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STUDY OF HETEROSIS IN BARLEY (*HORDEUM VULGARE* L.) FOR GRAIN YIELD AND ITS COMPONENT CHARACTERS IN DIFFERENT ENVIRONMENTAL CONDITION

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ABSTRACT

The experiment was conducted on barley to estimate the magnitude and direction of heterosis in normal and heat stress environment condition for grain yield and its related characters. Eight genetically diverse parents were selected and crossed in diallel fashion excluding reciprocals in *rabi* 2021-22 at S.K.N. College of Agriculture, Jobner. Eight parents along with their 28 F_1's were evaluated for fifteen characters in two environments with three replications in a randomized block design during *rabi* 2022-23. Pooled analysis of variance revealed that significant differences existed between genotypes for all the characters under studied. Moreover, the mean sum of squares due to parents vs. F_1's displayed significant difference for all the studied characters except harvest index indicating that between parents and between hybrids difference was significant and average heterosis was there. Comparison across the environments revealed that the crosses RD-2035 x RD-2794, RD-2035 x RD-2899, RD-2052 x RD-2624, RD-2052 x RD-2660, RD-2624 x RD-2715 and RD-2624 x RD-2899 showed significant positive heterosis and heterobeltiosis, hence these crosses were considered to be most desirable for improvement of grain yield in both environments. Therefore, the crosses which showed positive significant heterosis and heterobeltiosis under specific environment may be considered suitable material for environment specific breeding.

Key words : Barley, Environments, Heat Stress, Heterobeltiosis, Heterosis.

Introduction

Barley (*Hordeum vulgare* L.) is a self-pollinated, annual, winter season diploid valuable cereal crop having chromosome number 2n=2x=14 and a member of grass family Poaceae. It possesses a large genome size of 5.1 gigabase pairs (Gbp). It is originated from the near east and Ethiopian high lands, but now grown throughout the temperate and tropical regions of the world over a wide range of environments because of its broad ecological adaptation, low input requirement and better adaptability to harsh conditions such as drought, salinity, alkalinity and marginal lands (Yadav *et al.*, 2021). 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). It is an important food grain crop and stands at fourth position next to wheat, rice and maize in India and the top most barley producing nations are Russia, Germany, France and Ukraine (Shaveta *et al.*, 2019). In India, it is mainly grown in Rajasthan, Uttar Pradesh, Bihar, Haryana, Punjab, Madhya Pradesh, Himachal Pradesh and Uttarakhand states and covering a total area of about 6.17 lakh hectares and total production of 16.88 lakh tonnes with an average grain productivity of 2733 kg per hectare (Anonymous, 2022-23). Crop yield is determined by genotypes, management, environment and their interaction. Heat stress is an important abiotic stress causing negative impact on crop productivity worldwide and has terrible consequences on food security. Heat tolerance is a complex polygenic trait involving epistatic interactions among loci and powerful genotype × environment interactions (Abou-Elwafa and Amein, 2016). The different growth and developmental stages of the plants differ in their sensitivity to heat stress. For example, in barley, the period of spike initiation to flowering is very sensitive to high temperature stress and acceleration of this phase seems to be the main cause of yield reduction under hot condition. Each crop species has an optimum range of temperature for its normal growth and development and different stages of growth have different optima such as 20-25°C for germination, 16-20°C for tillering and 20-23°C for grain formation in case of barley. When temperature moves beyond this optimal range, it generates temperature stress, *i.e.* temperature interferes with the performance (Hemming *et al*., 2012). Present study is confined to estimation of heterosis in normal and heat stress condition, which means the adverse effects on the plants of temperature higher than the optimal range. It is a *rabi* season crop and its cultivation is limited by temperature at both the ends of the cropping season: early planting exposes the crop to heat stress during its vegetative phase and late planting is exposed to heat stress at post anthesis. The study of heterosis helps the plant breeder in eliminating the less productive crosses in early generations (Lal *et al*., 2018a). Heterosis in most of the 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.

