https://doi.org/10.56093/ijas.v90i7.105600

Indian Journal of Agricultural Sciences **90** (7): 1306–9, July 2020/Article

Heterosis studies in 6-rowed barley (*Hordeum vulgare*) under different sowing condition

CHHAGAN LAL, A S SHEKHAWAT, JOGENDRA SINGH*, S S RAJPUT, SHEETAL RAJ SHARMA and PAWAN KUMAR

Rajasthan Agricultural Research Institute, Durgapura, Rajasthan 302 018, India

Received: 11 September 2019; Accepted: 03 October 2019

ABSTRACT

A set of diallel crosses involving 10 diverse parents (excluding reciprocals) of barlay (*Hordeum vulgare* L.) was made and its F_2's were evaluated under three different date of sowings during *rabi* 2015-16 and 2016-17 at RARI, Durgapura, Jaipur, Rajasthan, India. Heterosis for grain yield per plant ranged from -20.75 to 41.86 %; -21.95 to 39.65 %and -48.13 to 64.34 % under early (E_1), normal (E_2) and late (E_3) sowing conditions, respectively. Out of 45 crosses, nine crosses in E_1 and fifteen crosses in each E_2 and E_3 exhibited positive significant heterosis while, seven crosses in E_1 and E_3 and nine crosses in E_2 exhibited positive significant heterobeltiosis. Negative significant inbreeding depression for grain yield per plant was reported. Overall, crosses BHS 400 × PL 426, PL 426 × RD 2552 and BH 959 × RD 2552 exhibited positive significant heterosis and heterobeltiosis. Hence, these crosses 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.

Key words: Heterosis, Inbreeding depression, Six-rowed barley, Diallel crosses, Grain yield.

Barley (*Hordeum vulgare* L., 2n=2x=14) generally grown in regions, where other cereals grow poorly due to low rainfall, altitude and soil salinity. In India, it is grown in 693 thousand ha with average grain productivity 2580 kg ha^{-1} and total production of 1788 MT [Anonymus 2016-17]. This production is far below to most of developed countries such as Germany (5425 kg ha^{-1}), France (6685 kg ha^{-1}) and United Kingdom (5931 kg ha^{-1}) [FAO 2016].

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 helps the plant breeder in eliminating the less productive crosses in early generations. The study of heterosis has a direct bearing on the breeding methodology to be employed for varietal improvement and it also provides information about usefulness of the parents in breeding programs (Singh *et al.* 2012).

However, grain yield as well as component character are highly influenced by environmental fluctuationthus, the study based on solitary environment may not be much useful because of genotype × environment interaction. Keeping in view the above points, the present investigation was undertaken to study the heterosis, heterobeltiosis and inbreeding in 6-rowed barley.

*Corresponding author e-mail:jschouhanpbg@gmail.com

MATERIALS AND METHODS

Ten varieties of barley namely, BHS 400, BG 105, PL 426, BHS 380, BH 902, BH 946, BH 959, RD 2715, RD 2786 and RD 2552 were crossed indiallel 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 (E_1- 5th November), normal (E_2- 20th November) and late (E_3- 5th December) sown conditions during *rabi* 2015-16 and 2016-17 at RARI, Durgapura, Jaipur, Rajasthan, India. Plots of parents and F_1's consisted of two rows of three meters 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 namely days to heading, days to maturity, plant height (cm), effective tillers per plant, flag leaf area (cm^2), grains per spike, 1000-grain weight (g), biomass per plant (g), grain yield per plant (g) and harvest index (%) 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). 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 and Foster (1998) and; Fonseca and Patterson (1968), respectively.

Table 1 Range of heterosis and number of desirable crosses for yield and its contributing characters in individual environment

