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Research Article

HETEROSIS AND INBREEDING DEPRESSION STUDIES FOR GRAIN YIELD AND RELATED TRAITS IN BARLEY (*Hordeum vulgare* L.) UNDER EARLY AND TIMELY SOWN CONDITIONS

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Abstract: Heterosis for grain yield per plant ranged from -20.75 (RD 2715 × RD 2552) to 41.86 per cent (BHS 400 × BH 959) and -21.95 (BHS 400 × BH 902) to 39.65 per cent (BHS 400 × BHS 380) under early and timely sown conditions, respectively. Out of 45 crosses, nine and fifteen crosses exhibited positive significant heterosis in early and timely sown conditions, respectively; while, seven and nine crosses exhibited positive significant heterobeltiosis in early and timely sown conditions, respectively. Negative significant inbreeding depression for grain yield per plant was reported during study which indicated that F2 plants attained comparatively higher grain yield per plant than F1 hybrids and considered to be desirable. In both the early and timely sown conditions, the crosses BG 105 x PL 426, PL 426 × RD 2552 and BH 959 x RD 2786 exhibited positive significant heterosis and heterobeltiosis as well as negative significant inbreeding depression. Hence, these crosses were considered to be most desirable for grain yield per plant. Accordingly, these cross combinations may be utilized for improving grain yield as well as production of better transgressive segregants in advance generations for maintain of specific gene pool of barley through breeding program in future.

Keywords: Heterosis, Inbreeding depression, Barley, Grain yield, Timely sown

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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 generally grown in regions, where other cereals grow poorly due to low rainfall, altitude and soil salinity. It is considered as the first cereal domesticated for use by man as food and feed [1].The major barley producing countries of world are Canada, USA, Germany, France, Spain, Turkey, UK, Denmark, Russia, central Asia countries and Australia. In India, it is grown in 693 thousand hectares with average grain productivity 2580 kg per hectare and total production of 1788 MT (Anonymous,2016-17), whereas in Rajasthan, it is grown in 276 thousand hectares with average grain productivity 3297 kg per hectare and total production of 910 thousand ton [2]. This production 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) [3]. 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. One of the most important factors in determining feasibility of hybrid is the amount of heterosis and its exploitation. The presence of heterosis indicates the ability of diverse parents to combine in a hybrid combination. Exploitation of heterosis is considered as one of the outstanding achievements of plant breeding. 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 - the bread bowl of India. 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 [4]. In a self-pollinated crop, like barley, the utilization of heterosis depends mainly upon the direction and magnitude of heterosis. However, grain yield as well as related traits is highly influenced by environmental fluctuation thus, the study based on solitary environment may not be much useful because of genotype x environment interaction. 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 undertaken to study the heterosis, heterobeltiosis and inbreeding in 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 under early (5^{th} November) and timely (20^{th} November) sown conditions at Rajasthan Agricultural Research Institute, 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 yield and related characters under early and timely sown conditions, 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 [5]. The following formulae were used for the estimation of heterosis and heterobeltiosis in the both environments for all the characters.

Heterosis over mid parent (H%) = [(F1 - MP)/MP x 100]

SE (F_1 - MP) = (3Me/2r)1/2

Heterosis over better parent (HB%) = [(F1- BP)/BP x 100]

SE (F_1 - BP) = (2Me/r)1/2

Where,

Me = error mean squares for parents and F1's data of individual environment;

MP =mean mid parent value =(P_1 + P_2)/2;

P1=mean performance of parent one;
P2 = mean performance of parent two; BP = mean better parent value;
R= number of replications;
Inbreeding depression (ID%)=[(F_1-F_2)/F_1 x 100]
SE (F_1-F_2) = (2Me/r)1/2
Where,
Me = error mean square from the ANOVA of individual environment.
Significance of heterosis and heterobeltiosis and inbreeding depression were tested by 't' test using S Evalues in all the characters under both the environment, separately.