Materials and Methods

The research was conducted on barley to estimate the magnitude and direction of heterosis and heterobeltiosis in normal and heat stress environment condition for grain yield and its related characters. Eight genetically diverse parents namely; RD-2035, RD-2052, RD-2624, RD-2660, RD-2715, RD-2794, RD-2899 and RD-2907 were selected and crossed in diallel fashion excluding reciprocals in *rabi* 2021-22 at Instructional Farm, Sri Karan Narendra College of Agriculture, Jobner (Rajasthan), India. Jobner is situated at 435 meters above mean sea level on latitude 26^0 50’ N and 75^0 20’ E. This site having sandy loam soils and the average rainfall is about 400 mm. The climate of this zone is typically semi-arid, which is characterized by extreme of the temperature in both summer and winter. The temperature may rise as high as 46^0C during summer while it falls below freezing point during winter. Eight parents along with their 28 F_1’s were evaluated for fifteen characters in two environments created by two different dates of sowing *i.e*. timely sown [14 November, normal (E_1)] and late sown [14 December, heat stress (E_2)] with three replications in a randomized block design during *rabi* 2022-23. Row length was kept 3 meters. Row to row and plant to plant distance was maintained 30 cm and 10 cm, respectively. Observations were recorded on days to anthesis, days to maturity, duration from anthesis to maturity (days), flag leaf area (cm^2), spike length (cm), grains per spike, 1000-grain weight (g), biological yield per plant (g), grain yield per plant (g), harvest index (%), proline content (ìg/100 mg fresh weight), total soluble sugars (mg/gm fresh weight), relative water content (%), membrane stability index (%) and chlorophyll content (SPAD) on ten randomly selected plants in each of the F_1’s progenies along with each parent from each replication except days to anthesis, days to maturity, duration from anthesis to maturity and 1000-grain weight which were observed on plot basis. Heterosis and heterobeltiosis were calculated according to the method suggested by Shull (1914) and Fonseca and Patterson (1968), respectively.

Results and Discussion

Pooled analysis of variance revealed that significant differences existed between genotypes for all the characters under studied. Significant differences between the environments were also observed, indicating that environments had significant effect on the expression of different characters. The mean sum of squares due to parents vs. F_1’s displayed significant difference for all the studied characters except harvest index indicating that between parents and between hybrids difference was significant and average heterosis was there. Similar findings were also reported for most of the characters studied in the present investigation by Kakani *et al*. (2007), Potla *et al*. (2013), Bornare *et al*. (2014), Sultan *et al*. (2016), Ram and Shekhawat (2017).

The magnitude and direction of heterosis are vary from cross to cross and character to character but in this research paper only those characters are mentioned that are important for earliness, grain yield and heat stress such days to anthesis, days to maturity, grain yield and proline content. In barley earliness is useful, hence the crosses possessing negative significant heterosis and heterobeltiosis were considered superior for days to anthesis. In this study, heterosis ranged from -10.69 per cent (RD-2052 × RD-2794) to 1.28 per cent (RD-2624 × RD-2660) in E_1 and -9.40 per cent (RD-2052 × RD-2624) to 3.45 per cent (RD-2035 × RD-2660) in E_2. The heterobeltiosis ranged from -8.77 per cent (RD-2052 × RD-2624) to 5.36 per cent (RD-2715 × RD-2794) in E_1 and -8.74 per cent (RD-2052 × RD-2624) to 4.52 per

Table 1 : Estimates of heterosis (H) and heterobeltiosis (HB) for days to anthesis and days to maturity under normal (E_1) and heat stress environment (E_2).

