rabi 2016-07* eight genotype along with their 28 F_1's progenies were evaluated in three environments created three date of sowing 15 Nov.(normal sown), 30 Dec. (late sown) and 15 Dec. (very late sown) with three replications at Rajasthan Agricultural Research Institute, Durgapura, Jaipur row length was grown in row (4m length) plot with row to row distance of 30 cm and plant to plant distance 10cm. Heterosis and heterobeltiosis parameters for grain yield and its contributing characters were workout as per procedure suggested by Fonseca and Patterson (1968).

3. Results and Discussion
Barley is a self-pollinated crop and an appropriate procedure of hybrid seed production at commercial scale is not yet available. Consequently, the heterosis *per se* may not be economic value at present. Nevertheless, knowledge of degree and magnitude of heterosis is imperative for deciding the direction of future breeding programme and to select the promising crosses to obtain better segregates in advance generations for further amelioration of grain yield. Heterosis for grain yield per plant range from -11.48 per cent to 18.93 per cent in E_1, -8.38 per cent to 14.91 per cent in E_2 and -18.13 per cent to 18.5 per cent in E_3. Seven crosses in E_1, eleven crosses in E_2 and E_3 each exhibited positive significant heterosis while four crosses in E_1, six crosses in E_2 and nine in E_3 exhibited positive significant heterobeltiosis.

The crosses BH902 × RD2904, BH902 × DWR143 (except E_1 both heterosis and HB), RD2904 × RD2909 (except E_1 and E_2 in HB), and DWR143 × DWR137 (except HB in E_1 and E_2) in all the environments exhibited positive significant heterosis.

In present experiment, the maximum range of heterosis has been estimated for all the characters. An overall appraisal of the recorded that range of heterosis for days to 50% flowering from -10.06 per cent to 10.12 per cent in E_1, -9.09 per cent to 9.63 per cent in E_2 and -7.44 per cent to 10.35 per cent in E_3; for days to maturity from -5.39 per cent to 8.55 per cent in E_1, -7.29 per cent to 6.87 per cent in E_2 and -7.39 per cent to 7.22 per cent in E_3; for plant height from -18.22 per cent to 21.83 per cent in E_1, -18.78 per cent to 14.79 per cent in E_2 and -12.95 per cent to 9.17 per cent in E_3; for number of effective tiller per plant from -28.03 per cent to 35.64 per cent in E_1, -30.93 per cent to 17.23 per cent in E_2 and -23.78 per cent to 34.27 per cent in E_3; for flag leaf area from -23.47 per cent to 29.31 per cent in E_1, -15.86 per cent to 27.83 per cent in E_2 and -27.83 per cent to 22.2 per cent in E_3; for peduncle area from -36.86 per cent to 25.68 per cent in E_1, -6.6 per cent to 25.54 per cent in E_2 and -22.04 per cent to 32.05 per cent in E_3; spike length from -8.55 per cent to 14.43 per cent in E_1, -4.99 per cent to 9.76 per cent in E_2 and -15.23 per cent to 11.94 per cent in E_3; for number of spikelet's per plant from -13.58 per cent to 21.22 per cent in E_1, -13.56 per cent to 14.03 per cent in E_2 and -14.21 per cent to 14.86 per cent in E_3; for number of grains per spike from -10.07 per cent to 17.35 per cent in E_1, -12.9 per cent to 12.4 per cent in E_2 and -12.47 per cent to 14.85 per cent in E_3; for 1000-grain weight from -9.79 per cent to 14.08 per cent in E_1, -11.01 per cent to 12.05 per cent in E_2 and -15.12 per cent to 16.03 per cent in E_3; for harvest index from -16.26 per cent to 10.38 per cent in E_1, -9.02 per cent to 11.78 per cent in E_2 and -9.37 per cent to 15.75 per cent in E_3 and for grain yield per plant from -11.48 per cent to 18.93 per cent in E_1, -8.38 per cent to 14.91 per cent in E_2 and -18.13 per cent to 18.5 per cent in E_3. The results in varying environments for different characters are in conformity with the findings of Subhani *et al.* (2000) [22], Rasul *et al.* (2002) [17], Singh *et al.* (2003) [9], Joshi *et al.* (2003.b) [9], Singh *et al.* (2004) [20] Chhagan *et al.* (2018) and Kajla *et al.* (2020) [10].

