



Research Article

Evaluation of combining ability and gene action in barley (*Hordeum vulgare* L.) using Line x Tester analysis

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Abstract

Eighteen hybrids generated from crossing six lines with three testers were studied along with their parents for combining ability and gene action involved in the expression of characters in barley to identify suitable parents and desirable hybrid combinations. Observations were recorded for days to ear emergence, days to maturity, the number of productive tillers per plant, ear length (cm.), grains per spike, biological yield per plant (g.), harvest index (%), 1000-grain weight and grain yield per plant (g.). The mean squares for General Combining Ability (GCA) and Specific Combining Ability (SCA) effects were found highly significant for all the traits studied. Among the parents, tester NDB-1173 and lines RD-2909, RD-2899 and RD-2768 were good general combiners for grain yield and its component traits. On the basis of SCA effects, RD-2909 x NDB-943, NDB-1618 x NDB-1173, RD-2768 x NDB-3, HUB-240 x NDB-1173 and RD-2899 x NDB-943 for grain yield were observed as most promising crosses.

Keywords

Barley (*Hordeum vulgare* L.), Combining ability, General combining ability (GCA),, Specific combining ability (SCA)-gene action.

INTRODUCTION

Barley (*Hordeum vulgare* L., 2n=14, sub family Poaceae) a crop of the winter season is grown ecofriendly worldwide for food, feed and forage under various agro-climatic situation. Barley ranks the fourth in terms of planting area and total production among all cereal crops in the world. Barley has a superior nutritional quality like presence of beta-glucan (an anti-cholesterol substance), acetylcholine substance (energize our nervous system and recover memory loss), low gluten, soluble and digestible fibers, lysine, thiamine and riboflavin vitamin B5 and also has antioxidant which improves our immune system. Barley reduces the risk for certain cancers, diabetes and heart disease. During 2015-16, India had about 6.55 lakh ha area with production of 16.18 lakh metric tonnes and productivity of 24.70 q/ha. In U.P., barley occupied an area of 1.46 lakh ha with a total production of 3.58 lakh metric tons with productivity of 24.50 q/ha. Uttar Pradesh alone contributes more than one-third of India's total production of barley (Anonymous 2016).

The selection of suitable parents for hybridization is an important pre-requisite for the success of the recombination breeding programme aimed at development of a superior pure line or hybrid crop varieties

through hybridization and subsequent selection. The per se performance of the parents have been considered as useful criterion for the choice of parents for hybridization programme, but the per se performance of parents may not always severe as an index of their genetic nicking ability (Allard, 1960). The selection of few parents having high genetic potential as per breeding objectives is essential because analyzing and handling of very large number of crosses resulting from numerous parents available in germplasm collections would be an impractical and perhaps impossible task.

Combining ability analysis is a useful technique for understanding the genetic worth of parents and their crosses for further exploitation in breeding programme. In addition, it also provides information about gene effects involved in the inheritance of various characters, which is essential for deciding suitable breeding strategy. Several reports advocating for selection of parents during hybridization programme on the basis of combining ability in barley are presented in literature. Among the various techniques available for combining ability analysis, the line x tester analysis (Kempthorne, 1957) has been widely utilized for screening of germplasm to identify valuable

donor parents and their crosses for breeding programmes in many crops including barley (Bornare *et al.*, 2013; Briggs, 1974; Hockett *et al.*, 1993; Kakani *et al.*, 2010; Madic *et al.*, 2014; Patial *et al.* 2016; Rodina, 1974; Sharma *et al.*, 2003; Singh and Srivastava, 2005; Yilmaz and Konak, 2000 and Zeng *et al.*, 2001).

The general combining ability (GCA), primarily a function of additive gene action, is used to discriminate the parents in respect of their capability of providing crosses of high genetic worth. The general combining ability (GCA) results from average performance of crosses of a line in a series of cross combinations. The specific combining ability helps in identifying superior cross combinations which could give rise to promising genotype in segregating generations. The promising F1's exhibiting significant SCA effects in desirable direction may be incorporated in future barley improvement programme. The general and specific combining ability is associated with interaction effects, which may be due to dominance and epistatic components of genetic variation that are non-fixable in nature. Thus, the study was conducted to identify superior parents and cross combinations from line x tester analysis for yield and its component traits in barley.