Crosses	Days to Anthesis				Days to Maturity			
	E_1		E_2		E_1		E_2	
	H	HB	H	HB	H	HB	H	HB
RD-2035 × RD-2052	-6.32**	-5.70**	-9.31**	-8.42**	-0.15	1.21	-8.59**	-6.99**
RD-2035 × RD-2624	-4.54**	-4.33*	-0.24	1.49	-3.76*	-1.77	-2.23	-0.35
RD-2035 × RD-2660	-2.36	-1.30	3.45	3.96	-3.30*	-0.59	-6.43**	-5.94**
RD-2035 × RD-2715	-1.98	-0.45	2.24	3.02	2.86	4.91*	-4.47**	-2.80
RD-2035 × RD-2794	-5.00**	-1.30	0.24	3.47	-2.87	-0.29	-9.76**	-6.29**
RD-2035 × RD-2899	-6.38**	-4.76*	-8.25**	-6.44**	-3.56*	0.00	-8.39**	-4.55*
RD-2035 × RD-2907	-4.46**	-2.60	-0.48	2.48	-4.31**	-1.77	-3.16*	1.75
RD-2052 × RD-2624	-9.57**	-8.77**	-9.40**	-8.74**	-1.02	2.42	-9.61**	-9.46**
RD-2052 × RD-2660	-4.31*	-2.63	-5.37**	-4.90*	-0.29	3.94*	-1.88	-0.69
RD-2052 × RD-2715	-2.65	-1.79	1.73	3.52	3.66*	4.29*	-7.77**	-7.77**
RD-2052 × RD-2794	-10.69**	-6.58**	-8.79**	-6.80**	-1.89	2.12	-1.99	0.00
RD-2052 × RD-2899	-6.21**	-3.95*	1.44	2.43	-0.58	4.55*	-3.63*	-1.35
RD-2052 × RD-2907	-2.56	0.00	-6.67**	-4.85*	-0.44	3.64	-3.76*	-0.68
RD-2624 × RD-2660	1.28	2.16	2.66	3.92	-3.23*	-2.55	2.05	3.46
RD-2624 × RD-2715	-0.44	1.34	1.47	4.02	0.74	4.91*	-7.25**	-7.09**
RD-2624 × RD-2794	-3.12	0.43	-8.96**	-7.66**	-3.94*	-3.40	-2.15	-0.34
RD-2624 × RD-2899	-4.03*	-2.59	-7.40**	-7.18**	-7.95**	-6.52**	-5.44**	-3.37
RD-2624 × RD-2907	-2.97	-1.29	0.71	1.91	-6.76**	-6.23**	-3.27*	-0.34
RD-2660 × RD-2715	-5.65**	-3.13	1.74	3.02	-0.88	3.99*	-2.56	-1.38
RD-2660 × RD-2794	-3.51*	-0.85	0.24	2.94	-5.73**	-5.60**	0.50	3.81*
RD-2660 × RD-2899	-3.58*	-2.97	0.97	2.45	-6.93**	-6.15**	-0.83	2.77
RD-2660 × RD-2907	-3.36*	-2.54	0.48	2.94	-9.09**	-8.96**	-3.64*	0.69
RD-2715 × RD-2794	-0.21	5.36*	0.00	4.02	-1.32	3.37	-2.98*	-1.01
RD-2715 × RD-2899	-9.72**	-6.70**	0.73	3.52	-8.99**	-3.68	-2.97*	-0.68
RD-2715 × RD-2907	-3.88*	-0.45	0.73	4.52	-0.73	3.99*	-9.33**	-6.42**
RD-2794 × RD-2899	-3.28*	-1.26	-6.82**	-5.71*	-2.91	-1.96	-5.50**	-5.19**
RD-2794 × RD-2907	-6.34**	-4.58*	1.63	1.87	-3.08	-3.08	-0.80	0.32
RD-2899 × RD-2907	-1.88	-1.67	0.47	1.43	-5.13**	-4.20*	-4.64**	-3.87*
SE	1.31	1.51	1.32	1.53	1.88	2.17	1.48	1.71

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

cent (RD-2715 × RD-2907) in E_2 for days to anthesis (Table 1). Out of 28 crosses, eighteen crosses in E_1 and nine crosses in E_2 exhibited significant negative heterosis over mid parent, whereas eight crosses in E_1 and nine crosses in E_2 exhibited significant negative heterobeltiosis. Hence, these crosses were considered to be the most desirable for earliness. Comparison across the environments revealed that the crosses *viz.,* RD-2035 × RD-2052, RD-2035 × RD-2899, RD-2052 × RD-2624 and RD-2052 × RD-2794 showed significant negative heterosis and heterobeltiosis, hence these crosses were considered to be desirable for earliness in both environments.