Character	Range of heterosis (%)						Number of crosses showing heterosis					
	Heterosis (over mid-parent)			Heterobeltiosis			Heterosis (over mid-parent)			Heterobeltiosis		
	E_1	E_2	E_3	E_1	E_2	E_3	E_1	E_2	E_3	E_1	E_2	E_3
Days to heading	-14.61-3.38	-10.14-7.34	-7.98-7.38	-5.95-11.51	-8.91-17.55	-5.63-14.36	7	13	8	3	8	1
Days to maturity	-6.39-9.78	-4.29-7.97	-3.22-15.38	-3.28-13.94	-3.92-12.23	-3.19-18.88	8	9	6	4	6	4
Plant height	-15.21-1.20	-12.54-9.43	-7.78-14.45	-13.08-4.12	-8.28-11.45	-7.01-17.24	29	12	12	19	8	8
Effective tillers per plant	-13.31-36.50	-20.4-30.64	-27.36-19.47	-26.2-20.20	-34.26-15.43	-31.83-10.45	19	11	2	5	2	0
Flag leaf area	-22.27-27.02	-17.68-32.25	-27.72-29.20	-35.77-18.59	-31.49-27.02	-37.14-19.98	13	8	9	4	2	5
Grains per spike	-11.30-21.34	-9.47-17.21	-9.06-28.70	-22.13-10.95	-24.39-8.13	-16.53-17.37	30	27	33	11	3	13
1000-grain weight	-3.99-12.81	-17.19-14.48	-17.21-13.44	-13.97-11.15	-24.15-11.18	-23.16-10.17	27	5	5	7	2	2
Biomass per plant	-32.29-36.47	-21.65-44.41	-58.80-60.84	-34.71-23.99	-30.73-33.08	-62.55-33.57	9	16	12	7	11	7
Grain yield per plant	-20.75-41.86	-21.95-39.65	-48.13-64.35	-27.12-30.03	-29.62-36.15	-51.36-50.58	9	15	15	7	9	7
Harvest index	-10.57-16.94	-19.00-10.93	-21.96-35.39	-17.65-15.74	-25.89-10.31	-32.08-28.98	27	18	29	16	12	20

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 of 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 segregants in advance generations for further amelioration of grain yield.

Heterosis ranged from -14.61 % to 3.38 % in E_1; -16.14 % to 7.34 % in E_2 and -7.98 % to 7.38 % in $E_3$for days to heading. Cross BG 105 xPL 426 and PL 426 × RD 2552 in all the three environments showed negative significant heterosis and heterobeltiosis (Table 1). Eight crosses in E_1 and twenty-one cross in E_2 and eighteen crosses in E_3 each exhibited positive significant inbreeding depression (Table 1). Similar results are in conformity with the findings obtained by Saad *et al.* (2013) and, Ram and Shekhawat (2017).

Heterosis ranged from -6.39 % to 9.78 % in E_1; -4.29% to 7.97 % in E_2 and -3.22 % to 15.38 % in E_3 for days to maturity. Crosses BH 959 × RD 2786 and BG 105 × BH 959 in all the environments exhibited negative significant heterosis and heterobeltiosis. Twenty eight crosses in E_1, 31 in E_2 and 29 cross in E_3 exhibited positive significant inbreeding depression (Table 1).

Heterosis ranged from -15.21 % to 1.20 % in E_1; -12.54 % to 9.43 % in E_2 and -7.78 % to 14.4 % in $E_3$for plant height. Crosses BHS 400 × BH 959, BG 105 × BH 959, PL 426 × BH 959, BG 105 × PL 426, BH 959 × RD 2552 and BG 105 × RD 2786 showed negative significant heterosis and heterobeltiosis in all the environments. Nineteen crosses in E_1, thirty-two crosses in E_2 and 29 crosses in E_3 exhibited positive significant inbreeding depression (Table 1). Results for days to maturity and plant height are similar with the findings obtained by Saad *et al.* (2013) and Mansour (2016).

Cross exhibited positive significant heterosis and heterobeltiosis were considered desirable. Heterosis ranged from -13.31% to 36.5% in E_1; -20.04 % to 30.64 % in E_2 and -27.36 % to 19.47 % in E_3 for effective tillers per plant. Crosses BHS 400 x BH 946 and BH 902 × BH 959 were reported positive significant heterosis and heterobeltiosis in E_1 and E_2. Eleven crosses in E_1, eight crosses in E_2 and 10 crosses in E_3 exhibited negative significant inbreeding depression (Table 1).Results are supported with the findings of Pesaraklu *et al.* (2016) and; Ram and Shekhawat (2017).

Heterosis ranged from -22.27 % to 27.02 % in E_1; -17.68 % to 32.25 % in E_2 and -27.72 % to 29.2 % in E_3 for flag leaf area. Crosses BG 105 × RD 2715 and RD 2715×RD 2552 showed positive significant heterosis and heterobeltiosis. Fourteen crosses in E_1, four crosses in E_2 and 16 crosses in E_3 exhibited negative significant inbreeding depression (Table 1). Results are in conformity with the investigation of Vishwakarma *et al.* (2011) and Saad *et al.* (2013).