This analysis besides providing reliable information on the combining ability of parents to produce superior progenies, also detect the estimates of additive and non-additive gene effects. Thus, the present study was conducted to identify the best combiners and their crosses based on general and specific combining ability effects for yield and its component traits in malt barley. This analysis besides providing reliable information on the combining ability of parents to produce superior progenies, also detect the estimates of additive and non-additive gene effects. Thus, the present study was conducted to identify the best combiners and their crosses based on general and specific combining ability effects for yield and its component traits in malt barley.

MATERIAL AND METHODS

The study was designed to work out the exploitation of combining ability and gene action in barley (*Hordeum vulgare* L.) using Line x Tester analysis in sodic soils among six lines and three testers at the Genetics and Plant Breeding Research farm of Narendra Deva University of Agriculture & Technology, Narendra Nagar, Kumarganj, Faizabad (U.P.) during rabi 2016-17. Geographically, Narendra Nagar is situated between 26047' N latitude, 82012'E longitude and at an altitude of 113 meters above the mean sea level. This area falls in sub-tropical climatic zone. Nearly 80 per cent of total rainfall is received during monsoon season from July to September with few occasional showers in the winter. The experiment was conducted in normal fertile soil (pH=7.5) and saline sodic (pH=8.9-9.1) soils. The experimental materials for the present investigation comprised of 27 (18 F1's) developed by crossing 6 lines (HUB-240, RD-2899, RD-2909, NDB-1618, NDB-1057 and RD-2768) with

3 testers (NDB-3, NDB-943 and NDB-1173). These materials were evaluated at Research Farm in Randomized Block Design with three replications. Row to row and plant to plant distance were kept 23cm. and 10cm, respectively. Intercultural operations were adopted to raise good normal crops. Five competitive plants, in each plot of parents, and F1's were randomly selected and tagged well in advance for recording the observations. Data were recorded on the Days to ear emergence, Days to maturity, Number of productive tillers/plant, Number of grains/spike, Ear length (cm), Biological yield/plant (g), Harvest index, Grain weight (1000-grain weight), Grain yield/plant.

The experimental data were compiled by taking the mean over selected plants of each treatment for each replication. The mean data was subjected for the following statistical analysis i.e. analysis of variance (Panse and Sukhatme, 1967), heritability in narrow sense (Kempthorne, 1957), genetic advance (Johnson *et al.*, 1955), heterosis (Fonseca and Patterson, 1968) and combining ability and their effect (Kempthorne, 1957).

RESULT AND DISCUSSION

Line x tester analysis technique used extensively in almost all the major field crops to estimates GCA and SCA variances and effects. Variances due to both lines and testers were significant for days to ear emergence, days to maturity, productive tillers per plant, spike length, grains per spike, biological yield per plant, harvest index and grain yield per plant.

The relative estimates of variance component due to specific combining ability were higher in amount than that of general combining ability for all the traits except productive tillers/plant and grains/spike. Hence, it indicated preponderance of non-additive type of gene action in the inheritance of the most studied traits. 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. Yilmaz and Konak (2000) and Verma *et al.*, (2009) corroborated with the findings of present study which reported the predominance of non- additive gene action for most of the traits studied by them and also matched with that of Potla *et al.*, (2013) who also reported the predominance of SCA variance over GCA variance.