Early maturity is an important parameter for barley crop improvement, which is reflected by negative significant heterosis and heterobeltiosis for this character. Heterosis ranged from -9.09 per cent (RD-2660 × RD-2907) to 3.66 per cent (RD-2052 × RD-2715) in E_1 and -9.76 per cent (RD-2035 × RD-2794) to 2.05 per cent (RD-2624 × RD-2660) in E_2. The heterobeltiosis ranged from -8.96 per cent (RD-2660 × RD-2907) to 4.91 per cent (RD-2035 × RD-2715 and RD-2624 × RD-2715) in E_1 and -9.46 per cent (RD-2052 × RD-2624) to 3.81 per cent (RD-2660 × RD-2794) in E_2 for days to maturity (Table 1). Out of 28 crosses, thirteen crosses in E_1 and nineteen crosses in E_2 exhibited significant negative

Table 2 : Estimates of heterosis (H) and heterobeltiosis (HB) for grain yield per plant and proline content under normal (E_1) and heat stress environment (E_2).

Crosses	Grain yield per plant				Proline content			
	E_1		E_2		E_1		E_2	
	H	HB	H	HB	H	HB	H	HB
RD-2035 × RD-2052	-9.02	-24.31**	-18.99**	-32.65**	1.14	-13.75**	6.59*	-5.51
RD-2035 × RD-2624	6.72	-10.00	55.93**	39.47**	-15.59**	-20.60**	-8.90**	-12.23**
RD-2035 × RD-2660	-1.46	-22.58**	27.82**	-1.30	-8.52**	-22.66**	-3.98	-15.55**
RD-2035 × RD-2715	33.54**	7.78	61.54**	34.67**	22.38**	9.18**	22.13**	10.40**
RD-2035 × RD-2794	40.93**	15.08*	64.44**	26.90**	10.64**	1.44	9.90**	3.14
RD-2035 × RD-2899	34.03**	30.13**	23.48**	22.51**	20.73**	-0.70	22.58**	11.32**
RD-2035 × RD-2907	31.54**	0.36	29.16**	4.13	11.44**	3.21	10.60**	4.72
RD-2052 × RD-2624	38.30**	36.02**	38.36**	27.29**	24.46**	12.05**	22.65**	12.48**
RD-2052 × RD-2660	42.83**	32.88**	34.98**	22.93**	-14.70**	-15.59**	-14.77**	-15.55**
RD-2052 × RD-2715	12.61	8.39	35.13**	34.66**	0.32	-4.71	3.48	1.25
RD-2052 × RD-2794	-17.00*	-18.92*	-8.56	-16.79**	20.98**	11.69**	17.01**	10.07**
RD-2052 × RD-2899	20.84*	3.01	25.94**	4.05	1.40	-2.96	-2.51	-5.09
RD-2052 × RD-2907	4.99	-5.91	5.42	1.43	21.01**	10.60**	17.19**	9.28*
RD-2624 × RD-2660	-6.22	-14.08*	-24.64**	-36.32**	-5.21	-15.45**	1.19	-7.97*
RD-2624 × RD-2715	48.82**	40.97**	39.39**	28.65**	-6.70*	-11.84**	0.26	-6.18
RD-2624 × RD-2794	0.97	-2.96	-0.60	-16.06**	14.33**	11.25**	12.60**	9.57**
RD-2624 × RD-2899	35.73**	17.33*	42.75**	26.80**	2.08	-11.61**	-13.50**	-18.66**
RD-2624 × RD-2907	-4.28	-15.47*	13.40**	0.71	-4.57	-6.15*	-10.47**	-12.07**
RD-2660 × RD-2715	-19.22**	-22.04**	-20.96**	-28.25**	15.24**	8.37*	13.75**	10.30*
RD-2660 × RD-2794	9.83	4.47	-13.34**	-13.40**	-20.45**	-27.27**	-5.76	-12.10**
RD-2660 × RD-2899	26.91**	1.95	33.48**	2.50	-20.82**	-23.45**	-4.74	-8.08
RD-2660 × RD-2907	-3.02	-6.87	7.46	1.49	19.26**	7.97*	7.24*	-0.85
RD-2715 × RD-2794	-17.81**	-19.04*	-3.85	-12.77**	-2.69	-5.57	-2.73	-6.56
RD-2715 × RD-2899	-4.34	-20.98**	7.12	-11.26*	-0.60	-9.43**	-7.91*	-8.38*
RD-2715 × RD-2907	-4.45	-11.30	11.83*	7.23	-23.24**	-26.30**	-9.24**	-13.60**
RD-2794 × RD-2899	18.12*	-1.23	11.97*	-14.07**	21.81**	8.02*	14.11**	10.16**
RD-2794 × RD-2907	-30.93**	-36.78**	-36.68**	-40.25**	-1.82	-2.89	-2.49	-3.41
RD-2899 × RD-2907	-18.98**	-36.87**	-16.16**	-32.81**	11.70**	-1.89	4.22	-0.29
SE	0.81	0.93	0.41	0.48	1.87	2.16	2.47	2.85

