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Study of heterosis in six-rowed barley (*Hordeum vulgare* L.)

Chhagan Lal, AS Shekhawat, Jogendra Singh and Vinod Kumar

Abstract
A set of diallel crosses involving 10 diverse parents (excluding reciprocals) was made. Heterosis for grain yield per plant ranged from -21.95 to 39.65 percent. Out of forty five crosses, fifteen crosses exhibited positive significant heterosis and nine crosses exhibited positive significant heterobeltiosis while eighteen crosses tilted towards negative magnitude, out of which five crosses manifested negative significant inbreeding depression. Nine crosses have positive significant heterosis and heterobeltiosis whereas, out of cross PL 426 × RD 2552 and BH 959 × RD 2786 have supported by negative inbreeding depression. Hence, these crosses were considered to be most desirable for grain yield per plant. The study revealed good scope for commercial exploitation of heterosis as well as isolation of pure lines among the progenies of heterotic F_1 for improvement of yield.

Keywords: Heterosis, six-rowed barley, *Hordeum vulgare* L.

Introduction
Barley (*Hordeum vulgare* L., 2n=2x=14) was domesticated about 10,000 years ago in the fertile crescent of the Near-East. It is a staple food in several regions which are characterised by harsh living conditions of people and for those who depend on the low productive systems. Barley is the world's fourth most produced and marketed cereal crop and considered as the first cereal domesticated for use by man as food and feed (Potla *et al*., 2013) [13]. The major barley producing countries of world are Canada, USA, Germany, France, Spain, Turkey, UK, Denmark, Russia, central Asia countries and Australia. The malting industry absorbs most of the production, and the rest is commonly used as animal feed and for human consumption (Amabile *et al*., 2007) [2].

It is an important winter cereal crop grown in the northern plains of India comprising the states of Rajasthan, Uttar Pradesh, Bihar, Haryana, Punjab, Madhya Pradesh, Himachal Pradesh and Uttarakhand that makes about 80% of total acreage of India (Madakemohekar *et al.*, 2015) [8] .In India, it is grown in 693 thousand hectares with total production of 1788 thousand ton and average grain productivity is 2580 kg per hectare (Anonymous 2016-17) [3], whereas in Rajasthan, it is grown in 276 thousand hectares with total production of 910 thousand ton and average grain productivity is higher than country i.e. 3297 kg per hectare (Anonymous 2016-17) [3]. But this productivity is far below to most of developed countries such as Germany (5425- kg per hectare), France (6685 kg per hectare) and the United Kingdom (5931 kg per hectare) (FAO 2016) [4]. Cultivated barley in India is now becoming oriented towards industrial utilization. Though presently only 12-15% of total produce is being utilized for malting/brewing, but it has been projected that by 2020 the demand will be more than double.

Exploitation of heterosis is considered as one of the outstanding achievements of plant breeding. In a self-pollinated crop, the utilization of heterosis depends mainly upon the direction and magnitude of heterosis. The study of heterosis and inbreeding depression has a direct bearing on the breeding methodology to be employed for varietal improvement. The study of heterosis helps the plant breeder in eliminating the less productive crosses in early generations. Utilization of heterosis through hybrid barley is better than conventional plant breeding methods, which obtain lower yield gain (1% per year) in the north-western plains zone. Allard (1960) [1] reported that the ability of parents to combine well depends on complex interaction among genes for trait of interest which cannot be adjusted by mere yield and yield adaptation of the parents. The study of heterosis has a direct bearing on the breeding methodology to be employed for varietal improvement and also provides information about usefulness of the parents in breeding programs (Singh *et al.*, 2012) [18]. However, grain yield as well as component character are highly influenced by environmental fluctuation. Efforts are needed to develop high yielding *vis a vis* quality assessing trait to be used in breeding the crop.

Keeping in view the above points, the present investigation was under taken to study the heterosis, heterobeltiosis and inbreeding in 6-rowed barley.

Material and methods

Ten varieties of barley [*Hordeum vulgare* (L.)] namely, BHS 400, BG 105, PL 426, BHS 380, BH 902, BH 946, BH 959, RD 2715, RD 2786 and RD 2552 were crossed in diallel fashion excluding reciprocals. The 10 parents and their resulting 45 F_1's and 45 F_2's were grown in a randomized block design with three replications with normal sowing date i.e 20^{th} November at RARI, Durgapura, Jaipur, Rajasthan, India. Plots of parents and F_1's consisted of two rows of three meter length while, each plot of F_2's consisted of four rows with the spacing of 30 cm between rows and 10 cm between plants. Ten competitive plants in parents and F_1's and 30 plants in F_2 progenies were selected randomly for recording observations on eleven characters namely days to heading, days to maturity, plant height (cm), number of effective tillers per plant, flag leaf area (cm^2), number of grains per spike, 1000-grain weight (g), biomass per plant (g), grain yield per plant (g), harvest index (%) and malt score (%) under each environment, separately. The mean value of each plot was used for statistical analysis. Analysis of variance for all the characters in each environment was done as suggested by Panse and Sukhatme (1967) [11]. The heterosis (H%) and heterobeltiosis (HB%) were estimated as deviation of F_1 value from the mid-parent and the better-parent values as suggested by Martinez *et al*. (1962) [10] and Fonseca and Patterson (1968) [5], respectively. The following formulae were used for the estimation of heterosis and heterobeltiosis in each environment for all the characters.

