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COMBINING ABILITY AND GENE ACTION STUDIES FOR GRAIN YIELD AND ITS COMPONENT TRAITS IN BARLEY (*Hordeum vulgare* L.)

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SUMMARY

Combining ability estimates are important genetic attributes to barley breeders for identifying desirable parent and crosses and also helps in predicting improvement via hybridization and selection. The line *x* tester analysis involving 3 lines and 3 testers was carried out for identification of superior combiners for their use for yield enhancement in barley. Significant differences among parents, crosses and parent vs. cross for all the 7 traits studied indicated the presence of sufficient variability that can be exploited for the development of high yielding barley hybrids. Variance of specific combining ability (SCA) were higher than the general combining ability (GCA) for all the traits which indicated the predominance of non-additive (dominant, overdominance and epistasis) type of gene action in the inheritance of the traits. Hence, selection of superior plants should be deferred to later generation. The GCA estimates suggested that if the yield traits are to be improved through hybridization and selection, then priority should be given to the male parents RD 2668 and female lines HBL 703 and HBL 704. The 2 crosses; HBL 703/RD 2668 and HBL 704/ RD 2751 were found to be good specific cross combinations for grain yield and its related traits having high significant SCA.

Key words: Barley, combining ability, grain yield, line x tester analysis

Key findings: Breeding material evaluated had adequate genetic variability which may be exploited further in breeding programs. Among the lines, HBL 703 and HBL 704 and among testers RD 2668 were considered to be good general combiner and the cross combinations, HBL 703/ RD 2668 showed excellent performance for the yield contributing traits under study. The 7 traits studied were under the control of non-additive gene action.

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INTRODUCTION

Combining ability analysis is one of the powerful tools to compare the performance of different lines in different hybrid combinations and aid in selecting desirable parents and crosses for exploitation of heterosis (Rashid *et al*., 2007; Salgotra *et al*., 2009). Combining ability or productivity in crosses is defined as the ability of parents or cultivars to combine amongst each other during the process of hybridization so that favorable genes/characters are transmitted to their progenies. Since *per se* performance of parent may not reveal it's combining ability, so the information on nature of gene action and their expression in terms of combining ability is necessary. For evaluating combining ability the mating design (Line x Tester) suggested by Kempthorne (1957) is one of the efficient methods whereby large number of inbred lines can be evaluated (Rashid *et al*., 2007).

In India, barley (*Hordeum vulgare* L.) productivity is below the world average productivity level (2.74 tons/ha) because barley is cultivated under minimum input management and varietal replacement is also slow. However, the growing demand of industry and need for diversification of wheat cultivation has given some impetuous to the barley cultivation thereby requiring the development of high yielding varieties. For developing high yielding varieties presence of genetic variability and broadening the genetic base are important requirements where hybridization plays a pivot role. During hybridization the breeders often face with the problem of identifying rewarding parents and crosses. For this combining ability analysis provides useful information to select the suitable parent for hybridization program (Kakani *et al*., 2007). Potla *et al.*, (2013) and Bornare *et al.*, (2014) and Zhang *et al*., (2015) have also undergone combining ability analysis for selection of efficient parent and cross in barley breeding.

Since the development of new cultivars through hybridization is a continuous process in barley, information on combining ability of breeding material is imperative. Hence, this study was aimed at evaluating the combining ability pattern of barley lines for grain yield and yield related traits for their use for yield enhancement in barley and to identify and select superior hybrid combinations based on crosses of selected lines with testers.

MATERIALS AND METHODS

Three barley lines (BHS 352, HBL 703 and HBL 704) and three testers (RD 2715, RD 2668 and RD 2751) (Table 1) were assessed for combining ability studies for grain yield and its contributing traits. These genotypes were selected based on their performance for yield *per se* or for other desirable yield contributing traits.

Experimental site and year

The experiment was conducted at ICAR-Indian Agricultural Research Institute, Regional Station, Shimla, Himachal Pradesh (India) during the year 2012-13 (for making crosses) and 2013-14 (for combining ability studies).

Methodology

Nine F_1's hybrids (Table 2) along with parents obtained by crossing three lines with three testers were sown during 2013-14 in randomized complete block design with three replications. Each entry was grown in single row plot, with row length of 3 m and row to row distance of 22 cm.