Three best heterotic and heterobeltiosis crosses for grain yield per plant are presented. The crosses RD2904×RD2909 and RD2904 × DWR143 showed desirable heterosis and heterobeltiosis. Hence, these crosses may be considered as promising type for tangible advancement of barley yield under normal sown and thermal stress condition Vishwakarma *et al* (2011) [24], Bornara *et al*. (2013) [6], Chhagan *et al.* (2018) and Kajla *et al.* (2020) [10].

Best three crosses based on heterosis and heterobeltiosis for different characters' traits under different environments are presented in Table 1. In present study, heterosis over mid parent and better parent has been estimated in order to explore the possibility of using in the production of hybrids. The expression of heterosis and heterobeltiosis, in general, was variable for different traits under all the environments. Perusal of revealed that heterotic expression was fairly high and desirable for grain yield per plant (18.93 per cent in E_1), number of effective tillers per plant (35.64 per cent in E_1), flag leaf area (29.31 per cent in E_1), peduncle length (32.05 per cent in E_3), number of spikelet's per spike (21.22 per cent in E_1), harvest index (16.26 per cent in E_1), number of grains per spike (17.35 in E_1), spike length (14.43 per cent in E_1), and 1000-seed weight (16.03 per cent in E_3). Similarly, magnitude of heterobeltiosis was fairly high and desirable for grain yield per plant (18.22per cent in E_1), number of effective tillers per plant (35.04 per cent in E_1), peduncle length (19.09 per cent in E_3), number of spikelet's per spike (18.99 per cent in E_1),number of grains per spike (15.67 per cent in E_1), flag leaf area (21.46 per cent in E_2), harvest index (14.04 per cent in E_3), spike length (12.32 per cent in E_1) and 1000-seed weight (13.58 per cent in E_3). The results are in agreement with those of others obtained in varying environments for different characters Afiah *et al.* (2000) [1], Rasul *et al.* (2002) [17], Singh and Singh (2003) [9], Singh *et al.* (2004) [20], Akbar *et al*. (2010) [2], Kumar and Maloo (2011) [11], Beche *et al.* (2013) [5], Bornara *et al*. (2013) [6], Kumar *et al.* (2014) and Saren (2018) [18] also reported maximum heterosis for grain yield per plant.

Three best heterotic and heterobeltiotic crosses for grain yield per plant along with their SCA effects and *per se* performance in different environments are presented in Table 2. Perusal of this table indicated that the crosses RD2904 x DWR143 in all three environments, BH902 x DWR143 in E_1 and H4B242 x BH959 in E_2 as good heterotic as well as heterobeltiotic crosses for grain yield per plant showed desirable heterosis and heterobeltiosis for one or more characters in all the environments.

Sufficient degree of heterosis and heterobeltiosis was observed for all the attributes. The crosses RD2904 × RD2909 and RD2904 × DWR143 showed desirable heterosis and heterobeltiosis for harvest index and days to 50% flowering had one or more characters in all the environments and found as heterotic as well as heterobeltiotic crosses for grain yield per plant. These crosses were considered promising for their use for yield improvement in barley. Heterosis and heterobeltiosis were observed for all the traits.

Out of 28 crosses studied the cross combinations RD2904 x DWR143, BH902 x DWR143 in E_1 found good crosses for grain yield per plant and also had significant SCA effects and heterotic effect in desirable direction for yield and most of the associated traits. All these crosses offer good opportunity for developing these as promising varieties.