Heterosis over mid parent (H%) = $[(F_1 - MP)/MP \times 100]$

$SE\ (F_1 - MP) = (3M_e/2r)^{1/2}$

Heterosis over better parent (HB%) = $[(F_1 - BP)/BP \times 100]$

$SE\ (F_1 - BP) = (2Me/r)^{1/2}$

Where, M_e = error mean squares for parents and F_1sdata of individual environment; MP = mean mid parent value = $(P_1 + P_2)/2$; P_1 = mean performance of parent one; P_2 = mean performance of parent two; BP = mean better parent value; R= number of replications;

Inbreeding depression (ID%) = $[(F_1-F_2)/F_1 \times 100]$

$SE\ (F_1-F_2) = (2M_e/r)^{1/2}$

Where, M_e = error mean square from the ANOVA of individual environment.

Significance of heterosis and heterobeltiosis and inbreeding depression were tested by 't' test using SE values in all the characters under each environment, separately.

Results

The analysis of variance in individual environment (Table 1) revealed significant differences among the genotypes for all the characters; means the characters manifested the presence of ample genetic diversity among the parents. Further analysis revealed significant mean sum of squares due to generations and parents for all the characters in both the environments. Mean squares due to F_1 and F_2 were found significant for all the characters in both the environments (Table 1). The presence of inbreeding depression was supported by the significance of F_1 vs F_2 for most of the characters in both the environments (Table 1). The genotypic mean squares due to parents *vs* generations (F_1's and F_2's) were reported significant for most of the characters under study. The differences among parents *vs* generations indicated the presence of heterosis in both the environments.), similar results were also observed by Sultan *et al.* (2016) [19], Pesaraklu *et al.* (2016) [12] and Lal *et al.* (2018) [7].

The commercial utilization of heterosis is regarded as magnificent implementation of genetics in the plant breeding. The magnitude of heterosis in a crop relies on its exploitation, utilization and practicability of hybrid seed production. Barley is a self-pollinated crop and an appropriate procedure of hybrid seed production at commercial scale is not yet available. As a consequence, the heterosis *per se* may not be of economic value in this crop 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 segregants in advance generations for further amelioration of grain yield.

In present investigation, the maximum range of heterosis has been estimated for all the characters. Higher grain yield is the primary objective of plant breeding programme which is associated with positive heterotic effect, hence positive significant heterosis and heterobeltiosis is desirable.

In present investigation heterosis ranged from -14.61 percent (BHS 400 × BH 959) to 3.38 percent (PL 426 × RD 2786) for days to heading; -6.39 percent (BHS 400 x BH 946) to 9.78 percent (PL 426 x RD 2715) for days to maturity; -15.21 percent (BHS 400 x BH 959) to 1.20 percent (BHS 400 x BH 902) for plant height; -13.31 percent (RD 2715 x RD 2552) to 36.5 percent (PL 426 x BH 959) for number of effective tillers per plant; -22.27 percent (BHS 380 x BH 902) to 27.02 percent (RD 2715 x RD 2552) for flag leaf area; -11.3 percent (BH 902 x BH 959) to 21.34 percent (BG 105 x BHS 380) for number of grains per spike; -3.99 percent (BHS 400 × BHS 380) to 12.81 percent (BH 946 × RD 2786) for 1000-grain weight; -32.29 percent (RD 2715 × RD 2552) to 36.47 percent (BHS 400 × BH 959) for biomass per plant; -10.57 percent (BG 105 × BHS 380) to 16.94 percent (RD 2715 × RD 2552) for harvest index; -4.85 percent (BH 902 × BH 959) to 9.98 percent (BH 902 × RD 2552) for malt score and; -21.95 percent (BHS 400 × BH 902) to 39.65 percent (BHS 400 × BHS 380) for grain yield per plant (Table 2, 3 and 4).

Discussion

The superiority of hybrids particularly over better parent (heterobeltiosis) is more important and 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.

Heterosis for grain yield per plant ranged from -21.95 percent (BHS 400 × BH 902) to 39.65 percent (BHS 400 × BHS 380) and heterobeltiosis ranged from -29.62 percent (BHS 400 × BH 902) to 36.15 percent (BHS 400 × BHS 380) while Inbreeding depression ranged from -20.50 percent (PL 426 × RD 2552) to 18.86 percent (BH 959 × RD 2715) as presented in Table 4. The results are in conformity with the findings of other obtained for different characters such as Vishwakarma *et al.* (2011) [20], Saad *et al.* (2013) [15], Shendy (2015) [17], Mansour (2016) [9], Pesarkhlu *et al.* (2016) [12] and Ram and Shekhawat (2017) [14].