Statistical analysis

Five plants of each entry in each replicate were taken at random and data were recorded on 7 traits (maturity, plant height, spike length, spiklets per spike, grain weight per spike, 1000 grain weight and grain yield per plant). The data were subjected to ANOVA according to Gomez and Gomez (1984) which was further analyzed for general combing ability (GCA) and specific combing ability (SCA) following line x tester method (Kempthorne, 1957; Singh and Choudhry 1979) and software SPAR Version 2.0 was used. The significance of GCA and SCA effects was determined at the 1% level using t-test.

Table 1. List of barley varieties used for the study with their percentage.

No.	Variety	Parentage
1	BHS 352	HBL240/BHS504//VLB129
2	HBL 703	HBL 231/ HBL 113
3	HBL 704	HBL 276/HBL 364
4	RD 2715	RD 387/ BH 602// RD 2035
5	RD 2668	RD 2503/AR-80
6	RD 2751	BH646/RD2636

Table 2. SCA effects for hybrid (crosses) for yield related traits in barley.

Hybrids	Maturity (days)	Plant height (cm)	Spike length (cm)	Spiklets per spike	Grain weight per spike (g)	1000 grain weight (g)	Grain yield per plant
BHS 352 / RD 2715	1.85**	3.60**	-0.25**	-0.99	-0.59**	1.15	1.56**
BHS 352 / RD 2751	-2.37**	-1.71	0.38**	0.29	0.09	-0.85	-1.22**
BHS 352 / RD 2668	0.52	-1.89	-0.13	0.71	0.49**	-0.29	-0.33
HBL 703 / RD 2715	-1.48	-1.56	0.17	0.16	-0.05	-1.41**	-1.56**
HBL 703 / RD 2751	3.29**	-0.41	-0.43**	-1.42	-0.59**	-0.74	1.33**
HBL 703 / RD 2668	-1.81	1.97	0.26**	1.26	0.64**	2.15**	0.22
HBL 704 / RD 2715	-0.37	-2.04	0.08	0.83	0.67**	0.26	0.01
HBL 704 / RD 2751	-0.93	2.11	0.04	1.13	0.48**	1.59**	-0.11
HBL 704 / 2668	1.29	-0.07	-0.13	-1.97**	-1.13**	-1.85**	0.11
S.E (SCA effect)	0.66	0.93	0.09	0.52	0.17	0.47	0.24
S.E. (Sij-Skl)	0.93	1.32	0.12	0.73	0.25	0.67	0.42

*** Significant at 1% level*

RESULTS AND DISCUSSION

Genetic variability among parents and hybrids

Analysis of variance revealed significant differences among barley genotypes for all the traits (Table 3) indicating presence of sufficient genetic variability in the breeding material used in the study. This genetic variability may be exploited in the breeding program for improvement of barley yield and its related traits. Partitioning of sum of squares of genotypes into parents, cross and parent *vs.* crosses revealed that the mean squares due to crosses were highly significant (Table 3) indicating varying performance of cross combinations for the studied traits and hence, selection is possible to identify the most desirable cross. Significant differences among parents *vs.* crosses indicated that the hybrids differ considerably from parents for all the traits and hence considerable heterosis was reflected in the hybrid which may be exploited for the development of high yielding barley genotypes. The mean sum of squares due to crosses were further portioned into lines, testers and line x testers interaction. High significant differences were displayed among line x tester interaction for all the traits indicated the importance of non-additive variance. Significant differences among barley genotypes and F_1's hybrids for yield related traits have also been reported earlier by Bhatnagar and Sharma (1998), Sharma *et al.*, (2002) and Eshghi and Akhundova (2009).

Table 3. Analysis of variance for combining ability of yield and yield attributes in barley.