ANOVA of combining ability showed the variances of GCA were significant for most of the traits (**Table 1**). The variances of SCA were significant for all traits except productive tillers/plant and grains/spike (**Table 2**). General combining ability (GCA) expressed main effects and specific combining ability (SCA) expressed interactions. GCA/SCA ratio was used as a measure to understand the nature of gene action involved. The ratios of GCA/SCA were lesser than unity for most of the studied traits which mean that non-additive gene effects played an

Table 1. Analysis of variance for line x tester for nine characters in barley

| S. No. | Source of variation | Replications | Lines (L) | Testers(T) | LxT |
|--------|------------------------------------|--------------|-----------|------------|---------|
| 1 | D.F. | 2 | 5 | 2 | 10 |
| 2 | Days to ear emergence | 0.32 | 4.63* | 0.11 | 4.06* |
| 3 | Days to maturity | 2.53 | 8.49** | 0.78 | 2.17 |
| 4 | Number of productive tillers/plant | 0.77 | 2.94** | 0.43 | 0.34 |
| 5 | Ear length (cm) | 0.24 | 0.78** | 2.32** | 0.49* |
| 6 | Grains/spike | 12.32 | 137.29** | 2.76 | 9.02 |
| 7 | Biological yield/plant (g) | 0.81 | 5.31* | 1.93 | 5.72** |
| 8 | Harvest index (%) | 3.67 | 4.34 | 5.75 | 3.98* |
| 9 | 1000-grain weight (g) | 0.53 | 25.79** | 0.78 | 33.65** |
| 10 | Grain yield/plant (g) | 0.15 | 1.07** | 0.05 | 0.65* |

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

Table 2. Analysis of variance for combining ability following line x tester mating design for nine characters in barley

| Source of variation | D. F. | Days to ear emergence | Days to maturity | Productive tillers/plant | Ear length (cm) | Grains/spike | Biological yield/plant (g) | Harvest index (%) | 1000-grain weight (g) | Grain yield/plant (g) |
|---------------------|-------|-----------------------|------------------|--------------------------|-----------------|--------------|----------------------------|-------------------|-----------------------|-----------------------|
| Replicates | 2 | 0.57 | 3.56 | 0.39 | 0.30 | 6.68 | 0.08 | 1.54 | 3.53 | 0.06 |
| Crosses | 17 | 4.70** | 3.22* | 0.60** | 0.70** | 27.96** | 7.40** | 6.05** | 27.59** | 1.11** |
| Line Effect | 5 | 5.93 | 3.90 | 1.30* | 1.23 | 71.19** | 10.42 | 11.67 | 19.72 | 2.40* |
| Tester Effect | 2 | 4.80 | 6.80 | 0.19 | 0.43 | 14.63 | 8.23 | 2.28 | 16.96 | 0.19 |
| Line x Tester Eff. | 10 | 4.06* | 2.17 | 0.34 | 0.49* | 9.02* | 5.72** | 3.98* | 33.65** | 0.65* |
| Variance GCA | | 0.28 | 0.27 | 0.01* | 0.04* | 2.72* | 0.55* | 0.38* | 1.22 | 0.07* |
| Variance SCA | | 0.83* | 0.26* | -0.07 | 0.09* | 0.94 | 1.29** | 0.71* | 10.61** | 0.12* |
| GCA/SCA | | 0.33 | 1.03 | -0.14 | 0.44 | 2.89 | 0.42 | 0.53 | 0.11 | 0.58 |
| Error | 34 | 1.59 | 1.64 | 0.20 | 0.18 | 3.85 | 1.76 | 1.52 | 1.08 | 0.27 |
| Total | 53 | 2.55 | 2.23 | 0.33 | 0.35 | 11.69 | 3.50 | 2.97 | 9.68 | 0.53 |

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

important role in the inheritance of these traits. Amer (2010), Eid (2010) and Amer et al. (2011) advocated the findings of present study. The ratio of GCA/SCA was more than unity for days to maturity and grains/spike which means that additive gene effects played an important role in the inheritance of these traits. Comparison of GCA and SCA variance indicated the preponderance of non-additive gene effects for yield and additive gene effects for other traits. The preponderance of non-additive gene effects for yield were also reported by Phogat et al. (1995), Sharma et al. (2003b) and Verma et al. (2009), while of additive gene effects for yield components was reported by Kalashnik and Smyalovskaya (1986) and Yang and Lu (1991).

