Int.J.Curr.Microbiol.App.Sci (2018) *7*(9): 2651-2660

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 7 Number 09 (2018)**
Journal homepage: http://www.ijcmas.com

Original Research Article https://doi.org/10.20546/ijcmas.2018.709.331

Heterosis and Inbreeding Depression Studies for Yield and its Contributing Traits in Barley (*Hordeum vulgare* L.) under Normal and Late Sown Condition

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Keywords

Barley (*Hordeum vulgare* L.), Heterosis and heterobeltiosis

Article Info

Accepted:
18 August 2018
Available Online:
10 September 2018

A B S T R A C T

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 per cent and -48.13 to 64.34 per cent under normal and late sown conditions, respectively. Out of 45 crosses fifteen crosses in both the sowing conditions exhibited positive significant heterosis while, nine crosses in normal and seven crosses in late sown condition exhibited positive significant heterobeltiosis. In both the environments the crosses BHS 400 × PL 426, BHS 400 x BHS 380, BG 105 x BH 959, PL 426 × RD 2552 and BH 959 × RD 2552 exhibited positive significant heterosis and heterobeltiosis while out of only one cross 426 × RD 2552 has desirable negative significant 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 levels in barley.

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 of the world i.e. in some areas of North Africa and the Near East, highlands of Central Asia, Horn of Africa, Andean countries and Baltic States. These regions are characterised by harsh living conditions and home to some of the poorest farmers in the world who depend on the low productive systems. It is considered as the first cereal domesticated for use by man as food and feed (Potla *et al.*, 2013). 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 thousand ton (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 (Anonymous, 2016-17). 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). 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. 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. 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. Allard (1960) 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. For this, combining ability analysis provides useful information to select the suitable parents for a hybridization programme (Kakani *et al.,* 2007). 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). 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.

Materials 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 normal (20th November) and late (5th December) sown conditions 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). 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) and Fonseca and Patterson (1968), 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 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 -21.95 per cent (BHS 400 × BH 902) to 39.65 per cent (BHS 400 × BHS 380) in normal and -48.13 per cent (BH 902 × RD 2715) to 64.34 per cent (BHS 400 × PL 426) in late sown condition (Table 2 and 3). Heterobeltiosis for grain yield per plant ranged from -29.62 per cent (BHS 400 × BH 902) to 36.15 per cent (BHS 400 × BHS 380) in normal and -51.36 per cent (BG 105 × BH 946) to 50.58 per cent (PL 426 x RD 2552) in late sown condition (Table 2 and 3). Out of 45 crosses, fifteen crosses in each of normal and late sown condition exhibited positive significant heterosis while, nine crosses in normal and seven crosses in late sown condition exhibited positive significant heterobeltiosis (Table 2 and 3).

Table.1 Analysis of variance showing mean squares in normal (E_1) and late (E_2) sown condition for parents, F_1 and F_2 for yield and its contributing attributes