Source	df	Maturity (days)	Plant height (cm)	Spike length (cm)	Spiklets per spike	Grain weight/ spike (g)	1000 grain weight (g)	Grain yield/ plant
Replication	2	4.82	8.89	0.03	1.04	0.13	0.29	0.29
Genotypes	14	39.60**	48.72**	0.96**	11.51**	1.17**	8.07**	6.02**
Parents	5	51.66**	29.04**	0.97**	3.48**	0.41**	3.07**	6.18**
P vs. C	1	11.20**	162.09**	2.48**	62.33**	1.12**	17.13**	12.03**
Crosses	8	35.62**	46.86**	0.76**	10.37**	1.63**	10.06**	5.17**
Lines	2	91.70	111.17	1.77	22.47	1.17	12.70	6.78
Testers	2	8.26	24.33	0.47	2.33	0.39	4.59	1.44
L x T	4	21.26**	25.97**	0.39**	8.33**	2.46**	11.48**	6.22**
Error	28	1.29	2.61	0.02	0.80	0.91	0.67	0.27
$\sigma 2\ GCA$		0.79	1.16	0.02	0.11	-0.05	-0.08	-0.06
$\sigma 2\ SCA$		11.45	14.75	0.25	3.19	0.52	3.13	1.64
$\sigma 2\ GCA/\sigma 2\ SCA$		0.07	0.08	0.08	0.03	-0.10	-0.03	-0.04

** Significant at 1% level

Gene action

The relative estimates of variance component due to specific combining ability were higher in amount than that of general combining ability (Table 3) for all the traits. Hence indicating preponderance of non-additive type of gene action in the inheritance of all the studied traits. This was further supported by low magnitude of MS GCA/MS SCA ratio (Table 3). Hence, for exploiting heterosis, selection of superior plants, in terms of yield and associated traits should be postponed to later generation, where these traits can be improved by making selections among the recombinants within the segregating populations. These findings are consistent with that of Yilmaz and Konak (2000) and Verma *et al.,* (2007) who also reported the predominance of non- additive gene action for most of the traits studied by them and also matches with that of Potla *et al.,* (2013) who also reported the predominance of SCA variance over GCA variance.

Proportion contribution

The proportion contribution of lines, testers and their interaction to total variance showed that lines played important role for most of the traits (maturity, plant height, spike length and spikelets per spike) (Table 4), which indicated that lines contributed more positive alleles for these characters and there is predominance maternal influence. The contributions of testers for all the traits were small. The maternal and paternal interaction (line x tester) contributed toward grains yield per plant and 2 yield contributing traits *viz.*, grain weight per spike and 1000 grain weight. This indicated that the concerned characters were influenced by non-additive gene action. Hossain *et al.,* (2009) in rice; Akter *et al*., (2010) and Madic *et al*., (2014) in barley have also reported the major contribution of line x tester and presence of non-additive gene action for yield.

Table 4. Proportional contribution of lines, testers and their interaction to total variance in barley.

Source	Maturity (days)	Plant height (cm)	Spike length (cm)	Spiklets per spike	Grain weight per spike (g)	1000 grain weight (g)	Grain yield per plant
Lines	64.36	59.30	58.42	54.19	17.96	31.55	32.79
Testers	5.79	12.97	15.34	5.61	6.16	11.41	6.99
Lines x Testers	29.84	27.71	26.23	40.19	75.89	57.04	60.21

General combining ability analysis

Variation in general combining ability effects was estimated among lines and testers for 7 plant traits to identify the best parent for deriving desirable transgressive segregants. For maturity and plant height negative GCA effects, while for other traits positive GCA effects are desirable. Minimum plant height is required to protect the crop from lodging. The estimates of general combining ability effects revealed that the only line HBL 703 was having good combining ability for reduced plant height and lesser days for maturity along with the grain contributing trait (spikelets per spike), while the line HBL 704 was found to be a good combiner for grain yield per plant and spike length (Table 5). Therefore, it can be a potential parent which can contribute in subsequent development of hybrid with increased yield and spike length.

Among testers RD 2668 was good combiner for plant height and spike length. These 3 parents (HBL 703, HBL 704 and RD 2668) have good potential and may be used in synthesizing a dynamic population with combination of most of the favorable genes. Apparently, thus, there is still further scope for improving upon the combining ability for component traits, as none of high combiners for grain yield was a high combiner or at least an average combiner for all the desirable traits. Different parents having good general combining ability have also been reported by several workers (Singh *et al*., 2007; Madic *et al*., 2014).

Table 5. Estimates of GCA effects for yield related traits in barley.