Out of 45 crosses, fifteen crosses exhibited positive significant heterosis for grain yield per plant while, nine crosses exhibited positive significant heterobeltiosis (Table 4). Higher grain yield per plant is an advantageous and most desirable parameter which is associated with negative inbreeding depression. Eighteen crosses tilted towards negative magnitude, out of which five crosses manifested negative significant inbreeding depression (Table 4) which indicated that F_2 plants attained comparatively higher grain yield per plant than F_1 hybrids and considered to be desirable. Total nine crosses have positive significant heterosis and heterobeltiosis whereas, out of only crosses PL 426 × RD 2552 and BH 959 × RD 2786 have supported by negative inbreeding depression. Hence, these crosses were considered to be most desirable for grain yield per plant. The results for grain yield per plant are in conformity with the previous findings in varying environments for different characters by Saad *et al.* (2013) [15], Mansour (2016) [9], Pesaraklu *et al.* (2016) [12] and Ram and Shekhawat (2017) [14].

Perusal of this table 2, 3 and 4 divulged cross BHS 400 x BHS 380, BHS 400 x PL 426 and BG 105 x PL 426 exhibited desirable heterosis and heterobeltiosis for three or more yield attributing characters. Hence, these crosses may be considered as promising type for tangible advancement of barley yield. Such as, heterosis and heterobeltiosis for grain yield per plant was mainly contributed biomass per plant, plant height and number of grains per spike. Findings of this investigation supported the contentions of Grafius (1959) [6], 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 possibly due to significant G x E interaction. The results in varying environments for different characters are in harmony with the findings of Sharma *et al.* (2002) [16], Potla *et al.* (2013) [13], Saad *et al.* (2013) [15], Mansour (2016) [9] and Ram and Shekhawat (2017) [14] who also reported maximum heterosis for grain yield per plant.

Table 1: Analysis of variance showing mean squares for parents, F_1 and F_2 for yield and its contributing attributes

Characters	Replication	Genotype	Parents	Generation	F_1	F_2	F_1 vs F_2	Parents vs Generation	Error
Days to heading	1.16	99.10**	89.37**	100.81**	95.86**	107.31**	32.96**	34.83**	0.54
Days to maturity	1.66*	49.23**	25.69**	51.65**	46.81**	46.63**	485.35**	46.41**	0.37
Plant height	1.66*	49.23**	25.69**	51.65**	46.81**	46.63**	485.35**	46.41**	0.37
No. of effective tillers per plant	0.18	7.31**	7.94**	7.30**	5.88**	8.85**	1.61	2.90**	0.42
Flag leaf area	1.88	29.14**	56.66**	26.67**	25.69**	28.00**	11.30	1.80	5.66
No. of grains per spike	0.52	162.27**	306.94**	148.03**	121.08**	175.12**	141.36**	127.82**	1.05
1000-grain weight	0.99	47.58**	62.68**	45.49**	31.86**	60.14**	0.25	98.43**	1.30
Biomass per plant	7.72	221.08**	112.22**	233.55**	193.03**	274.90**	197.13**	91.20*	16.49
Grain yield per plant	1.04	28.13**	15.83**	29.29**	20.62**	38.55**	2.64	36.25**	3.11
Harvest index	3.57*	76.10**	41.09**	80.31**	56.62**	103.00**	124.56**	16.20**	0.87
Malt Score	0.21	31.21**	41.29**	30.52**	23.80**	37.88**	2.96	1.43	0.79

*, ** Significant at 5 percent and 1 percent levels, respectively.

Table 2: Extent of heterosis (H), heterobeltiosis (HB) and inbreeding depression (ID) for days to heading, days to maturity, plant height and number of effective tillers per plant