General combining ability effects varied from one parent to another giving negative or positive value (Table 3). The parental line NDB-1173 exhibited desirable significant positive GCA for 1000-grain weight, means that, this genotype could be considered as good combiner for these traits. The parental line RD-2909 exhibited highly significant positive GCA for productive tillers/plant, spike length, grains/spike, biological yield/plant, 1000-grain

weight. The parental line RD-2899 gave significant positive GCA for grains/spike, grain yield/plant. The parental lines viz; RD-2768 for days to ear emergence and grains/spike; NDB-1618 for harvest index, 1000-grain weight and grain yield/plant; NDB-1057 for days to ear emergence, number of productive tillers/plant and harvest index; HUB-240 for ear length, grains/spike, 1000-grain weight and grain yield/plant and NDB-943 for 1000-grain weight showed significant GCA. Yap and Harvey; 1972, Sharma et al.; 2003, Joshi and Singh; 2004, Kakani et al.; 2007, Amer (2010), Eid (2010) and Amer et al. (2011) agreed with the results of present study.

All crosses exhibited significant and desirable SCA effects for one or more characters. Crosses namely, RD-2909 x NDB-943, NDB-1618 x NDB-1173, RD-2768 x NDB-3, HUB-240 x NDB-1173 and RD-2899 x NDB-943 displayed good specific combinations for grain yield. Whereas, the common good crosses on the basis of per se performance and SCA effects were NDB-1057 x NDB-943, RD-2899 x NDB-1173, RD-2899 x NDB-3, NDB-1618 x NDB-943 and RD-2768 x NDB-1173 for days to ear emergence; RD-2899 x NDB-943, RD-2768 x NDB-3, HUB-240 x NDB-3,

NDB-1057 x NDB-943 and RD-2909 x NDB-1173 for days to maturity and HUB-240 x NDB-3, RD-2768 x NDB-1173, RD-2899 x NDB-943, NDB-1618 x NDB-1173 and RD-2909 x NDB-943 for productive tillers/plant; NDB-1057 x NDB-3, RD-2768 x NDB-3, RD-2909 x NDB-1173, NDB-1618 x NDB-943 and RD-2909 x NDB-943 for Ear length; HUB-240 x NDB-3, RD-2909 x NDB-1173, RD-2899 x NDB-943, NDB-1057 x NDB-3 and NDB-1618 x NDB-1173

for Grains/spike; HUB-240 x NDB-943, NDB-1618 x NDB-1173, RD-2768 x NDB-1173, RD-2909 x NDB-3 and RD-2899 x NDB-3 for biological yield/plant; RD-2899 x NDB-3, HUB-240 x NDB-1173, RD-2768 x NDB-943, NDB-1057 x NDB-943 and NDB-1618 x NDB-943 for harvest index and NDB-1057 x NDB-943, HUB-240 x NDB-1173, RD-2899 x NDB-3, RD-2768 x NDB-943 and RD-2909 x NDB-1173.

Table 3. Estimates of general combining ability (GCA) effects of parents (lines and testers) for nine characters in barley