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

heterosis over mid parent, whereas six crosses in E_1 and ten crosses in E_2 exhibited significant negative heterobeltiosis. Hence, these crosses were considered to be the most desirable for earliness. Comparison across the environments revealed that the cross RD-2899 x RD-2907 showed significant negative heterosis and heterobeltiosis, hence these crosses were considered to be desirable for early maturity in both environments.

Higher grain yield is the primary objective of breeding programme, hence positive significant heterosis and heterobeltiosis is desirable. Heterosis ranged from -30.93 per cent (RD-2794 × RD-2907) to 48.82 per cent (RD-2624 × RD-2715) in E_1 and -36.68 per cent (RD-2794 × RD-2907) to 64.44 per cent (RD-2035 × RD-2794) in E_2. The heterobeltiosis ranged from -36.87 per cent (RD-2899 × RD-2907) to 40.97 per cent (RD-2624 × RD-2715) in E_1 and -40.25 per cent (RD-2715 x RD-2907) to 39.47 per cent (RD-2035 × RD-2624) in E_2 for days to maturity (Table 2). Out of 28 crosses, eleven crosses in E_1 and sixteen crosses in E_2 exhibited significant positive heterosis over mid parent, whereas six crosses in E_1 and nine crosses in E_2 exhibited significant positive heterobeltiosis. Hence, these crosses were considered to be the most desirable for this character. Comparison across the environments revealed that the crosses RD-2035 × RD-2794, RD-2035 × RD-2899, RD-2052 × RD-

Table 3 : Top three crosses for their heterosis and heterobeltiosis estimates in normal (E_1) and heat stress environment (E_2) for different characters.