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	1.16	99.10**	89.37**	100.81**	95.86**	107.31**	32.96**	34.83**	0.54
	E_2	1.27	66.24**	95.54**	64.00**	52.40**	76.08**	43.06**	1.91	1.84
Days to maturity	E_1	1.66*	49.23**	25.69**	51.65**	46.81**	46.63**	485.35**	46.41**	0.37
	E_2	1.43*	98.15**	26.17**	98.04**	94.74**	88.08**	681.47**	755.20**	0.33
Plant height	E_1	1.66*	49.23**	25.69**	51.65**	46.81**	46.63**	485.35**	46.41**	0.37
	E_2	1.43*	98.15**	26.17**	98.04**	94.74**	88.08**	681.47**	755.20**	0.33
No. of effective tillers per plant	E_1	0.18	7.31**	7.94**	7.30**	5.88**	8.85**	1.61	2.90**	0.42
	E_2	1.01	2.85**	3.53**	2.81**	2.90**	2.66**	5.44**	0.17	0.44
Flag leaf area	E_1	1.88	29.14**	56.66**	26.67**	25.69**	28.00**	11.30	1.80	5.66
	E_2	0.08	16.84**	23.16**	16.20**	17.16**	15.38**	10.21**	16.46**	0.78
No. of grains per spike	E_1	0.52	162.27**	306.94**	148.03**	121.08**	175.12**	141.36**	127.82**	1.05
	E_2	0.11	136.93**	206.59**	123.69**	100.18**	138.22**	518.24**	689.14**	0.90
1000-grain weight	E_1	0.99	47.58**	62.68**	45.49**	31.86**	60.14**	0.25	98.43**	1.30
	E_2	0.66	37.10**	45.72**	36.07**	32.50**	40.17**	12.30**	51.71**	1.06
Biomass per plant	E_1	7.72	221.08**	112.22**	233.55**	193.03**	274.90**	197.13**	91.20*	16.49
	E_2	12.32	307.16**	103.37**	330.15**	243.06**	424.72**	0.98	95.22**	8.20
Grain yield per plant	E_1	1.04	28.13**	15.83**	29.29**	20.62**	38.55**	2.64	36.25**	3.11
	E_2	1.88	23.90**	28.79**	23.64**	22.38**	25.42**	0.94	2.30	0.96
Harvest index	E_1	3.57*	76.10**	41.09**	80.31**	56.62**	103.00**	124.56**	16.20**	0.87
	E_2	14.19**	152.91**	109.29**	154.50**	90.44**	221.20**	38.32**	404.50**	1.07
Malt Score	E_1	0.21	31.21**	41.29**	30.52**	23.80**	37.88**	2.96	1.43	0.79
	E_2	0.25	47.49**	38.16**	48.56**	43.76**	38.24**	713.70**	36.06**	0.84

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

Table.2 Extent of heterosis (H), heterobeltiosis (HB) and inbreeding depression (ID) for grain yield per plant in normal (E_1) and late (E_2) sown condition

Crosses	Grain yield per plant					
	E_1			E_2		
	H	HB	ID	H	HB	ID
BHS 400 x BG 105	1.04	-5.66	17.83*	-10.92	-29.67**	0.58
BHS 400 x PL 426	36.98**	32.49**	3.37	64.35**	48.44**	10.39
BHS 400 x BHS 380	39.65**	36.15**	16.64*	17.52**	14.60*	-47.74**
BHS 400 x BH 902	-21.95**	-29.62**	2.10	-21.10**	-39.45**	-0.04
BHS 400 x BH 946	20.65**	2.16	4.84	2.94	-25.49**	22.30**
BHS 400 x BH 959	29.61**	13.39	-9.55	39.71**	6.04	-13.27*
BHS 400 x RD 2715	-3.55	-12.42	11.39	-18.43**	-35.27**	11.65
BHS 400 x RD 2786	-0.61	-14.55*	-0.85	-33.06**	-50.17**	2.76
BHS 400 x RD 2552	-2.67	-11.30	0.74	-10.56	-22.52**	1.70
BG 105 x PL 426	35.48**	30.62**	-5.48	28.95**	10.77	11.47*
BG 105 x BHS 380	-4.03	-12.47	0.36	-18.27**	-36.64**	9.57
BG 105 x BH 902	5.82	1.93	-9.82	14.84**	10.47	13.63**
BG 105 x BH 946	-11.92	-20.75**	6.29	-45.13**	-51.36**	-57.75**
BG 105 x BH 959	21.09**	12.87	-12.66*	0.55	-4.76	-16.88**
BG 105 x RD 2715	28.00**	24.21**	12.53*	14.51**	13.73*	-2.91
BG 105 x RD 2786	0.39	-8.16	11.22	-19.15**	-25.45**	9.00
BG 105 x RD 2552	7.04	4.28	10.46	-8.12	-17.75**	-9.81
PL 426 x BHS 380	32.83**	25.36**	1.08	17.00**	3.33	9.78
PL 426 x BH 902	17.77*	9.53	5.53	48.35**	23.38**	16.61**
PL 426 x BH 946	-5.88	-18.01**	0.29	3.52	-19.51**	7.36
PL 426 x BH 959	9.22	-1.59	15.46*	4.56	-14.14*	-1.43