| Genotypes | Days to ear emergence | Days to maturity | Productive tillers/plant | Ear length (cm) | Grains/spike | Biologic al yield/plant (g) | Harvest index (%) | 1000-grain weight (g) | Grain yield/plant (g) |
|-------------------|-----------------------|------------------|--------------------------|-----------------|--------------|-----------------------------|-------------------|-----------------------|-----------------------|
| RD-2768 | -1.02* | -0.48 | 0.18 | 0.04 | -3.08** | 0.51 | -0.45 | 0.68 | 0.07 |
| NDB-1618 | -0.24 | 0.74 | 0.16 | 0.05 | 0.03 | -0.65 | -1.12* | -1.54** | -0.49** |
| RD-2909 | -0.57 | -0.81 | 0.53* | 0.51** | 3.29** | 1.39** | 1.90** | 1.02* | 0.24 |
| NDB-1057 | 1.31** | 0.18 | -0.51* | -0.25 | 0.53 | -1.54 | -1.07* | -0.37 | -0.15 |
| RD-2899 | 0.20 | -0.37 | -0.01 | 0.20 | 2.67** | 0.75 | 0.31 | 1.96** | 0.85** |
| HUB-240 | 0.31 | 0.74 | -0.35 | -0.56** | -3.44** | -0.46 | 0.44 | -1.76** | -0.52** |
| SE (g) line | 0.42 | 0.45 | 0.25 | 0.15 | 0.83 | 0.45 | 0.45 | 0.45 | 0.18 |
| SE (gi-gj) line | 0.59 | 0.64 | 0.35 | 0.21 | 1.17 | 0.64 | 0.64 | 0.63 | 0.25 |
| CD 5% | 0.85 | 0.91 | 0.50 | 0.30 | 1.68 | 0.92 | 0.92 | 0.91 | 0.36 |
| CD 1% | 1.14 | 1.23 | 0.67 | 0.40 | 2.26 | 1.24 | 1.24 | 1.22 | 0.48 |
| Testers | | | | | | | | | |
| NDB-1173 | 0.15 | -0.65* | 0.08 | -0.10 | 0.07 | 0.78* | 0.18 | 1.07** | 0.11 |
| NDB-3 | 0.43 | 0.57 | -0.11 | 0.18 | 0.86 | -0.37 | 0.22 | -0.26 | -0.01 |
| NDB-943 | -0.57 | 0.07 | 0.03 | -0.08 | -0.94 | -0.41 | -0.41 | -0.81* | -0.09 |
| SE (g) tester | 0.29 | 0.32 | 0.17 | 0.10 | 0.59 | 0.32 | 0.32 | 0.32 | 0.12 |
| SE (gi-gj) tester | 0.42 | 0.45 | 0.25 | 0.15 | 0.83 | 0.45 | 0.45 | 0.45 | 0.18 |
| CD 5% | 0.60 | 0.65 | 0.35 | 0.21 | 1.19 | 0.65 | 0.65 | 0.64 | 0.25 |
| CD 1% | 0.81 | 0.87 | 0.47 | 0.28 | 1.60 | 0.87 | 0.88 | 0.86 | 0.34 |

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

Table 4. Estimates of specific combining ability (SCA) effects of crosses for nine characters in barley