Parents	Maturity (days)	Plant height (cm)	Spike length (cm)	Spiklets per spike	Grain weight per spike (g)	1000 grain weight (g)	Grain yield per plant
BHS 352	2.37**	3.06**	0.01	-1.82**	0.14	0.74	-1.00**
HBL 703	-3.62**	-3.84**	-0.45**	1.02**	-0.41**	-1.37**	0.44
HBL 704	1.26**	0.77	0.44**	0.79	0.27	0.62	0.56**
S. E. (gi)	.038	0.54	0.05	0.29	0.10	0.27	0.17
S.E(gi-gj)	0.54	0.76	0.07	0.42	0.14	0.39	0.23
RD 2715	-0.85	1.89**	-0.14**	0.57	0.19	0.52	0.33
RD 2668	1.04	-1.14**	0.26**	-0.18	0.02	-0.82**	0.12
RD 2751	-0.19	-0.75	-0.13	-0.39	-0.22	0.29	-0.45
S.E(gi)	0.38	0.54	0.05	0.30	0.10	0.27	0.18
S.E (gi-gj)	0.54	0.76	0.07	0.43	0.14	0.39	-0.24

** Significant at 1% level

Specific combining ability analysis

SCA effect is an index to determine the usefulness of a particular cross combination in the exploitation of heterosis. Since yield is a complex trait having low heritability, *per se*, selection for it is generally ambiguous and leads to unpredictable results. Indirect selection by making use of simple inherited traits have been advocated and used for the improvement of yield since time immemorial (Borojevic, 1990). While selecting the best specific combination for yield, it would be important to give due weightage to yield related traits. Grafius (1959) had already suggested that there is no separate gene for yield, but yield is an end product of multiplicative interaction among various yield components which were validated by different workers in different crops (Bagheri and Babaeian, 2010; Rani and Satyanarayana, 2014).

The cross HBL 703/ RD 2668 showed significant positive SCA effects for yield contributing traits (spike length, grain weight per spike and 1000 grain weight), while HBL 704/ RD 2751 showed significant positive SCA effects for grain weight per spike along with 1000 grain weight and BHS 352/ RD 2668 for grain weight per spike (Table 2). The crosses BHS 352/ RD 2715 and HBL 703/ RD 2751 showed significant SCA towards grain yield per plant. For earliness the cross BHS 352/ RD 2751 was found to be good which may also contribute to grain yield *via.* spike length.

Crosses with significant SCA for different traits in the desirable direction are listed in Table 6. It was found that the crosses involves average and poor combiners rather that good combiners. Many researchers have identified the potential cross combinations for different traits in different crops (Singh *et al*., 2013; Singh *et al*., 2007; Istipliler *et al*., 2015).

Table 6. Hybrid showing high SCA effects for different traits in barley.

Character	Cross	SCA effect	GCA status of the parents
Maturity	BHS 352 / RD 2751	-2.37**	P X A
Plant height	-	-	-
Spike length	BHS 352 / RD 2751	0.38**	A X P
	HBL 703 / RD 2668	0.26**	P X G
Spiklet/spike	-	-	-
Grain weight/spike	BHS 352 / RD 2668	0.49**	A X P
	HBL 703 / RD 2668	0.64**	P X P
	HBL 704 / RD 2715	0.67**	A X A
	HBL 704 / RD 2751	0.48**	A X P
1000 grain weight	HBL 703 / RD 2668	2.15**	P X P
	HBL 704 / RD 2751	1.59**	A X A
Grain yield per plant	BHS 352 / RD 2715	1.56**	P X A
	HBL 703 / RD 2751	1.33**	A X P

*** Significant at 1% level; P, A, G: Poor, average and good GCA effects*

CONCLUSION

This study highlighted the rewarding parents and crosses of barley that can exploited by barley breeders to launch effective breeding strategies. We conclude that breeding material evaluated had adequate genetic variability which may be exploited further in breeding programs. The SCA and GCA ANOVA proposed that the 7 traits studied were under control of non-additive gene action. Among the lines, HBL 703 and HBL 704 and among testers RD 2668 showed maximum GCA effects and were considered to be good general combiner for most of the traits under study and therefore, can be exploited for further breeding programs in barley. Cross combinations, HBL 703 / RD 2668 showed excellent SCA performance for the yield contributing traits under study. This cross can be exploited vigorously in future barley breeding program to obtain segregants which would deliver a population with high yield potential. Since non-additive type of gene action was found for all of the plant traits thereby suggesting that selection of superior plants should be deferred to later generation.

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