Crosses	Days to heading			Days to maturity			Plant height			Number of effective tillers per plant		
	H	HB	ID	H	HB	ID	H	HB	ID	H	HB	ID
BHS 400 x BG 105	1.48*	6.20**	-2.55**	0.64	2.07**	-1.02**	1.17	2.80**	3.63**	-0.31	-10.83	-10.45
BHS 400 x PL 426	0.94	7.63**	0.00	2.06**	4.49**	1.77**	-0.96	4.24**	2.48**	11.06	-2.84	2.44
BHS 400 x BHS 380	6.04**	7.39**	6.21**	2.05**	3.92**	4.77**	-2.34**	-0.04	2.48**	0.56	-3.30	-17.75*
BHS 400 x BH 902	3.60**	6.92**	-0.24	-2.84**	-0.27	-2.39**	2.86**	4.85**	3.50**	-4.55	-13.10*	7.21
BHS 400 x BH 946	-1.47*	2.29**	-2.99**	0.26	3.49**	4.40**	1.98**	2.61**	3.35**	29.66**	15.43**	30.72**
BHS 400 x BH 959	-16.14**	-5.75**	0.00	-2.82**	-1.04**	3.69**	-12.54**	-8.28**	1.94*	-0.29	-9.30	-42.56**
BHS 400 x RD 2715	0.00	6.40**	-3.01**	4.43**	8.09**	2.49**	2.22**	3.34**	-1.40	10.79	6.82	22.76**
BHS 400 x RD 2786	-0.18	1.09	2.52**	7.97**	12.23**	7.51**	-8.94**	-4.69**	-1.77*	9.15	-10.14*	3.92
BHS 400 x RD 2552	-3.09**	-0.74	-3.25**	-1.30**	2.16**	-3.69**	4.29**	8.31**	10.40**	-9.70	-11.07	-14.75
BG 105 x PL 426	-5.33**	-3.61**	3.33**	1.44**	2.37**	9.54**	-7.06**	-3.78**	2.04*	26.77**	0.88	15.06**
BG 105 x BHS 380	-11.82**	-8.91**	-16.17**	-1.43**	-1.04**	0.26	-1.86**	-1.16	6.35**	4.50	-9.69	27.87**
BG 105 x BH 902	6.95**	8.40**	8.42**	3.28**	4.51**	3.30**	-1.35	-1.04	3.06**	3.37	1.36	-8.73
BG 105 x BH 946	-3.08**	-2.33**	1.98**	2.24**	4.02**	4.64**	-1.83**	-0.87	2.16**	7.41	6.82	18.72**
BG 105 x BH 959	-9.50**	-3.10**	4.46**	-4.29**	-3.92**	2.45**	-8.83**	-5.96**	5.31**	12.62*	10.53	5.81
BG 105 x RD 2715	0.39	2.00**	0.00	-0.40	1.62**	3.45**	0.40	0.91	3.33**	-3.59	-10.83	17.70**
BG 105 x RD 2786	1.19*	4.52**	4.53**	6.90**	9.51**	1.99**	-4.78**	-1.96*	-0.19	13.22**	3.01	-4.20
BG 105 x RD 2552	0.32	2.45**	1.64*	2.51**	4.58**	-1.80**	0.56	2.74**	-2.00*	11.19	-1.87	21.35**
PL 426 x BHS 380	-5.34**	-0.40	-6.85**	2.89**	3.43**	3.32**	4.46**	7.36**	4.01**	-20.04**	-27.56**	-29.42**
PL 426 x BH 902	4.41**	7.76**	4.60**	-1.06**	-0.80*	-4.81**	1.01	4.23**	0.99	-0.35	-19.51**	-54.17**
PL 426 x BH 946	-4.50**	-2.01**	-3.28**	3.99**	4.83**	4.60**	3.34**	8.07**	8.53**	16.33*	-7.80	16.54**
PL 426 x BH 959	-0.63	4.42**	-3.81**	-3.41**	-2.90**	5.43**	-1.54*	-1.19	8.13**	30.64**	5.45	-8.35
PL 426 x RD 2715	1.00	1.20	-1.59*	7.20**	8.36**	3.48**	0.55	4.65**	2.49**	-2.80	-17.57*	-6.39
PL 426 x RD 2786	2.29**	7.63**	3.36**	0.67	2.17**	1.86**	2.54**	3.09**	5.87**	10.39	-18.05**	-32.55**
PL 426 x RD 2552	-9.27**	-5.62**	7.66**	-1.60**	-0.54	0.00	3.79**	5.14**	-0.83	-1.54	-12.71	-14.01
BHS 380 x BH 902	0.37	2.26**	4.43**	2.37**	3.18**	0.00	0.40	0.80	0.24	-4.00	-15.62*	6.88
BHS 380 x BH 946	-0.56	1.91**	-0.75	1.85**	3.22**	2.60**	0.54	2.26**	4.91**	15.40**	-0.73	-6.84
BHS 380 x BH 959	-4.19**	6.19**	-1.25	3.13**	3.13**	2.78I**	-7.87**	-5.66**	8.75**	-1.89	-13.83*	-59.58**
BHS 380 x RD 2715	3.62**	8.80**	5.15**	7.16**	8.89**	5.20**	-0.74	0.48	-0.57	3.56	-3.84	4.18
BHS 380 x RD 2786	-0.85	-0.85	-0.12	2.26**	4.35**	-2.08**	0.46	2.68**	4.62**	21.09**	-3.31	17.54**
BHS 380 x RD 2552	0.00	1.12	5.60**	3.71**	5.39**	2.81**	-1.06	0.35	1.52	7.32	4.75	6.14
BH 902 x BH 946	4.87**	5.47**	4.46**	2.67**	3.22**	2.60**	0.27	1.57	0.92	-9.83	-12.05*	-5.32
BH 902 x BH 959	-1.02	7.52**	6.17**	6.05**	6.90**	6.20**	0.73	3.58**	5.08**	13.29*	13.19*	0.61
BH 902 x RD 2715	0.19	3.20**	2.33**	7.49**	8.36**	2.74**	1.13	1.97*	4.08**	1.48	-4.39	-0.76
BH 902 x RD 2786	-0.74	1.13	2.24**	-0.40	0.82*	3.50**	3.49**	6.22**	-1.01	6.33	-4.96	-15.19**