Heterosis ranged from -11.3 % to 21.34 % in E_1; -9.47 % to 17.21 % in E_2 and -9.06 %to 28.7 %in $E_3$for grain per spike. Crosses BH 959 × RD 2786, BH 902 × RD 2786 and BG 105 ×RD 2715 in all the environments exhibited positive significant heterosis and heterobeltiosis. Eleven crosses in E_1; 23 crosses in E_2 and 13 crosses in E_3 exhibited negative significant inbreeding depression (Table 1). Results are in conformity with the findings obtained by Mansour (2016) and Pesaraklu *et al.* (2016).

Heterosis ranged from -3.99 % to 12.81 % in E_1; -17.19 %to 14.48 % in E_2 and -17.19 % to 14.48 % in $E_3$for 1000-grain weight. The cross BHS 380 × RD 2786 in all the environments exhibited positive significant heterosis and heterobeltiosis. Sixteen crosses in E_1 and 11

Table 2 Extent of heterosis (H), heterobeltiosis (HB) and inbreeding depression (ID) for grain yield per plant in individual environment

Crosse	Grain yield per plant								
	E_1			E_2			E_3		
	H	HB	ID	H	HB	ID	H	HB	ID
BHS 400 ×BG 105	-4.95	-15.00*	-1.50	1.04	-5.66	17.83*	-10.92	-29.67**	0.58
BHS 400 × PL 426	36.89**	22.32**	4.52	36.98**	32.49**	3.37	64.35**	48.44**	10.39
BHS 400 × BHS 380	9.02	5.35	-5.58	39.65**	36.15**	16.64*	17.52**	14.60*	-47.74**
BHS 400 × BH 902	-8.42	-20.65**	-4.14	-21.95**	-29.62**	2.10	-21.10**	-39.45**	-0.04
BHS 400 × BH 946	1.27	-18.26**	1.75	20.65**	2.16	4.84	2.94	-25.49**	22.30**
BHS 400 × BH 959	41.86**	18.25**	-10.68*	29.61**	13.39	-9.55	39.71**	6.04	-13.27*
BHS 400 × RD 2715	-4.93	-18.90**	6.61	-3.55	-12.42	11.39	-18.43**	-35.27**	11.65
BHS 400 × RD 2786	-11.29*	-27.12**	-3.70	-0.61	-14.55*	-0.85	-33.06**	-50.17**	2.76
BHS 400 × RD 2552	0.96	-11.94*	-0.30	-2.67	-11.30	0.74	-10.56	-22.52**	1.70
BG 105 × PL 426	30.12**	30.03**	-15.68**	35.48**	30.62**	-5.48	28.95**	10.77	11.47*
BG 105 × BHS 380	2.91	-5.05	-7.41	-4.03	-12.47	0.36	-18.27**	-36.64**	9.57
BG 105 × BH 902	12.31*	8.36	-2.19	5.82	1.93	-9.82	14.84**	10.47	13.63**
BG 105 × BH 946	-9.39*	-19.39**	4.82	-11.92	-20.75**	6.29	-45.13**	-51.36**	-57.75**
BG 105 × BH 959	31.54**	21.43**	-9.74*	21.09**	12.87	-12.66*	0.55	-4.76	-16.88**
BG 105 × RD 2715	-9.20	-13.94*	-3.24	28.00**	24.21**	12.53*	14.51**	13.73*	-2.91
BG 105 × RD 2786	-6.55	-15.16**	6.11	0.39	-8.16	11.22	-19.15**	-25.45**	9.00
BG 105 × RD 2552	1.93	-0.91	7.98	7.04	4.28	10.46	-8.12	-17.75**	-9.81
PL 426 × BHS 380	0.03	-7.77	-13.22**	32.83**	25.36**	1.08	17.00**	3.33	9.78
PL 426 × BH 902	3.43	-0.14	1.79	17.77*	9.53	5.53	48.35**	23.38**	16.61**
PL 426 × BH 946	8.97	-2.99	12.81*	-5.88	-18.01**	0.29	3.52	-19.51**	7.36
PL 426 × BH 959	-6.84	-13.94**	0.86	9.22	-1.59	15.46*	4.56	-14.14*	-1.43
PL 426 × RD 2715	7.09	1.58	4.98	22.40**	14.64	-1.95	1.63	-12.19	-10.7
PL 426 × RD 2786	-4.81	-13.53**	0.72	-12.37	-22.44**	-7.57	-20.58**	-36.22**	10.08
PL 426 × RD 2552	24.26**	20.89**	-17.48**	28.41**	20.73**	-20.50**	57.80**	50.58**	-16.41**
BHS 380×BH 902	0.43	-10.32	-2.56	21.71**	7.31	9.38	17.81**	-11.15	-16.31*
BHS 380 × BH 946	-7.25	-23.07**	5.05	0.21	-16.89**	7.01	-1.28	-29.65**	3.97
BHS 380 × BH 959	-3.62	-17.33**	-8.07	-5.61	-19.20**	-12.26	-3.69	-28.15**	-10.11
BHS 380 × RD 2715	6.95	-6.03	5.32	4.35	-7.38	-0.68	6.00	-17.43**	-19.92**
BHS 380 × RD 2786	-13.64**	-27.05**	-3.88	-11.96	-25.89**	5.28	-7.35	-32.16**	8.94
BHS 380 × RD 2552	7.50	-3.34	-2.87	6.82	-4.85	-15.05*	54.07**	30.67**	-14.32*
BH 902 × BH 946	-10.76*	-17.97**	18.69**	-11.76	-17.80**	15.39	-16.58**	-23.39**	3.80
BH 902 × BH 959	-5.50	-9.74	-0.56	4.03	0.53	15.44*	-13.21**	-14.60**	16.53*
BH 902 × RD 2715	-2.93	-4.70	0.04	-3.85	-4.58	15.71*	-48.13**	-50.44**	21.40
BH 902 × RD 2786	0.75	-5.42	8.00	3.72	-1.69	-9.52	-8.95	-12.88*	-2.54
BH 902 × RD 2552	5.94	5.11	4.41	-13.04*	-14.06	-3.78	-0.97	-14.33*	13.78*
BH 946 × BH 959	-14.80**	-18.17**	-12.79**	-4.23	-7.82	14.47*	4.85	-2.26	17.70**
BH 946 × RD 2715	-1.10	-7.52	5.25	10.22	1.95	5.46	12.41**	-0.94	1.11
BH 946 × RD 2786	9.68*	7.24	-0.56	-13.23*	-14.81*	-18.67*	-21.80**	-25.10**	-6.70
BH 946 × RD 2552	1.13	-7.71	-9.67	3.21	-4.90	-6.53	-15.91**	-32.26**	0.78
BH 959 × RD 2715	6.62	3.68	7.74	22.40**	17.42*	18.86**	1.52	-4.46	8.37
BH 959 × RD 2786	30.24**	27.89**	-10.88**	19.65**	17.26*	-13.80*	11.00*	7.89	1.18
BH 959 × RD 2552	21.78**	15.46**	5.19	21.64**	16.24*	0.54	49.43**	27.53**	20.11**
RD 2715 × RD 2786	-19.95**	-23.52**	1.18	-9.73	-15.06*	0.09	-8.22	-15.91**	11.96
RD 2715 × RD 2552	-20.75**	-22.79**	-4.15	-15.06*	-15.40*	-3.02	-0.53	-10.41	11.30
RD 2786 × RD 2552	3.99	-3.09	-10.50*	-4.72	-10.69	-9.17	13.18**	-5.65	11.71*
SE	0.84	0.97		1.25	1.44		0.69	0.80	