Characters	Env.	Heterosis	Heterobeltiosis
Days to anthesis	E_1	RD-2052 × RD-2794 RD-2715 × RD-2899 RD-2052 × RD-2624	RD-2052 × RD-2624 RD-2715 × RD-2899 RD-2052 × RD-2794
	E_2	RD-2052 × RD-2624 RD-2035 × RD-2052 RD-2624 × RD-2794	RD-2052 × RD-2624 RD-2035 × RD-2052 RD-2624 × RD-2794
Days to maturity	E_1	RD-2660 × RD-2907 RD-2715 × RD-2899 RD-2624 × RD-2899	RD-2660 × RD-2907 RD-2624 × RD-2899 RD-2624 × RD-2907
	E_2	RD-2035 × RD-2794 RD-2052 × RD-2624 RD-2715 × RD-2907	RD-2052 × RD-2624 RD-2052 × RD-2715 RD-2624 × RD-2715
Duration from anthesis to maturity	E_1	RD-2052 × RD-2794 RD-2052 × RD-2715 RD-2052 × RD-2624	RD-2052 × RD-2715 RD-2052 × RD-2794 RD-2035 × RD-2052
	E_2	RD-2624 × RD-2794 RD-2052 × RD-2794 RD-2052 × RD-2660	RD-2052 × RD-2794 RD-2624 × RD-2794 RD-2052 × RD-2660
Flag leaf area	E_1	RD-2624 × RD-2660 RD-2794 × RD-2907 RD-2035 × RD-2715	RD-2624 × RD-2660 RD-2035 × RD-2715 RD-2660 × RD-2907
	E_2	RD-2794 × RD-2907 RD-2624 × RD-2660 RD-2660 × RD-2899	RD-2624 × RD-2660 RD-2660 × RD-2907 RD-2660 × RD-2899
Spike length	E_1	RD-2660 × RD-2899 RD-2052 × RD-2899 RD-2624 × RD-2715	RD-2035 × RD-2624 RD-2052 × RD-2899 RD-2660 × RD-2899
	E_2	RD-2660 × RD-2899 RD-2052 × RD-2899 RD-2624 × RD-2899	RD-2624 × RD-2899 RD-2035 × RD-2907 RD-2624 × RD-2907
Grains per spike	E_1	RD-2035 × RD-2794 RD-2660 × RD-2899 RD-2052 × RD-2899	RD-2035 × RD-2794 RD-2035 × RD-2052 RD-2035 × RD-2907
	E_2	RD-2660 × RD-2899 RD-2035 × RD-2624 RD-2035 × RD-2794	RD-2660 × RD-2899 RD-2035 × RD-2794 RD-2035 × RD-2624
1000-grain weight	E_1	RD-2794 × RD-2899 RD-2052 × RD-2715 RD-2052 × RD-2907	RD-2052 × RD-2907 RD-2052 × RD-2715 RD-2624 × RD-2660
	E_2	RD-2715 × RD-2907 RD-2052 × RD-2715 RD-2715 × RD-2899	RD-2035 × RD-2715 RD-2715 × RD-2907 RD-2660 × RD-2794
Biological yield per plant	E_1	RD-2624 × RD-2715 RD-2052 × RD-2907 RD-2035 × RD-2715	RD-2624 × RD-2715 RD-2052 × RD-2715 RD-2624 × RD-2899

Table 3 continued...

2624, RD-2052 × RD-2660, RD-2624 × RD-2715 and RD-2624 × RD-2899 showed significant positive heterosis and heterobeltiosis, hence these crosses were considered to be most desirable for improvement of grain yield per plant in both environments. Therefore, the crosses, which showed positive significant heterosis and heterobeltiosis under specific environment may be considered suitable material for environment specific breeding.