Results and discussion

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. 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. Heterosis for grain yield per plant ranged from -20.75 percent (RD 2715 × RD 2552) to 41.86 percent (BHS 400 × BH 959) in early and -21.95 percent (BHS 400 × BH 902) to 39.65 percent (BHS 400 × BHS 380) in timely sown condition (Table 2). Out of 45 crosses, nine and fifteen crosses exhibited positive significant heterosis in early and timely sown conditions, respectively while, seven crosses in early and nine crosses in timely sown conditionexhibited positive significant heterobeltiosis.

Table-1 Analysis of variance showing mean squares for parents, F1 and F2 for yield and related traits under early (E1) and timely (E2) sown conditions

Characters	Env.	Replication	Genotype	Parents	Generation	F_1	F_2	F_1 vs F_2	Parents vs Generation	Error
d.f.		(2)	(99)	(9)	(89)	(44)	(44)	(1)	(1)	(198)
Days to heading	E_1	0.72	94.38**	97.93**	94.79**	79.58**	111.95**	8.89	26.21**	3.78
	E_2	1.16	99.10**	89.37**	100.81**	95.86**	107.31**	32.96**	34.83**	0.54
Days to maturity	E_1	1.24	132.48**	35.63**	143.75**	67.66**	179.84**	1904.03**	0.48	2.22
	E_2	1.66*	49.23**	25.69**	51.65**	46.81**	46.63**	485.35**	46.41**	0.37
Plant height	E_1	1.24	132.48**	35.63**	143.75**	67.66**	179.84**	1904.03**	0.48	2.22
	E_2	1.66*	49.23**	25.69**	51.65**	46.81**	46.63**	485.35**	46.41**	0.37
No. of effective tillers per plant	E_1	0.19	9.68**	8.89**	9.72**	8.03**	11.62**	0.16	13.84**	0.46
	E_2	0.18	7.31**	7.94**	7.30**	5.88**	8.85**	1.61	2.90**	0.42
Flag leaf area	E_1	0.58	29.07**	43.14**	27.97**	31.26**	25.23**	3.44	0.45	1.11
	E_2	1.88	29.14**	56.66**	26.67**	25.69**	28.00**	11.30	1.80	5.66
No. of grains per spike	E_1	0.30	125.01**	308.78**	105.57**	127.02**	86.25**	11.65**	201.28**	1.12
	E_2	0.52	162.27**	306.94**	148.03**	121.08**	175.12**	141.36**	127.82**	1.05
1000-grain weight	E_1	1.12	49.27**	63.21**	47.77**	35.76**	60.75**	5.42*	57.41**	1.10
	E_2	0.99	47.58**	62.68**	45.49**	31.86**	60.14**	0.25	98.43**	1.30
Biomass per plant	E_1	17.68	129.54**	52.47**	138.59**	108.61**	171.72**	0.29	17.52	7.70
	E_2	7.72	221.08**	112.22**	233.55**	193.03**	274.90**	197.13**	91.20*	16.49
Grain yield per plant	E_1	1.30	22.74**	19.36**	23.29**	15.92**	30.98**	9.13*	3.99	1.41
	E_2	1.04	28.13**	15.83**	29.29**	20.62**	38.55**	2.64	36.25**	3.11
Harvest index	E_1	39.51**	94.23**	63.18**	95.76**	65.29**	127.41**	43.68**	237.23**	1.55
	E_2	3.57*	76.10**	41.09**	80.31**	56.62**	103.00**	124.56**	16.20**	0.87
Malt Score	E_1	0.12	35.32**	41.82**	34.76**	29.24**	40.81**	10.99**	27.33**	1.04
	E_2	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 Range of heterosis and number of desirable crosses for yield and its contributing characters in early (E1) and timely (E2) sown condition