| o. | Cross | Days to ear emergence | Days to maturity | Productive tillers/plant | Ear length (cm) | Grains/spike | Biologic al yield/plant (g) | Harvest index (%) | 1000-grain weight (g) | Grain yield/plant (g) |
|-----|---------------------|-----------------------|------------------|--------------------------|-----------------|--------------|-----------------------------|-------------------|-----------------------|-----------------------|
| 1. | RD-2768 X NDB-1173 | -0.70 | -0.02 | 0.49 | 0.18 | -0.30 | 1.29 | -1.02 | 0.26 | -0.08 |
| 2. | RD-2768 X NDB-3 | 0.35 | -0.91 | -0.24 | 0.39 | 0.62 | -0.09 | 0.23 | -2.41** | 0.38 |
| 3. | RD-2768 X NDB-943 | 0.35 | 0.93 | -0.25 | -0.57* | -0.32 | -1.19 | 0.79 | 2.15** | -0.30 |
| 4. | NDB-1618 X NDB-1173 | 1.18 | -0.24 | 0.25 | -0.29 | 1.16 | 1.49 | -0.22 | -0.52 | 0.54 |
| 5. | NDB-1618 X NDB-3 | -0.43 | 0.20 | -0.07 | 0.01 | -1.93 | -1.58 | -0.25 | 1.81* | -0.26 |
| 6. | NDB-1618 X NDB-943 | -0.76 | 0.04 | -0.18 | 0.28 | 0.77 | 0.08 | 0.47 | -1.30 | -0.27 |
| 7. | RD-2909 X NDB-1173 | -0.15 | -0.35 | -0.25 | 0.33 | 1.80 | -1.75* | 0.30 | 1.93* | -0.52 |
| 8. | RD-2909 X NDB-3 | -0.09 | 0.09 | 0.01 | -0.56 | -1.92 | 0.98 | -0.59 | 1.26 | -0.12 |
| 9. | RD-2909 X NDB-943 | 0.24 | 0.26 | 0.24 | 0.23 | 0.11 | 0.77 | 0.29 | -3.18** | 0.64* |
| 10. | NDB-1057 X NDB-1173 | 0.29 | 0.65 | -0.03 | -0.42 | -0.21 | -0.87 | -0.09 | -4.52** | -0.21 |
| 11. | NDB-1057 X NDB-3 | 1.02 | 0.09 | -0.13 | 0.43 | 1.70 | 0.65 | -0.57 | -0.35 | -0.01 |
| 12. | NDB-1057 X NDB-943 | -1.31 | -0.74 | 0.16 | -0.01 | -1.50 | 0.22 | 0.66 | 4.87** | 0.21 |
| 13. | RD-2899 X NDB-1173 | -1.26 | -0.13 | -0.21 | -0.03 | -1.11 | 0.30 | -0.68 | -1.35 | -0.14 |
| 14. | RD-2899 X NDB-3 | -0.87 | 1.31 | -0.07 | -0.09 | -0.63 | 0.94 | 1.89* | 2.48** | -0.18 |
| 15. | RD-2899 X NDB-943 | 2.13** | -1.18 | 0.28 | 0.13 | 1.74 | -1.24 | -1.21 | -1.13 | 0.32 |
| 16. | HUB-240 X NDB-1173 | 0.63 | 0.09 | -0.26 | 0.23 | -1.35 | -0.46 | 1.71* | 4.20** | 0.41 |
| 17. | HUB-240 X NDB-3 | 0.02 | -0.80 | 0.49 | -0.17 | 2.15 | -0.90 | -0.72 | -2.80** | 0.19 |
| 18. | HUB-240 X NDB-943 | -0.65 | 0.70 | -0.24 | -0.06 | -0.80 | 1.36 | -0.99 | -1.41 | -0.60 |
| 19. | CD 95% SCA | 1.47 | 1.58 | 0.87 | 0.51 | 2.92 | 1.59 | 1-60 | 1.58 | 0.63 |

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

Cross combination RD-2768 x NDB-1173 had desirable SCA effects for multiple traits viz., days to ear emergence, number of productive tillers/plant and biological yield/plant; RD-2909 x NDB-1173 for ear length, grains/spike and 1000-grain weight; RD-2899 x NDB-3 for, days to ear emergence, biological yield/plant, harvest index and 1000-grain weight; RD-2899 x NDB-943 for days to maturity, number of productive tillers/plant, grains/spike and grain yield/plant; NDB-1057 x NDB-943 for days to ear emergence, days to maturity and 1000-grain weight (**Table 4**). Therefore, based on good performance of selective parents and crosses in the present study can be concluded that desirable parent could be used as donors to get high yield and the selective crosses were identified as better for grain yield and it's contributing traits as they possess high SCA effect, may further be utilized in future breeding program. The results are in agreement with the findings of Bornare et al., 2013; Bornare et al., 2014; Bornare et al., 2015; Kakani et al., 2012; Madic et al., 2014; Patial et al., 2016; Pawar et al., 2013; Saad et al., 2005; Sayed et al., 2008; Sharma et al., 2003; Singh et al., 2005; Verma et al., 2009; Yilmaz and Konak, 2000 and Zeng et al. 2001.