Table 1: Best three crosses based on heterosis and heterobeltiosis for different traits under different environments

Characters	Envs.	Heterotic crosses	Heterosis	Heterobeltiosis crosses	Hetero beltiosis
1. Days to heading	E_1	1. BH902 x DWR137	-10.06	1. BH902 x DWR137	-13.31
		2. DWR143 x DWR137	-9.05	2. BH902 x RD2909	-11.03
		3. RD2904 x DWR143	-6.65	3. RD2909 x DWR143	-9.1
	E_2	1. BH902 x DWR137	-9.09	1. BH902 x DWT137	-13.31
		2. RD2904 x DWR143	-7.41	2. BH902 x RD2909	-10.89
		3. RD2909 x DWR143	-6.99	3. RD2909 x DWR143	-8.84
	E_3	1. BH902 x DWR137	-7.44	1.BH902 x DWR137	-10.24
		2. RD2904 x DWR143	-7.2	2. BH902 x RD2909	-9.31

Characters	Envs.	Heterotic crosses	Heterosis	Heterobeltiosis crosses	Hetero beltiosis
		3. RD2909 x DWR137	-5.28	3. RD2904x DWR143	-8.78
2. days to maturity	E_1	1. BH902 x DWR137	-5.39	1. BH902 x DWR137	-7.21
		2. RD2904 x DWR137	-5.15	2. RD2904 x DWR137	-6.43
		3. RD2909 x DWR137	-4.38	3. RD2909 x DWR137	-6.16
	E_2	1. BH902 x DWR137	-7.29	1. BH902 x DWR137	-9.32
		2. RD2904 x DWR137	-6.15	2. RD2909 x DWR137	-8.30
		3. RD2909 x DWR137	-6.00	3. RD2904 x DWR137	-8.02
	E_3	1. BH902 x DWR137	-7.39	1. BH902 x DWR137	-10.19
		2. RD2909 x DWR137	-4.17	2. BH902 x UPB1059	-8.28
		3. RD2904 x DWR143	-4.15	3. RD2904 x DWR137	-6.44
3. Plant height	E_1	1. BH902 x DWR137	-18.92	1. BH902 x DWR137	-22.49
		2. DWR143 x DWR137	-16.02	2.DWR143 x DWR137	-17.33
		3. RD2904 x DWR137	-13.6	3. RD2904 x DWR137	-15.33
	E_2	1. BH902 x DWR137	-18.78	1. BH902 x DWR137	-23.08
		2. DWR143 x DWR137	-15.47	2. RD2909 x DWR137	-17.92
		3. RD2909 x DWR143	-15.08	3. RD2909 x DWR143	-17.69
	E_3	1. BH902 x DWR137	-12.95	1. BH902 x DWR137	-16.01
		2. RD2904 x DWR143	-10.97	2. RD2909 x DWR143	-13.72
		3. RD2909 x DWR143	-10.84	3. RD2904 x DWR143	-13.31
4. Effective tiller per plant	E_1	1. RD2904 x DWR143	35.64	1. RD2904 x DWR143	35.04
		2. RD2904 x RD2909	34.81	2. RD2904 x RD2909	32.29
		3. BH902 x RD2909	29.01	3. RD2909 x DWR143	23.45
	E_2	1. DWR143 x DWR137	17.27	1. RD2909 x DWR143	14.73
		2. BH902 x DWR137	15.85	2. RD2904 x DWR143	12.37
		3. RD2904 x DWR143	14.27	3. RD2904 x DWR137	9.61
	E_3	1. BH902 x DWR137	34.27	1. BH902 x DWR137	28.51
		2. HUB242 x BH959	31.22	2. HUB242 x BH959	16.45
		3. HUB242 x UPB1059	16.06	3. RD2909 x DWR137	7.27
5. Flag leaf area	E_1	1. RD2904 x HUB242	29.31	1. RD2904 x HUB242	19.59
		2. BH902 x RD2904	21.82	2. HUB242 x DWR143	11.51
		3. RD2909 x BH959	13.06	3. BH902 x BH959	11.33
	E_2	1. RD2904 x HUB242	27.83	1. RD2904 x HUB242	21.46
		2. HUB242 x DWR143	24.96	2. HUB242 x DWR143	17.94
		3. BH902 x RD2904	13.31	3. HUB242 x UPB1059	10.48
	E_3	1. BH902 x RD2904	22.20	1. BH902 x RD2904	17.65
		2. HUB242 x DWR143	15.56	2. RD2909 x DWR137	10.91
		3. HUB242 x DWR137	12.94	3. HUB242 x DWR143	10.49
6. Peduncle Length	E_1	1. DWR143 x DWR137	25.68	1. HUB242 x UPB1059	11.12
		2. RD2909 x HUB242	23.48	2. RD2909 x BH959	10.22
		3. RD2904 x HUB242	23.02	3. DWR143 x DWR137	9.20
	E_2	1. UPB1059 x DWR143	25.54	1. BH902 x HUB242	8.82
		2 DWR143 x DWR137	23.83	2. DWR143 x DWR137	8.41
		3. RD2909 x HUB242	22.83	3. BH902 x RD2904	7.76
	E_3	1. UPB1059 x DWR143	32.05	1. RD2909 x DWR137	19.09
		2. RD2909 x HUB242	25.12	2. BH902 x BH959	11.26
		3. DWR143 x DWR137	24.20	3. BH902 x HUB242	10.86
7. Spike length	E_1	1. RD2904 x RD2909	14.43	1. RD2909 x DWR137	12.32
		2. RD2909 x DWR137	13.49	2. RD2904 x RD2909	12.20
		3. RD2909 x DWR143	12.96	3. RD2904 x DWR143	11.42
	E_2	1. RD2909 x DWR137	9.76	1. RD2904 x DWR143	7.87
		2. RD2909 x DWR143	8.95	2. RD2904 x RD2909	6.73
		3. BH902 x UPB1059	8.54	3. BH902 x RD2909	4.70
	E_3	1. RD2904 x RD2909	11.94	1. RD2904 x RD2909	11.17
		2. DWR143 x DWR137	10.69	2. DWR143 x DWR137	8.89
		3. RD2904 x DWR143	10.23	3. UPB1059 x DWR143	3.83
8. Number of spikelet's per spike	E_1	1. RD2904 x DWR143	21.22	1. HUB242 x DWR137	16.93
		2. DWR143 x DWR137	16.20	2. RD2904 x DWR143	18.99
		3. BH902 x DWR143	14.34	3. DWR143 x DWR137	13.05
	E_2	1. BH902 x RD2904	14.03	1. BH902 x RD2904	11.52
		2. RD2909 x DWR143	9.49	2. RD2909 x DWR143	9.26
		3. DWR143 x DWR137	9.26	3. RD2904 x DWR143	8.83
	E_3	1. BH902 x DWR143	14.86	1. BH902 x DWR143	12.78
		2. DWR143 x DWR137	13.55	2. RD2909 x DWR143	10.51
		3. RD2909 x DWR143	10.96	3. DWR143 x DWR137	9.46
9. Number of grains perspike	E_1	1. DWR143 x DWR137	17.35	1. RD2904 x DWR143	15.67
		2. RD2909 x DWR143	14.96	2. DWR143 x DWR137	14.44