Characters	Range of heterosis (%)				Number of crosses showing heterosis			
	Heterosis (over mid-parent)		Heterobeltiosis		Heterosis (over mid-parent)		Heterobeltiosis	
	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2
Days to heading	-14.61 - 3.38	-10.14 - 7.34	-5.95 - 11.51	-8.91 - 17.55	7	13	3	8
Days to maturity	-6.39 - 9.78	-4.29 - 7.97	-3.28 - 13.94	-3.92 - 12.23	8	9	4	6
Plant height	-15.21 - 1.20	-12.54 - 9.43	-13.08 - 4.12	-8.28 - 11.45	29	12	19	8
Effective tillers per plant	-13.31 - 36.50	-20.4 - 30.64	-26.2 - 20.20	-34.26 - 15.43	19	11	5	2
Flag leaf area	-22.27 - 27.02	-17.68 - 32.25	-35.77 - 18.59	-31.49 - 27.02	13	8	4	2
No. of grains per spike	-11.30 - 21.34	-9.47 - 17.21	-22.13 - 10.95	-24.39 - 8.13	30	27	11	3
1000-grain weight	-3.99 - 12.81	-17.19 - 14.48	-13.97 - 11.15	-24.15 - 11.18	27	5	7	2
Biomass per plant	-32.29 - 36.47	-21.65 - 44.41	-34.71 - 23.99	-30.73 - 33.08	9	16	7	11
Grain yield per plant	-20.75 - 41.86	-21.95 - 39.65	-27.12 - 30.03	-29.62 - 36.15	9	15	7	9
Harvest index	-10.57 - 16.94	-19.00 - 10.93	-17.65 - 15.74	-25.89 - 10.31	27	18	16	12
Malt Score	-4.85 - 9.98	-8.03 - 5.35	-8.03 - 5.35	-7.92 - 6.59	14	12	8	7

Table-3 Extent of heterosis (H), heterobeltiosis (HB) and inbreeding depression (ID) for grain yield per plant in early (E1) and timely (E2) sown condition