In fact, the specific combining ability effects have limited role to play in the breeding of self-pollinated crops like barley, except where commercial exploitation of heterosis is feasible. However, in barley, the additive x additive type of interaction component is fixable in later generations (Sharma et al., 2002). A breeder's interest, therefore, vests

in obtaining transgressive segregants through crosses and producing more potent homozygous lines. This is in conformity with early reports of Sharma et al. (2002), Sharma et al. (2003), Kularia and Sharma (2005), Verma et al. (2007), Singh et al. (2012)

This study highlighted the rewarding parents and crosses of barley that can be exploited by barley breeders to launch effective breeding strategies. It concluded that combining ability analysis elucidated higher magnitude of SCA variance ($\sim 2sca$) than GCA variance ($\sim 2gca$) indicating preponderance of non-additive gene action for all the traits except days to maturity, productive tillers/plant and grains/spike. Selection of superior plants may be deferred to later generation, since non-additive type of gene action was found for most of the plant traits. The magnitude of GCA variance was higher than SCA variance indicated the preponderance of additive gene action and progeny selection would be effective for the genetic improvement of the studied traits. Maximum significant GCA effects were showed by RD 2668 among the testers and RD-2899, HUB-240 and NDB-1618 among the lines that were considered to be good general combiner for most of the traits. The cross combination of RD-2909 x NDB-943 showed excellent SCA performance for the yield contributing traits of the present study. This cross can be exploited vigorously in future barley breeding program to obtain segregants which would deliver a population with high yield potential.

REFERENCES

Amer, K.A., 2010. Inheritance of drought tolerance in some barley genotypes. *Egypt. J. Agric. Res.*, **88**: 85-102.

Amer, K.A., A.A. Eid and M.M.A. El-Sayed, 2011. Genetic analysis of yield and its component under normal and drought conditions in some barley crosses. *Egypt. J. Plant Breed.*, **2**: 65-79.

Arabi, M.I.E. 2005. Diallel analysis of barley for resistance to leaf stripe and impact of the disease on genetic variability for yield components. *Euphytica*, **145**(1/2): 161-170.

Bornare, S.S., Prasad, L.C., Lal, J.P. and Singh, J. 2013. Heterosis and combining ability for yield and its contributing traits in crosses of two-row and six-row barley under rainfed environment. *Crop Improvement*, **40**(1): 81.

Bornare, S.S.; Prasad, L.C.; Lal, J.P.; Madakemohekar, A.H.; Prasad, R.; Singh, J. and Kumar, S. 2014. Exploitation of heterosis and combining ability for yield and its contributing traits in crosses of two-row and six-row barley (*Hordeum vulgare* L.) under rainfed environment. *Vegetos*, **27**(3): 40.

Briggs, D.E.; Waring, R.H. and Hackett, A.M. 1974. The metabolism of carboxin in growing barley. *Pest Management Sci.*, **5**: 599-607.

Fonseca, A. and F.L. Patterson. 1968. Hybrid vigour in a seven parent diallel cross in common winter wheat (*T. aestivum* L.). *Crop Sci.*, **8**: 85-88.

Griffing, J.B. 1956. Concept of general and specific combining ability in relation to diallel crossing systems. *Aust. J. Biol. Sci.*, **9**: 463-493.

Hockett, E.A.; Cook, A.E.; Khan, M.A.; Marthin, J.M. and Jones, B.I. 1993. Hybrid performance and combining ability for malt quality in diallel cross in barley. *Crop Sci. (USA)*, **33**: 1239-1244.

Johnson, H.W., H.F. Robinson and Comstock, R.E. 1955. Estimation of genetic and environmental variability in soybean. *Agro. J.* **47**: 314-318.

Joshi, R.P. and Singh A.K. 2004. Combining ability for seedling traits and grain yield in barley. JNKVV Research Journal, **38**(2):9- 12.

Kakani, R.K.; Sharma, Y. and Sharma, S.N. 2007. Combining ability of barley genotypes in diallel crosses. *SABRAO J.*, **39**: 117-126.

Kakani, R.K. and Sharma, Y. 2010. Genetic component analysis for yield and yield contributing traits under diverse environments in barley. *SABRAO J. Breed. Genet.*, **42**(1): 9-20.

Kalashnik, N. A., and Y. E. Smyalovskaya. 1986. Breeding and genetical analysis of yield in barley hybrids. *Genetika USSR* **22**: 7, 1155-62.