BH 902 x RD 2552	-0.37	0.38	-3.01**	0.27	1.08**	-0.80*	9.43**	11.45**	6.08**	16.16**	4.31	2.56
BH 946 x BH 959	0.82	8.85**	0.41	4.50**	5.90**	4.56**	2.62**	6.92**	2.99**	1.17	-1.23	-8.49
BH 946 x RD 2715	-0.39	2.00**	-2.75**	1.34**	1.62**	2.92**	3.74**	4.22**	3.46**	-15.76**	-22.47**	-9.32
BH 946 x RD 2786	-0.06	2.42**	0.12	7.15**	7.88**	3.78**	-0.38	3.61**	1.70*	-11.58*	-19.16**	-6.62
BH 946 x RD 2552	-0.56	0.76	1.14	2.96**	3.23**	2.61**	0.07	3.26**	2.21**	-4.79	-16.37**	11.37
BH 959 x RD 2715	-0.84	4.42**	2.54**	6.90**	8.63**	2.48**	-0.44	3.24**	1.97*	13.24*	6.59	12.73*
BH 959 x RD 2786	-2.99**	7.52**	6.58**	-3.86**	-1.90**	-5.54**	-4.02**	-3.85**	1.88*	-11.11*	-20.48**	1.13
BH 959 x RD 2552	7.34**	17.55**	1.46*	2.39**	4.04**	-1.55**	-7.33**	-6.45**	-3.75**	-16.29**	-24.89**	-8.37
RD 2715 x RD 2786	0.32	5.33**	-0.2	3.92**	4.35**	0.52	0.33	3.84**	4.03**	-7.11	-21.20**	-6.30
RD 2715 x RD 2552	-0.58	3.20**	-0.39	3.23**	3.23**	2.61**	4.38**	7.19**	-0.30	-8.88	-13.43	-21.80**
RD 2786 x RD 2552	-4.66**	-3.59**	-5.27**	0.68	1.09**	-1.61**	3.39**	4.18**	2.68**	-19.19**	-34.26**	0.91
SE	0.52	0.60		0.43	0.49		0.72	0.83		0.46	0.53	

*, ** Significant at 5 percent and 1 percent levels, respectively.

Table 3: Extent of heterosis (H), heterobeltiosis (HB) and inbreeding depression (ID) for flag leaf area, number of grains per spike, 1000-grain weight and biomass per plant