PL 426 x RD 2715	22.40**	14.64	-1.95	1.63	-12.19	-10.7
PL 426 x RD 2786	-12.37	-22.44**	-7.57	-20.58**	-36.22**	10.08
PL 426 x RD 2552	28.41**	20.73**	-20.50**	57.80**	50.58**	-16.41**
BHS 380 x BH 902	21.71**	7.31	9.38	17.81**	-11.15	-16.31*
BHS 380 x BH 946	0.21	-16.89**	7.01	-1.28	-29.65**	3.97
BHS 380 x BH 959	-5.61	-19.20**	-12.26	-3.69	-28.15**	-10.11
BHS 380 x RD 2715	4.35	-7.38	-0.68	6.00	-17.43**	-19.92**
BHS 380 x RD 2786	-11.96	-25.89**	5.28	-7.35	-32.16**	8.94
BHS 380 x RD 2552	6.82	-4.85	-15.05*	54.07**	30.67**	-14.32*
BH 902 x BH 946	-11.76	-17.80**	15.39	-16.58**	-23.39**	3.80
BH 902 x BH 959	4.03	0.53	15.44*	-13.21**	-14.60**	16.53*
BH 902 x RD 2715	-3.85	-4.58	15.71*	-48.13**	-50.44**	21.40
BH 902 x RD 2786	3.72	-1.69	-9.52	-8.95	-12.88*	-2.54
BH 902 x RD 2552	-13.04*	-14.06	-3.78	-0.97	-14.33*	13.78*
BH 946 x BH 959	-4.23	-7.82	14.47*	4.85	-2.26	17.70**
BH 946 x RD 2715	10.22	1.95	5.46	12.41**	-0.94	1.11
BH 946 x RD 2786	-13.23*	-14.81*	-18.67*	-21.80**	-25.10**	-6.70
BH 946 x RD 2552	3.21	-4.90	-6.53	-15.91**	-32.26**	0.78
BH 959 x RD 2715	22.40**	17.42*	18.86**	1.52	-4.46	8.37
BH 959 x RD 2786	19.65**	17.26*	-13.80*	11.00*	7.89	1.18
BH 959 x RD 2552	21.64**	16.24*	0.54	49.43**	27.53**	20.11**
RD 2715 x RD 2786	-9.73	-15.06*	0.09	-8.22	-15.91**	11.96
RD 2715 x RD 2552	-15.06*	-15.40*	-3.02	-0.53	-10.41	11.30
RD 2786 x RD 2552	-4.72	-10.69	-9.17	13.18**	-5.65	11.71*
SE	**1.25**	**1.44**		**0.69**	**0.80**	

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

Table.3 Range of heterosis and number of desirable crosses for yield and its contributing characters in normal (E_1) and late (E_2) 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	-10.14 - 7.34	-7.98 - 7.38	-8.91 - 17.55	-5.63 - 14.36	13	8	8	1
Days to maturity	-4.29 - 7.97	-3.22 - 15.38	-3.92 - 12.23	-3.19 - 18.88	9	6	6	4
Plant height	-12.54 - 9.43	-7.78 - 14.45	-8.28 - 11.45	-7.01 - 17.24	12	12	8	8
Effective tillers per plant	-20.4 - 30.64	-27.36 - 19.47	-34.26 - 15.43	-31.83 - 10.45	11	2	2	0
Flag leaf area	-17.68 - 32.25	-27.72 - 29.20	-31.49 - 27.02	-37.14 - 19.98	8	9	2	5
No. of grains per spike	-9.47 - 17.21	-9.06 - 28.70	-24.39 - 8.13	-16.53 - 17.37	27	33	3	13
1000-grain weight	-17.19 - 14.48	-17.21 - 13.44	-24.15 - 11.18	-23.16 - 10.17	5	5	2	2
Biomass per plant	-21.65 - 44.41	-58.80 - 60.84	-30.73 - 33.08	-62.55 - 33.57	16	12	11	7
Grain yield per plant	-21.95 - 39.65	-48.13 - 64.35	-29.62 - 36.15	-51.36 - 50.58	15	15	9	7
Harvest index	-19.00 - 10.93	-21.96 - 35.39	-25.89 - 10.31	-32.08 - 28.98	18	29	12	20
Malt Score	-8.03 - 5.35	-9.13 - 8.60	-7.92 - 6.59	-13.91 - 5.52	12	14	7	10