Crosses	Grain yield per plant					
	E_1			E_2		
	H	HB	ID	H	HB	ID
BHS 400 x BG 105	-4.95	-15.00*	-1.50	1.04	-5.66	17.83*
BHS 400 x PL 426	36.89**	22.32**	4.52	36.98**	32.49**	3.37
BHS 400 x BHS 380	9.02	5.35	-5.58	39.65**	36.15**	16.64*
BHS 400 x BH 902	-8.42	-20.65**	-4.14	-21.95**	-29.62**	2.10
BHS 400 x BH 946	1.27	-18.26**	1.75	20.65**	2.16	4.84
BHS 400 x BH 959	41.86**	18.25**	-10.68*	29.61**	13.39	-9.55
BHS 400 x RD 2715	-4.93	-18.90**	6.61	-3.55	-12.42	11.39
BHS 400 x RD 2786	-11.29*	-27.12**	-3.70	-0.61	-14.55*	-0.85
BHS 400 x RD 2552	0.96	-11.94*	-0.30	-2.67	-11.30	0.74
BG 105 x PL 426	30.12**	30.03**	-15.68**	35.48**	30.62**	-5.48
BG 105 x BHS 380	2.91	-5.05	-7.41	-4.03	-12.47	0.36
BG 105 x BH 902	12.31*	8.36	-2.19	5.82	1.93	-9.82
BG 105 x BH 946	-9.39*	-19.39**	4.82	-11.92	-20.75**	6.29
BG 105 x BH 959	31.54**	21.43**	-9.74*	21.09**	12.87	-12.66*
BG 105 x RD 2715	-9.20	-13.94*	-3.24	28.00**	24.21**	12.53*
BG 105 x RD 2786	-6.55	-15.16**	6.11	0.39	-8.16	11.22
BG 105 x RD 2552	1.93	-0.91	7.98	7.04	4.28	10.46
PL 426 x BHS 380	0.03	-7.77	-13.22**	32.83**	25.36**	1.08
PL 426 x BH 902	3.43	-0.14	1.79	17.77*	9.53	5.53
PL 426 x BH 946	8.97	-2.99	12.81*	-5.88	-18.01**	0.29
PL 426 x BH 959	-6.84	-13.94**	0.86	9.22	-1.59	15.46*
PL 426 x RD 2715	7.09	1.58	4.98	22.40**	14.64	-1.95
PL 426 x RD 2786	-4.81	-13.53**	0.72	-12.37	-22.44**	-7.57
PL 426 x RD 2552	24.26**	20.89**	-17.48**	28.41**	20.73**	-20.50**
BHS 380 x BH 902	0.43	-10.32	-2.56	21.71**	7.31	9.38
BHS 380 x BH 946	-7.25	-23.07**	5.05	0.21	-16.89**	7.01
BHS 380 x BH 959	-3.62	-17.33**	-8.07	-5.61	-19.20**	-12.26
BHS 380 x RD 2715	6.95	-6.03	5.32	4.35	-7.38	-0.68
BHS 380 x RD 2786	-13.64**	-27.05**	-3.88	-11.96	-25.89**	5.28
BHS 380 x RD 2552	7.50	-3.34	-2.87	6.82	-4.85	-15.05*
BH 902 x BH 946	-10.76*	-17.97**	18.69**	-11.76	-17.80**	15.39
BH 902 x BH 959	-5.50	-9.74	-0.56	4.03	0.53	15.44*
BH 902 x RD 2715	-2.93	-4.70	0.04	-3.85	-4.58	15.71*
BH 902 x RD 2786	0.75	-5.42	8.00	3.72	-1.69	-9.52
BH 902 x RD 2552	5.94	5.11	4.41	-13.04*	-14.06	-3.78
BH 946 x BH 959	-14.80**	-18.17**	-12.79**	-4.23	-7.82	14.47*
BH 946 x RD 2715	-1.10	-7.52	5.25	10.22	1.95	5.46
BH 946 x RD 2786	9.68*	7.24	-0.56	-13.23*	-14.81*	-18.67*
BH 946 x RD 2552	1.13	-7.71	-9.67	3.21	-4.90	-6.53
BH 959 x RD 2715	6.62	3.68	7.74	22.40**	17.42*	18.86**
BH 959 x RD 2786	30.24**	27.89**	-10.88**	19.65**	17.26*	-13.80*
BH 959 x RD 2552	21.78**	15.46**	5.19	21.64**	16.24*	0.54
RD 2715 x RD 2786	-19.95**	-23.52**	1.18	-9.73	-15.06*	0.09
RD 2715 x RD 2552	-20.75**	-22.79**	-4.15	-15.06*	-15.40*	-3.02
RD 2786 x RD 2552	3.99	-3.09	-10.50*	-4.72	-10.69	-9.17
SE	0.84	0.97		1.25	1.44	

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

Table-4 Crosses possessing high heterosis and heterobeltiosis for grain yield per plant along with desirable (+) heterotic expression for other characters in early (E1) and timely (E2) sown condition

Particulars	Heterosis						Heterobeltiosis					
Environments	E_1			E_2			E_1			E_2		
Crosses possessing high heterosis and heterobeltiosis for grain yield per plant	BHS 400 x BH 959	BHS 400 x PL 426	BG 105 x BH 959	BHS 400 x BHS 380	BHS 400 x PL 426	BG 105 x PL 426	BG 105 x PL 426	BH 959 x RD 2786	BHS 400 x PL 426	BHS 400 x BHS 380	BHS 400 x PL 426	BG 105 x PL 426
Days to heading	+	-	+	-	-	+	+	-	-	-	-	+
Days to maturity	+	-	+	-	-	-	-	+	-	-	-	-
Plant height	+	-	+	+	-	+	+	+	-	-	-	+
No. of effective tillers per plant	+	+	+	-	-	+	-	-	-	-	-	-
Flag leaf area	-	-	+	-	-	+	-	+	-	-	-	-
No. of grains per spike	+	-	-	+	+	+	-	+	-	-	-	-
1000-grain weight	+	-	+	-	-	-	-	-	-	-	-	-
Biomass per plant	+	+	+	+	+	+	+	+	-	+	+	+
Harvest index	+	+	+	-	-	-	-	+	+	-	-	-
Malt Score	+	-	+	+	-	-	+	-	-	-	-	-