Characters	Envs.	Heterotic crosses	Heterosis	Heterobeltiosis crosses	Hetero beltiosis
		3. BH902 x DWR143	14.36	3. BH902 x DWR143	13.27
	E_2	1. RD2909 x DWR143	11.27	1. RD2904 x RD2909	11.26
		2. DWR143 x DWR137	9.26	2. RD2909 x DWR137	10.45
		3. BH902 x DWR137	8.96	3. BH902 x DWR143	8.48
	E_3	1. DWR143 x DWR137	14.85	1. DWR143 x DWR137	11.17
		2. BH902 x RD2909	1312	2. RD2904 x DWR143	10.88
		3. RD2904 x DWR143	12.37	3. RD2909 x DWR137	10.26
10. 1000-seed weight	E_1	1. DWR143 x DWR137	14.08	1. BH902 x DWR143	12.60
		2. BH902 x DWR143	13.25	2. DWR143 x DWR137	12.45
		3. RD2909 x DWR143	12.60	3. RD2909 x DWR137	10.46
	E_2	1. DWR143 x DWR137	12.05	1. BH902 x DWR137	10.51
		2. BH902 x DWR137	12.01	2. DWR143 x DWR137	10.34
		3. BH902 x DWR143	10.48	3. BH902 x DWR143	10.27
	E_3	1. DWR143 x DWR137	16.03	1. DWR143 x DWR137	13.58
		2. RD2904 x RD2909	12.05	2. RD2904 x RD2909	10.01
		3. BH902 x RD2904	10.79	3. RD2909 x DWR137	8.79
11.harvest index	E_1	1. RD2904 x DWR143	16.26	1. RD2904 x DWR143	13.33
		2. DWR143 x DWR137	14.77	2. DWR143 x DWR137	10.13
		3. RD2909 x DWR143	12.20	3. RD2904 x DWR137	9.98
	E_2	1. RD2909 x DWR143	11.78	1. RD2904 x BH959	10.46
		2. RD2904 x DWR143	11.11	2. RD2904 x HUB242	8.15
		3. RD2904 x RD2909	10.80	3. RD2904 x DWR137	7.30
	E_3	1. DWR143 x DWR137	15.75	1. RD2904 x RD2909	14.04
		2. RD2904 x RD2909	15.68	2. RD2904 x DWR143	8.72
		3. RD2904 x DWR143	15.41	3. RD2909 x DWR137	8.02
12. grain yield per plant	E_1	1. RD2904 x DWR143	18.93	1. RD2904 x DWR143	18.22
		2. BH902 x DWR143	12.59	2. BH902 x DWR143	11.54
		3. RD2904 x RD2909	10.77	3. BH902 x RD2904	9.30
	E_2	1. RD2904 x RD2909	15.79	1. BH902 x RD2904	10.43
		2. HUB242 x DWR137	8.62	2. BH902 x DWR143	9.32
		3. RD2904 x DWR143	14.46	3. RD2904 x DWR143	9.05
	E_3	1. HUB242 x BH959	18.50	1. HUB242 x BH959	17.97
		2. BH902 x DWR137	11.13	2. BH902 x RD2904	9.76
		3. RD2904 x DWR143	10.35	3. RD2904 x DWR143	8.95