Crosses	Flag leaf area			Number of grains per spike			1000-grain weight			Biomass per plant		
	H	HB	ID	H	HB	ID	H	HB	ID	H	HB	ID
BHS 400 x BG 105	15.03*	9.21	0.18	-7.38**	-17.27**	3.87*	-15.05**	-21.01**	-0.30	6.30	0.46	16.61
BHS 400 x PL 426	-5.48	-18.75**	-0.42	3.96*	0.94	-11.11**	-6.39**	-6.77**	7.67**	34.13**	23.18**	9.43
BHS 400 x BHS 380	-14.23*	-15.91*	-7.75	5.77**	2.03	-1.87	-17.19**	-24.15**	-0.45	40.75**	33.88**	20.32**
BHS 400 x BH 902	6.51	-5.14	20.59**	17.21**	0.34	1.58	-5.17**	-10.10**	10.3**	-19.73*	-25.10**	7.19
BHS 400 x BH 946	-8.90	-17.64**	1.90	4.01**	-14.26**	-4.92**	0.74	0.54	1.49	29.42**	11.27	9.84
BHS 400 x BH 959	-8.90	-15.11*	-19.52*	5.45**	-13.13**	2.33	-5.08*	-11.90**	-3.70	44.41**	27.11**	-0.20
BHS 400 x RD 2715	21.04**	14.57	6.63	9.89**	-1.17	11.83**	-1.81	-2.29	4.61	-6.76	-19.95**	12.50
BHS 400 x RD 2786	-1.84	-4.27	13.83	-8.97**	-24.39**	-23.31**	5.49*	-1.12	-6.43**	9.17	-3.75	5.64
BHS 400 x RD 2552	-4.94	-13.38	-14.31	4.63**	-3.55*	-8.22**	-7.72**	-8.72**	-1.38	-10.63	-24.11**	0.41
BG 105 x PL 426	14.14*	-6.04	-3.16	10.99**	-3.40*	-10.38**	-7.41**	-13.58**	-1.69	37.64**	33.51**	2.11
BG 105 x BHS 380	-7.15	-13.48	-7.55	11.40**	2.84	-7.73**	-0.27	-14.48**	2.16	-0.97	-10.71	7.05
BG 105 x BH 902	-3.17	-17.59**	-9.62	3.82**	-1.08	-2.91*	-1.93	-3.93*	-3.71	-3.10	-4.40	-7.29
BG 105 x BH 946	-1.75	-15.19*	5.40	-6.48**	-14.67**	-16.95**	-8.63**	-15.20**	-13.52**	-20.51**	-28.13**	11.68
BG 105 x BH 959	14.50*	1.70	-3.84	-3.83**	-12.33**	6.31**	14.48**	-0.63	4.99*	11.69	3.55	-2.44
BG 105 x RD 2715	21.22**	20.84*	-15.15*	8.97**	8.13**	7.29**	-5.41**	-12.45**	9.98**	26.90**	14.56*	10.32
BG 105 x RD 2786	-1.60	-8.77	-10.56	5.97**	-2.47*	-5.58**	9.41**	-4.16*	3.43	-5.58	-12.30	18.80*
BG 105 x RD 2552	3.49	-0.90	5.26	-0.36	-3.74*	4.69**	-15.35**	-20.49**	-3.82	30.48**	16.42*	16.70**
PL 426 x BHS 380	-6.65	-18.38**	17.17*	4.92**	-1.62	0.31	-5.82**	-14.05**	-0.19	37.81**	20.94*	3.23
PL 426 x BH 902	-2.45	-6.33	10.68	4.92**	-12.35**	-9.67**	-5.06**	-9.65**	-11.41**	21.76**	19.68*	6.85
PL 426 x BH 946	-11.75*	-16.60**	-10.13	9.90**	-11.47**	-1.48	-2.10	-2.69	-3.46	-2.54	-9.37	-0.41
PL 426 x BH 959	-8.20	-15.88**	3.10	16.92**	-5.89**	-2.85*	-9.39**	-16.22**	-24.81**	3.75	-0.98	20.21**
PL 426 x RD 2715	-1.98	-19.51**	-5.63	3.93**	-8.95**	-0.93	-2.41	-3.28	-6.78**	15.77*	7.48	-2.19