Higher value of proline content is desirable, hence positive significant heterosis and heterobeltiosis is desirable for this trait. Heterosis ranged from -23.24 per cent (RD-2715 × RD-2907) to 24.46 per cent (RD-2052 × RD-2624) in E_1 and -14.77 per cent (RD-2052 × RD-2660) to 22.65 per cent (RD-2052 × RD-2624) in E_2. The heterobeltiosis ranged from -27.27 per cent (RD-2660 × RD-2794) to 12.05 per cent (RD-2052 × RD-2624) in E_1 and -18.66 per cent (RD-2624 × RD-2899) to 12.48 per cent (RD-2052 × RD-2624) in E_2 (Table 2). Out of 28 crosses, twelve crosses each in E_1 and E_2 exhibited significant positive heterosis over mid parent, whereas eight crosses in E_1 and eight crosses in E_2 exhibited significant positive heterobeltiosis. Hence, these crosses were considered to be the most desirable for this character. Comparison across the environments revealed that the crosses RD-2035 × RD-2715, RD-2052 × RD-2624, RD-2052 × RD-2794, RD-2052 × RD-2907, RD-2624 × RD-2794, RD-2660 × RD-2715 and RD-2794 × RD-2899 showed significant positive heterosis and heterobeltiosis, hence these crosses were considered to be most desirable for improvement of proline content in both environments. Therefore, the crosses which showed positive significant heterosis and heterobeltiosis under specific environment may be considered suitable material for environment specific breeding.

The superiority of hybrids particularly over better parent (heterobeltiosis) is more important and useful in determining the

Table 3 continued...

	E_2	RD-2052 × RD-2715 RD-2052 × RD-2660 RD-2624 × RD-2715	RD-2052 × RD-2715 RD-2624 × RD-2715 RD-2052 × RD-2660
Grain yield per plant	E_1	RD-2624 × RD-2715 RD-2052 × RD-2660 RD-2035 × RD-2794	RD-2624 × RD-2715 RD-2052 × RD-2624 RD-2052 × RD-2660
	E_2	RD-2035 × RD-2794 RD-2035 × RD-2715 RD-2035 × RD-2624	RD-2035 × RD-2624 RD-2035 × RD-2715 RD-2052 × RD-2715
Harvest index	E_1	RD-2035 × RD-2794 RD-2035 × RD-2899 RD-2660 × RD-2899	RD-2035 × RD-2899 RD-2035 × RD-2794 RD-2052 × RD-2624
	E_2	RD-2035 × RD-2794 RD-2035 × RD-2715 RD-2052 × RD-2624	RD-2052 × RD-2624 RD-2035 × RD-2624 RD-2035 × RD-2715
Proline content	E_1	RD-2052 × RD-2624 RD-2035 × RD-2715 RD-2794 × RD-2899	RD-2052 × RD-2624 RD-2052 × RD-2794 RD-2624 × RD-2794
	E_2	RD-2052 × RD-2624 RD-2035 × RD-2899 RD-2035 × RD-2715	RD-2052 × RD-2624 RD-2035 × RD-2899 RD-2035 × RD-2715
Total soluble sugars	E_1	RD-2794 × RD-2899 RD-2624 × RD-2794 RD-2660 × RD-2794	RD-2660 × RD-2794 RD-2624 × RD-2794 RD-2794 × RD-2899
	E_2	RD-2624 × RD-2794 RD-2794 × RD-2899 RD-2660 × RD-2794	RD-2624 × RD-2794 RD-2660 × RD-2794 RD-2035 × RD-2794
Relative water content	E_1	RD-2624 × RD-2660 RD-2052 × RD-2715 RD-2052 × RD-2794	RD-2052 × RD-2794 RD-2715 × RD-2899 RD-2624 × RD-2660
	E_2	RD-2052 × RD-2899 RD-2035 × RD-2715 RD-2715 × RD-2899	RD-2052 × RD-2899 RD-2035 × RD-2715 RD-2052 × RD-2715
Membrane stability index	E_1	RD-2035 × RD-2660 RD-2052 × RD-2794 RD-2660 × RD-2715	RD-2035 × RD-2660 RD-2035 × RD-2624 RD-2624 × RD-2794
	E_2	RD-2035 × RD-2660 RD-2052 × RD-2660 RD-2052 × RD-2794	RD-2035 × RD-2660 RD-2052 × RD-2794 RD-2035 × RD-2624
Chlorophyll content	E_1	RD-2035 × RD-2907 RD-2624 × RD-2907 RD-2052 × RD-2624	RD-2035 × RD-2907 RD-2715 × RD-2794 RD-2624 × RD-2907
	E_2	RD-2715 × RD-2794 RD-2052 × RD-2624 RD-2660 × RD-2907	RD-2715 × RD-2794 RD-2035 × RD-2907 RD-2052 × RD-2715