The crosses BHS 400 × PL 426, BG 105 x PL 426, PL 426 × RD 2552, BH 959 x RD 2786 and BH 959 × RD 2552 in both the sowing time exhibited positive significant heterosis and heterobeltiosis. Hence, these crosses were considered to be most desirable for grain yield per plant. Higher grain yield per plant is an advantageous and most desirable parameter which is associated with negative inbreeding depression. Inbreeding depression for grain yield per plant ranged from -17.48 percent (PL 426 × RD 2552) to 18.69 percent (BH 902 × BH 946) in early and -20.50 percent (PL 426 × RD 2552) to 18.86 percent (BH 959 × RD 2715) in timely sown condition (Table 2). Twenty four and eighteen crosses tilted towards negative magnitude in early and timely sown condition, respectively; out of which eight crosses in early and five crosses in timely sown condition manifested negative significant inbreeding depression which indicated that F_2 plants attained comparatively higher grain yield per plant than F_1 hybrids and considered to be desirable. The results in different environments for grain yield per plant are in conformity with the previous findings in varying environments for different characters [6-9]. 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. Three best heterotic and heterobeltiotic crosses for grain yield per plant are presented in (Table 3). Perusal of this table divulged an interesting relationship between heterosis and heterobeltiosis of grain yield per plant and other yield attributing characters that the cross BHS 400 x PL 426 for both the sowing time and cross BHS 400 x BHS 380 and BG 105 x PL 426 in timely sown condition only exhibited desirable heterosis and heterobeltiosis at least for one or more yield related traits. Hence, these crosses may be considered as promising type for tangible advancement of barley yield under early and timely sown conditions. Such as, heterosis and heterobeltiosis for grain yield per plant was mainly contributed by days to maturity, plant height, number of effective tillers per plant, number of grains per spike, biomass per plant and harvest index in all the three environments. Findings of this investigation [10], 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 earlier findings [1,7] as they also reported maximum heterosis for grain yield per plant.

Conclusion

Sufficient degree of heterosis and heterobeltiosis were observed for all the characters. Among the top three crosses for grain yield per plant the cross BHS 400 x PL 426 had showed desirable heterosis and heterobeltiosis for one or more characters in both the sowing conditions. The cross combination PL 426 x RD 2552 depicted significant heterosis and heterobeltiosis along with desirable inbreeding depression i.e. a significant increase in F_2 over F_1, in both the sowing times. This cross was considered most desirable as it may throw transgressive segregants in higher frequency in later generations. On the basis of per se performance, SCA effects, heterosis, heterobeltiosis and inbreeding depression, the cross PL 426 x RD 2552 emerged as best cross for grain yield per plant as well as other characters in both early and timely sown conditions. The results of present investigation have an important relevance on future breeding strategies. The additive gene action has been exploited more in barley, whereas the non-additive variance which is outcome of dominance and epistasis gene interaction remains to be utilized, which can be exploited for further improvement of barley through systematic breeding programme for the targeted environment. Overall appraisal of the results in the present study, advocated that reciprocal recurrent selection [11], 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 [12,13].

Application of research: As non-additive gene actions were found to be more dominant in the present investigation and heterosis may not be worthwhile in a crop like barley so that In addition to conventional breeding methods some non-conventional breeding methods such as diallel selective mating, bi-parental mating in early segregating generations or reciprocal recurrent selection followed by selection or multiple crosses might prove to be effective alternative approach for advancement of grain yield in barley.

Research Category: Plant breeding

Abbreviations

MP-Mid parent, BP-Better parent, ANOVA-Analysis of variance, F_1-First filial generation, F_2-Second filial generation

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