PL 426 x RD 2786	2.27	-10.17	4.40	9.28**	-11.34**	-6.59**	12.18**	4.76*	5.03*	-8.82	-12.81	-7.42
PL 426 x RD 2552	8.99	-13.27*	-4.65	7.74**	-3.33*	6.49**	-1.72	-2.38	-1.13	36.63**	25.33**	-14.87**
BHS 380 x BH 902	-11.20	-19.49**	-0.19	3.06*	-8.98**	-13.59**	-11.82**	-23.04**	-10.24**	25.60**	11.89	9.56
BHS 380 x BH 946	-16.70**	-23.32**	-10.12	4.21**	-11.53**	9.72**	-4.43*	-12.30**	-18.76**	23.65**	1.97	7.16
BHS 380 x BH 959	-0.89	-5.90	17.45*	-9.47**	-23.20**	-18.40**	0.14	-1.28	8.82**	-6.79	-21.41**	-9.00
BHS 380 x RD 2715	-6.45	-13.08	-9.34	4.34**	-2.99*	4.65**	-4.54*	-12.17**	-3.35	10.86	-8.70	-3.95
BHS 380 x RD 2786	-6.59	-7.09	-10.34	3.95**	-11.05**	8.84**	13.97**	11.18**	-4.22	-17.98*	-30.73**	10.09
BHS 380 x RD 2552	12.65	0.83	7.51	-4.59**	-8.99**	-5.38**	-12.35**	-20.50**	2.49	-5.85	-23.26**	-20.45*
BH 902 x BH 946	-3.27	-4.87	21.22**	-4.27**	-8.55**	-12.56**	-4.18*	-9.33**	5.52*	-20.33**	-27.08**	21.54*
BH 902 x BH 959	1.11	-3.71	5.62	-6.87**	-11.10**	-15.63**	0.15	-11.51**	-1.11	-3.17	-9.08	26.31**
BH 902 x RD 2715	-0.89	-15.87*	4.45	-2.79*	-8.06**	-5.83**	-5.34**	-10.67**	10.96**	-8.07	-15.99*	12.41
BH 902 x RD 2786	-11.81	-19.66**	1.69	8.48**	4.59**	-1.30	-13.87**	-23.18**	-30.53**	-3.51	-9.24	-1.33
BH 902 x RD 2552	-9.30	-25.51**	-17.00*	-4.76**	-12.18**	3.29*	-0.64	-4.82*	16.06**	-14.00*	-22.34**	-7.48
BH 946 x BH 959	1.83	-1.45	24.54**	-4.33**	-4.41**	-3.33**	-13.34**	-19.42**	-0.32	-12.83*	-15.17*	17.82*
BH 946 x RD 2715	-9.55	-22.14**	-18.96*	5.27**	-4.61**	2.65*	-13.00**	-13.26**	-2.51	9.39	9.21	9.68
BH 946 x RD 2786	2.28	-5.38	10.76	1.12	0.16	-2.58*	3.79	-2.53	-3.64	-19.33**	-21.65**	-9.91
BH 946 x RD 2552	-17.68*	-31.49**	-3.31	-1.82	-13.16**	-13.53**	-3.64	-4.87*	9.92**	7.68	6.10	-16.14*
BH 959 x RD 2715	-4.16	-15.12*	-5.50	-0.67	-10.07**	10.21**	-9.27**	-15.41**	11.84**	27.48**	23.84**	17.89**
BH 959 x RD 2786	14.53*	9.30	-5.61	4.63**	3.56**	2.20	0.39	-0.67	-9.21**	15.54*	15.31*	-8.72
BH 959 x RD 2552	21.56**	3.96	14.38*	0.14	-11.50**	-11.61**	-16.29**	-23.07**	-9.73**	17.30**	12.51	3.65
RD 2715 x RD 2786	-2.17	-9.56	6.27	1.75	-7.01**	1.72	-3.66	-9.27**	-7.02**	0.73	-2.33	-13.80
RD 2715 x RD 2552	32.25**	27.02**	17.47*	3.27*	0.52	-5.08**	-12.71**	-14.07**	-2.02	-21.65**	-22.67**	1.84
RD 2786 x RD 2552	9.71	-2.26	17.59*	1.25	-9.70**	18.34**	-4.09	-11.00**	1.16	-3.27	-7.39	-13.04
SE	1.68	1.94		0.73	0.84		0.73	0.84		2.87	3.32	