feasibility of commercial exploitation of heterosis and also indicating the parental combinations capable of producing the highest level of transgressive segregants. Top three heterotic and heterobeltiosis crosses for all the characters are presented in Table 3. Perusal of this table indicated that the crosses RD-2624 × RD-2715 and RD-2052 × RD-2660 in E_1 and RD-2035 × RD-2715 and RD-2035 × RD-2624 in E_2 emerged as good heterotic as well as heterobeltiosis crosses for grain yield per plant and some other more characters. Hence, these crosses may be considered as promising type for tangible advancement of barley yield under normal sown and heat stress condition. Assessment of Table 4 revealed an interesting relation between heterosis and heterobeltiosis for grain yield per plant and its attributes. The parents, who exhibited desirable heterosis and heterobeltiosis for grain yield per plant, also exhibited desirable heterosis and heterobeltiosis for at least for one or more yield attributes. Such as, heterosis and heterobeltiosis for grain yield per plant were mainly contributed by spike length, grains per spike, 1000-grain weight and harvest index in both the environments. Results of this study 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 characters. Therefore, heterobeltiosis for various yield contributing characters might 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. This was because of significant G x E interaction. The results in varying environments for different characters are in agreement with the findings of Potla *et al*. (2013), Saad *et al*. (2013), Mansour (2016), Ram and Shekhawat (2017), who also reported maximum heterosis for grain yield per plant.

Table 4 : Crosses possessing high heterosis (H) and heterobeltiosis (HB) for grain yield per plant along with desirable (+/-) heterotic expression for other characters in normal (E_1) and heat stress environment (E_2).

Particulars	Environments	Crosses possessing high heterosis and heterobeltiosis for grain yield per plant	Days to anthesis	Days to maturity	Duration from anthesis to maturity	Flag leaf area	Spike length	Grains per spike	1000-grain weight	Biological yield per plant	Harvest index	Proline content	Total soluble sugars	Relative water content	Membrane stability index	Chlorophyll content
Heterosis	E_1	RD-2624 × RD-2715	-	-	-	-	+	+	-	+	+	-	-	-	-	+
		RD-2052 × RD-2660	+	-	-	-	+	-	-	+	+	-	-	+	+	+
		RD-2035 × RD-2794	+	-	-	-	+	+	-	-	+	+	+	+	-	+
	E_2	RD-2035 × RD-2794	-	+	-	-	+	+	-	+	+	+	+	-	-	-
		RD-2035 × RD-2715	-	+	-	+	-	+	+	+	+	+	-	+	-	+
		RD-2035 × RD-2624	-	-	-	-	+	+	+	+	+	-	-	-	+	+
Heterobeltiosis	E_1	RD-2624 × RD-2715	-	-	-	-	+	-	-	+	+	-	-	-	-	-
		RD-2052 × RD-2624	+	-	-	-	-	-	-	+	+	+	-	-	-	+
		RD-2052 × RD-2660	-	-	-	-	-	-	-	+	+	-	-	-	-	-
	E_2	RD-2035 × RD-2624	-	-	-	-	+	+	+	+	+	-	-	-	+	+
		RD-2035 × RD-2715	-	-	-	+	-	-	+	+	+	+	-	+	-	+
		RD-2052 × RD-2715	-	+	-	-	-	-	+	+	-	-	-	+	-	+

Conclusion

The crosses RD-2624 × RD-2715 and RD-2052 × RD-2660 in E_1 and RD-2035 × RD-2715 and RD-2035 × RD-2624 in E_2 emerged as good heterotic as well as heterobeltiosis crosses for grain yield per plant and some other more characters. Hence, these crosses may be considered as promising type for tangible advancement of barley yield under normal sown and heat stress condition.

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