Table.4 Crosses possessing high heterosis and heterobeltiosis for grain yield per plant along with desirable (+) heterotic expression for other characters in normal (E_1) and late (E_2) 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 BHS 380	BHS 400 x PL 426	BG 105 x PL 426	BHS 400 x PL 426	PL 426 x RD 2552	BHS 380 x RD 2552	BHS 400 x BHS 380	BHS 400 x PL 426	BG 105 x PL 426	PL 426 x RD 2552	BHS 400 x PL 426	BHS 380 x RD 2552
Days to heading	-	-	+	-	-	-	-	-	+	-	-	-
Plant height	+	-	+	-	-	-	-	-	+	-	-	-
No. of grains per spike	+	+	+	+	+	-	-	-	-	-	-	-
Biomass per plant	+	+	+	+	+	+	+	+	+	+	-	+
Harvest index	-	-	-	+	+	+	-	-	-	+	-	-

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 -20.50 per cent (PL 426 × RD 2552) to 18.86 per cent (BH 959 × RD 2715) in normal and -57.75 per cent (BG 105 × BH 946) to 20.11 per cent (BH 959 × RD 2552) in late sown conditions (Table 2 and 3). Eighteen crosses in normal and sixteen crosses in late sown condition tilted towards negative magnitude, out of which five crosses in normal and eight crosses in late sown condition manifested negative significant inbreeding depression (Table 2 and 3) which indicated that F_2 plants attained comparatively higher grain yield per plant than F_1 hybrids and considered to be desirable.

The crosses BHS 400 × PL 426, BHS 400 x BHS 380, BG 105 x BH 959, PL 426 × RD 2552 and BH 959 × RD 2552 in both the environments exhibited positive significant heterosis and heterobeltiosis while, out of only one cross 426 × RD 2552 has desirable negative significant inbreeding depression. Hence, these crosses were considered to be most desirable for grain yield per plant. The results in different environments for grain yield per plant are in conformity with the previous findings in varying environments for different characters by Saad *et al.,* (2013), Mansour (2016), Pesaraklu *et al.,* (2016), Ram and Shekhawat (2017).

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. Best three heterotic and heterobeltiotic crosses for grain yield per plant are presented in (Table 4). 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 environments exhibited desirable heterosis and heterobeltiosis at least for one or more yield attributing characters. Whereas crosses BHS 400 x BHS 380 and BG 105 x PL 426 in normal and, PL 426 x RD 2552 and BHS 380 x RD 2552 in late sown condition exhibited desirable heterosis and heterobeltiosis at least for one or more yield attributing characters. Hence, these crosses may be considered as promising type for tangible advancement of barley yield under normal and late conditions.

Such as, heterosis and heterobeltiosis for grain yield per plant was mainly contributed by days to heading, plant height, number of grains per spike, biomass per plant and harvest index in both the environments. Findings of this investigation 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 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), Potla *et al.,* (2013), Saad *et al.,* (2013), Mansour (2016) and Ram and Shekhawat (2017) who also reported maximum heterosis for grain yield per plant.

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 environments. 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 environment. 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 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.

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How to cite this article:

Chhagan Lal, A.S. Shekhawat, Jogendra Singh and Vinod Kumar. 2018. Heterosis and Inbreeding Depression Studies for Yield and Its Contributing Traits in Barley (*Hordeum vulgare* L.) under Normal and Late Sown Condition. *Int.J.Curr.Microbiol.App.Sci.* 7(09): 2651-2660. doi: https://doi.org/10.20546/ijcmas.2018.709.331