Table 2: Best three heterotic and heterobeltiotic crosses for grain yield per plant along with their SCA effects and *per se* performance in different environments

Environments	Heterotic crosses	Heterosis	SCA effect	Per se performance (g)	Heterobeltiotic crosses	Heterobeltiosis	SCA effect	Per se performance (g)
E_1	1. RD2904 x DWR143	18.93	1.70**	18.16	1. RD2904 x DWR143	18.22	1.70**	18.77
	2. BH902 x DWR143	12.59	0.82**	16.88	2. BH902 x DWR143	11.54	0.82**	16.88
	3. RD2904 x RD2909	10.77	1.25**	13.72	3. BH902 x RD2904	9.30	0.75**	16.85
E_2	1. RD2904 x RD2909	15.79	1.30**	12.31	1. BH902 x RD2904	10.43	1.30**	15.04
	2. HUB242 x DWR137	8.62	0.52	14.94	2. BH902 x DWR143	9.32	0.52	15.88
	3. RD2904 x DWR143	14.46	0.85*	16.94	3. RD2904 x DWR143	9.05	0.85**	15.79
E_3	1. HUB242 x BH959	18.50	2.17**	11.88	1. HUB242 x BH959	19.97	2.17**	11.88
	2. BH902 x DWR137	11.13	1. 05**	13.53	2. BH902 x RD2904	9.76	0.99**	12.37
	3. RD2904 x DWR143	10.35	0.79**	12.75	3. RD2904 x DWR143	8.95	0.79**	12.61

The parents, who showed desirable heterosis and heterobeltiosis for grain yield per plant, also exhibited desirable heterosis and heterobeltiosis at least for one or more yield attributing traits. Such as, heterosis for grain yield per plant was mainly contributed by number of grains per spike and number of effective tillers per plant while heterobeltiosis by number of grains per spike and number of effective tillers per plant in all the three environments. Findings of this investigation supported the contentions of Grafius (1959) [9], 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 plant 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. The results are in harmony with Singh *et al.* (2004) [20], Kumar and Sharma (2005) [12], Hassan *et al.* (2007), Akbar *et al*. (2010) [2], Kumar and Maloo (2011) [11], Vishwakarma *et al* (2011) [24], Lal *et al.* (2013) [13] and Baloch *et al.* (2016) [4].

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