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

crosses in each E_2 and E_3 manifested negative significant inbreeding depression (Table 1). Results are in conformity with the investigation such as Vishwakarma *et al.* (2011) and Mansour (2016).

Heterosis ranged from -32.29 %to 36.47 % in E_1; -21.65 % to 44.41 % in E_2 and -58.80 %to 60.84 % in $E_3$for biomass per plant. The crosses BHS 400 × BH 959, BG 105 × PL 426 and PL 426 × RD 2552 in all the environments exhibited positive significant heterosis and heterobeltiosis. Five crosses in E_1, three crosses in E_2 and 13 crosses in E_3 exhibited negative significant inbreeding depression (Table 1).Results are similar with the findings of obtained such as Saad *et al.* (2013) and; Ram and Shekhawat (2017).

Heterosis ranged from -20.75 % to 41.86 % in E_1; -21.95 % to 39.65 % in E_2 and -48.13 % to 64.34 % in $E_3$for grain yield per plant (Table 1). The cross BHS 400 × PL 426, PL 426 × RD 2552 and BH 959 × RD 2552 in all the environments exhibited positive significant heterosis and heterobeltiosis. Eight crosses in each E_1 and E_3, and five crosses in E2 manifested negative significant inbreeding depression (Table 1). Results are similar with the findings of Saad *et al.* (2013), Mansour (2016) and; Ram and Shekhawat (2017).