Kempthorne, O. 1957. An introduction to genetical statistics. *John Wiley and sons, Inc, New York, pp. 468-471.*

Madic, M.R.; Djurovic, D.S.; Knezevic, D.S.; Paunovic, A.S. and Tanaskovic, S.T. 2014. Combining abilities for spike traits in a diallel cross of barley. *J. Central European Agriculture*, **15**(1): 108.

Panse V.G. and Shukhatme P.V.; 1967. Statistical methods for agricultura workers. 2nd ICAR, New Delhi.

Patial, M., Pal, D. and Kumar, J. 2016. Combining ability and gene action studies for grain yield and its component traits in barley (*Hordeum vulgare L.*). *SABRAO J. Breed. and Genet.*, **48**(1): 90-96.

Phogat, D.S., D. Singh, G.S. Dahiya, and D. Singh. 1995. Genetics of yield and yield components in barley (*Hordeum vulgare L.*). *Crop Res. Hisar.* **9**: 3, 363-369.

Potla, K.R., Bornare, S.S. Prasad, L.C., Prasad R. and Madakemohekar A.H. 2013. Study of heterosis and combining ability for yield and yield contributing traits in barley (*Hordeum vulgare L.*). *The Bioscan* **8**(4): 1231-1235.

Pawar, K.K. and Singh, A.K. 2013. Combining ability analysis for grain yield and its attributing traits in barley. *International J. Agril. Sci. and Veterinary Medicine, ISSN : 2320-3730.*

Rodina, N.A. 1972. Heterosis in barley. *1-Ya-Nauch-Metod-Konfr-NII-S, Kh,-Sev,-Vost*, 59-67.

Rodina, N.A. 1974. The combining ability of some barley varieties. *Tr. NII-S-Kh-Sev.-Vostoka.*, pp. 97-105.

Saad, F.F.; Hindi, L.H.A.; Abd. El. Shafi, M.A. and Youssef, M.H.A. 2005. Heterosis and combining ability analysis in barley (*Hordeum vulgare L.*). *Bulletin of faculty of Agriculture, Cairo University*, **56**: 455-467.

Sayed, A.A.; Morshed, G.A.; Hassanein, A.M.; Ashmawy, H.A. 2008. Combining ability in the F_1 & F_2 generations of certion hull-less barley crosses. *Plant Breed.*, **11**(1): 271-279.

Sharma, Y. 2003a. Combining ability analysis in six rowed barley over the environments. *Indian Agri.*, **47**: 23-32.

Sharma, Y.; Sharma, S. N.; Joshi, P. and Sain, R.S. 2003b. Combining ability in the F_1 and F_2 generations of a diallel cross in six-row barley. *Acta Agronomica Hungarica*, **51**(3): 281-288.

Singh, G. and Srivastava, S.B.L. 2005. Combining ability analysis for yield and its components in barley (*Hordeum vulgare L.*). *Indian Sci. J.*, **14**: 36-39.

Verma, A.K.; Vishwakarma, S.R. and Singh, P.K. 2009. Line \times tester analysis in Barley (*Hordeum vulgare L.*) across environments. *Genet. Newsletter*, **37**:29-33.

Yap T.C. and Harvey B.L.; 1972. Inheritance of yield components and morpho-physiological traits in barley (*Hordeum vulgare L.*). *Crop Science*. **12**(3): 283-286.

Yang, Y. F., and D. Z. Lu. 1991. Genetic analysis on morpho-physiological traits of barley flagleaf. *Scientia Agricultura Sinica* **24**: 1, 20-26.

Yilmaz, Z.R. and Konak, C. 2000. Heterotic effects regarding salt tolerance in some characters of barley. *Turkish J. Agriculture and Forestry*, **24**: 643-648.

Zeng, Y.; Zeng, C.L. and Chen, L. Z. 2001. Combining ability and heterosis in forage barley. *Indian J. Genet. and Plant Breed.*, **61** (1): 71-73.