*, ** Significant at 5 percent and 1 percent levels, respectively.

Table 4: Extent of heterosis (H), heterobeltiosis (HB) and inbreeding depression (ID) for grain yield per plant, harvest index and malt score

Crosses	Grain yield per plant			Harvest index			Malt score		
	H	HB	ID	H	HB	ID	H	HB	ID
BHS 400 x BG 105	1.04	-5.66	17.83*	-4.82**	-6.01**	1.46	-0.10	-3.90**	0.37
BHS 400 x PL 426	36.98**	32.49**	3.37	1.41	-3.73*	-6.80**	-1.03	-6.99**	0.28
BHS 400 x BHS 380	39.65**	36.15**	16.64*	-0.93	-3.37*	-4.70**	2.11*	-0.70	3.32**
BHS 400 x BH 902	-21.95**	-29.62**	2.10	-2.42	-5.97**	-5.26**	8.92**	4.52**	1.18
BHS 400 x BH 946	20.65**	2.16	4.84	-6.43**	-8.12**	-5.44**	1.65*	-2.80**	-2.31*
BHS 400 x BH 959	29.61**	13.39	-9.55	-10.21**	-10.89**	-9.37**	3.92**	-1.93*	-2.79**
BHS 400 x RD 2715	-3.55	-12.42	11.39	2.25	-3.90*	-1.27	-0.45	-2.05*	-2.01*
BHS 400 x RD 2786	-0.61	-14.55*	-0.85	-8.66**	-11.30**	-6.94**	3.78**	1.27	-2.64**
BHS 400 x RD 2552	-2.67	-11.3	0.74	7.26**	-0.79	0.34	7.63**	6.59**	0.39
BG 105 x PL 426	35.48**	30.62**	-5.48	-1.91	-7.99**	-7.73**	1.33	-1.10	0.50
BG 105 x BHS 380	-4.03	-12.47	0.36	-3.15*	-4.35**	-7.13**	-2.59**	-3.67**	-7.78**
BG 105 x BH 902	5.82	1.93	-9.82	9.32**	6.64**	-2.45	2.60**	2.34*	-0.91
BG 105 x BH 946	-11.92	-20.75**	6.29	10.93**	10.31**	-6.09**	-0.73	-1.35	-3.13**
BG 105 x BH 959	21.09**	12.87	-12.66*	8.40**	7.84**	-9.96**	1.06	-0.94	1.01
BG 105 x RD 2715	28.00**	24.21**	12.53*	0.00	-7.11**	2.60	-0.97	-3.22**	-2.54**
BG 105 x RD 2786	0.39	-8.16	11.22	6.50**	4.72**	-9.18**	1.11	-0.37	-1.81
BG 105 x RD 2552	7.04	4.28	10.46	-18.94**	-25.89**	-7.64**	-1.83*	-6.43**	1.38
PL 426 x BHS 380	32.83**	25.36**	1.08	-4.80**	-11.74**	-2.07	-1.05	-4.47**	1.61
PL 426 x BH 902	17.77*	9.53	5.53	-3.73*	-11.76**	-1.57	-0.31	-2.46**	-0.93
PL 426 x BH 946	-5.88	-18.01**	0.29	-2.89	-9.39**	0.99	-0.50	-2.28*	2.97**
PL 426 x BH 959	9.22	-1.59	15.46*	5.29**	-0.76	-5.90**	-3.11**	-3.54**	-2.85**
PL 426 x RD 2715	22.40**	14.64	-1.95	5.33**	4.23*	0.10	-2.46**	-6.91**	-0.30
PL 426 x RD 2786	-12.37	-22.44**	-7.57	-3.63*	-11.02**	-0.02	0.98	-2.85**	-2.78**
PL 426 x RD 2552	28.41**	20.73**	-20.50**	-6.40**	-8.94**	-4.71*	3.00**	-4.07**	9.87**
BHS 380 x BH 902	21.71**	7.31	9.38	-2.97*	-4.17**	-0.42	1.55	0.17	-4.56**
BHS 380 x BH 946	0.21	-16.89**	7.01	-19.00**	-19.55**	-0.45	4.56**	2.75**	-0.12
BHS 380 x BH 959	-5.61	-19.20**	-12.26	0.88	-0.87	-3.00	1.39	-1.70	-2.39**
BHS 380 x RD 2715	4.35	-7.38	-0.68	-7.67**	-15.22**	3.24	-1.13	-2.30*	2.32*
BHS 380 x RD 2786	-11.96	-25.89**	5.28	7.47**	6.99**	-5.26**	2.85**	2.49**	-0.85
BHS 380 x RD 2552	6.82	-4.85	-15.05*	10.70**	0.08	4.51**	-2.95**	-6.51**	0.81
BH 902 x BH 946	-11.76	-17.80**	15.39	10.61**	8.50**	-7.73**	-3.20**	-3.57**	0.24
BH 902 x BH 959	4.03	0.53	15.44*	7.23**	4.09*	-14.76**	-3.86**	-5.53**	5.31**
BH 902 x RD 2715	-3.85	-4.58	15.71*	3.46*	-6.08**	3.71*	0.00	-2.51**	2.25*
BH 902 x RD 2786	3.72	-1.69	-9.52	7.64**	6.78**	-7.96**	5.78**	3.98**	2.21*
BH 902 x RD 2552	-13.04*	-14.06	-3.78	-0.13	-10.72**	3.60*	9.15**	3.78**	7.18**
BH 946 x BH 959	-4.23	-7.82	14.47*	9.73**	8.56**	-4.24**	-2.85**	-4.17**	2.88**
BH 946 x RD 2715	10.22	1.95	5.46	0.68	-6.97**	-4.75**	-2.79**	-5.58**	0.27
BH 946 x RD 2786	-13.23*	-14.81*	-18.67*	7.67**	6.46**	-7.86**	1.30	-0.80	4.82**
BH 946 x RD 2552	3.21	-4.90	-6.53	-4.57**	-13.19**	7.90**	-2.67**	-7.79**	1.90
BH 959 x RD 2715	22.40**	17.42*	18.86**	-4.30**	-10.69**	1.18	-2.53**	-6.58**	1.00
BH 959 x RD 2786	19.65**	17.26*	-13.80*	3.61*	1.36	-4.55**	-2.12**	-5.43**	-2.84**
BH 959 x RD 2552	21.64**	16.24*	0.54	3.23*	-5.18**	-3.16	-1.54	-7.92**	1.45
RD 2715 x RD 2786	-9.73	-15.06*	0.09	-10.78**	-18.41**	12.12**	-2.00*	-2.82**	3.90**
RD 2715 x RD 2552	-15.06*	-15.4*	-3.02	8.22**	6.39**	-4.94**	0.12	-2.42*	-3.48**
RD 2786 x RD 2552	-4.72	-10.69	-9.17	-2.12	-11.86**	3.40	-1.23	-4.51**	-0.78
SE	1.25	1.44		0.66	0.76		0.63	0.73	

*, ** Significant at 5 percent and 1 percent levels, respectively.

Conclusion

Sufficient degree of heterosis and heterobeltiosis were observed for all the characters. Cross BHS 400 x BHS 380, BHS 400 x PL 426 and BG 105 x PL 426 exhibited desirable heterosis and heterobeltiosis for three or more yield attributing characters. The crosses PL 426 x RD 2552 and BH 959 x RD 2786 depicted significant heterosis and heterobeltiosis along with desirable inbreeding depression i.e. a significant increase in F_2 over F_1. This cross was considered most desirable as it may throw transgressive segregants in higher frequency in later generations. The results of present investigation have an important relevance on future breeding strategies.

Application of Research

Overall appraisal of the results in the present study, advocated that reciprocal recurrent selection, diallel selective mating, use of multiple crosses and bi-parental mating may be effective alternative approaches for tangible advancement of barley yield in the coming years.

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