Heterosis ranged from -10.57 % to 16.94 % in E_1; -19.00 % to 10.93 % in E_2 and -21.96 % to 35.39 % in $E_3$for harvest index. The crosses BG 105 × BH 959, BG 105 × RD 2786, BG 105 × BH 902, BH 946 × BH 959, BG 105 × BH 946, BH 902 × BH 959, BH 902 × BH 946, BH 902 × RD 2786 and BH 946 × RD 2786 in all the environments exhibited positive significant heterosis and heterobeltiosis. Fourteen crosses in E_1, 23 crosses in E_2 and 18 crosses in E_3 exhibited negative significant inbreeding depression (Table 1). Results are in conformity with the findings of Vishwakarma *et al.* (2011), Saad *et al.* (2013) and Pesaraklu *et al.* (2016).

Three best heterotic and heterobeltiotic crosses for grain yield per plant are perusal and an interesting relationship between heterosis and heterobeltiosis of grain yield per plant and other yield attributing characters that the cross BHS 400 × PL 426 for all the three environments exhibited desirable heterosis and heterobeltiosis at least for three or more than three yield attributing characters. Whereas crosses BHS 400 × BHS 380 and BG 105 × PL 426 in E_2 and; PL 426 × RD 2552 and BHS 380 × RD 2552 in E_3 exhibited desirable heterosis and heterobeltiosis at least for three or more than three yield attributing characters. Hence, these crosses may be considered as promising type for tangible advancement yield under early, normal and late sown conditions.

Among the top three crosses for grain yield per plant the cross BHS 400 × PL 426 had showed desirable heterosis and heterobeltiosis for one or more charactersin all the environments.Cross combination PL 426 × RD 2552 depicted significant heterosis and heterobeltiosis along with desirable inbreeding depression (Table 2). This cross was considered most desirable as it may throw transgressive segregants in higher frequency in later generations. Based on *per se* performance, heterosis, heterobeltiosis and inbreeding depression, the cross PL 426 × RD 2552 emerged as best cross for grain yield per plant as well as other characters in all the environments.

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 Hull (1945), 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.

REFERENCES

Anonymous. 2016-17. *Progress report of All India Co-ordinated Wheat and Barley Improvement Project*. Indian Institute of Wheat & Barley Research, Karnal, India.

FAO. 2016: http://www.fao.org/faostat/en/#data/QC

Fonseca S and Patterson F L. 1968. Hybrid vigour in a seven parental diallel crosses in common winter wheat (*Triticum aestivum* L.). *Crop Science* **51**(9): 623–626.

Hull F H. 1945. Recurrent selection for specific combining ability in corn. *Journal of American Society of Agronomy* **37**: 134–145.

Mansour M. 2016. Genetical analysis of some quantitative traits in barley under saline soil conditions. *Proceedings, The sixth field crops conference* FCRI, ARC, Giza, Egypt, 22-23 November 2016, pp 99-107.

Martinez E J H and Foster A. E1998. Genetic analysis of heading date and other agronomic characters in barley (*Hordeum vulgare* L.). *Euphytica* **99**(3): 145–153.

Panse V C and Sukhatme P V. 1967. *Statistical Methods for Agricultural Workers*. ICAR, New Delhi.

Pesaraklu S, Soltanloo H, Ramezanpour S S, Kalate Arabi M, Nasrollah Nejad and Ghomi A A. 2016. An estimation of the combining ability of barley genotypes and heterosis for some quantitative traits. *Iran Agricultural Research* **35** (1): 73–80.

Ram M and Shekhawat A S 2017. Genotypic variances and interactions with environments in barley genotypes for grain yield and its associated characters. *Bioscan* **11**(4): 3173–3175.

Saad F F, MohenAbd El A A, ShafiAbd El M A and Soudan V I H. 2013. Genetic behaviour of grain yield and its components in barley crosses under water stress and non-stress conditions. *Scientia Agriculturae* **1**(2): 45–55.

Singh K, Sharma S N, Sharma Y and Tyagi B S. 2012. Combining ability for high temperature tolerance and yield contributing traits in bread wheat. *Journal of Wheat Research* **4** (1): 29–37.

Vishwakarma S R, Shukla A, Raj Bahadur and Singh N. 2011**.** Expression of heterosis for yield and chlorophyll content in barley. *Plant Archives* **11** (2): 894.