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Research Note

Combining ability analysis for yield traits in barley (*Hordeum vulgare* L.)

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Abstract
The 21 hybrids were generated by applying LxT mating design using seven lines and three testers and were subjected to study combining ability for nine yield traits of barley. ANOVA was significant for GCA and SCA effect, indicating parents and crosses differed significantly with regard to general and specific combining ability, respectively. The GCA effect recorded for most of the traits were low and non-significant. However, two lines EC-667509 and EC-667365; one tester, NDB3 recorded the high GCA effect in three traits each*viz*., productive tillers per plant, the number of grains per spike and 1000-grain weight; grain yield per plant, harvest index and 1000-grain weight; days to 75% maturity, the number of grains per spike and harvest index, respectively. Non-significant SCA effect for all the traits was observed in 12 out of 21 crosses. In respect to the SCA effect, cross EC-667498 x Azad performed better than the remaining cross combinations, as it recorded the high SCA effect in desirable direction in five out of nine traits.

Key words
Barley, line x tester, GCA effect, and SCA effect

Barley (*Hordeum vulgare* L.) is a cereal crop grown in r*abi* season in India. It is the fourth most cultivated cereal crop in the world. Barley has multifold uses as animal fodder, raw material for fermentable beer, component of health drinks. Barley crop has been used as a medicinal plant for a number of ailments *viz*., diuretics, pancreas and biliar ailments, digestive problems. It is also referred as "*balahar*" for infant and it is also recommended by doctors for children those suffering from minor infections, diarrhea and dry coughs. The versatile uses of barley make it an important cereal crop.

Combining ability analysis is an 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 traits, which is essential for deciding suitable breeding strategy. It can be used to assess the performance of lines in a hybrid combination (Griffing, 1956). Among the various techniques available for combining ability analysis, the line × tester analysis (Kempthorne, 1957) has been widely utilized for screening of germplasm to identify the valuable donor parents and their crosses for breeding programme in many crops including barley. An experiment was designed to study the nature of gene action and combining ability of barley genotypes for nine yield traits.

The present study was undertaken at Genetics and Plant Breeding Research Farm of Acharya Narendra Deva

University of Agriculture and Technology, Narendra Nagar, Kumarganj, Ayodhaya, Uttar Pradesh during *Rabi* 2013 and 2014. During *Rabi* 2013, the selected parental were sown in crossing block and a hybridization program was carried out following Line xTester mating design using seven genotypes (EC-667526, EC-667509, EC-667498, EC-667458, EC-667377, EC-667365 and EC-667454) as lines and three genotypes (NDB-3, Azad, RD-2552) as testers. The 21 F_1s obtained from the crossing program, along with 10 parents were sown in Randomized Block Design in two replications following a spacing of 25 x 10 cm during *Rabi* 2014. Recommended package of practice was followed strictly to ensure a healthy crop stand. Data was collected on randomly selected five plants from each of the 31 lines in two replications on nine traits *viz*., days to 50 per cent, ear emergence, days to 75 per cent maturity, the numbers of effective tillers per plant, the number of grains per main ear, ear length, biological yield per plant, harvest index, 1000-grain weight and yield per plant.

Table 1. Analysis of variance for combining ability for nine traits in barley

Source of variation	d.f.	Days to 50% Ear Emergence	Days to 75% maturity	Productive Tillers/ Plant	Ear Length	Grains/ Spike	Biological Yield/ Plant	Grain Yield/ Plant	Harvest Index	1000 Grain Weight
Replication	1	11.52	22.88**	0.33	0.02	5.89	0.59	0.74	7.83*	0.00
Crosses	20	7.68*	15.22**	0.60**	0.66	31.75**	7.35*	1.37*	3.59**	13.67**
Line Effect	6	3.76	30.25*	0.60	0.72	17.91	4.34	1.63	4.68	22.40
Tester Effect	2	6.64	24.45*	0.34	0.20	80.26	0.90	0.38	5.08	3.58
Line x Tester Effect	12	9.80*	6.17**	0.64**	0.70	30.58**	9.94*	1.40*	2.81*	10.98**
Variance GCA		-0.46	2.11**	-0.01	-0.02	1.85*	-0.73	-0.03	0.20*	0.20
Variance SCA		3.50*	1.91*	0.26*	0.15*	13.80*	3.40*	0.44*	0.86*	4.79*
Error	20	2.77	0.48	0.11	0.43	3.00	3.25	0.57	0.81	1.40
Total	41	5.37	8.22	0.36	0.53	17.10	5.19	0.96	2.34	7.35

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

Table 2. Estimates of general combining ability (*gca*) effects of parents

S.No	Genotypes	Days to 50% Ear Emergence	Days to 75% maturity	Productive Tillers/ Plant	Ear Length	Grains/ Spike	Biological Yield/ Plant	Grain Yield/ Plant	Harvest Index	1000 Grain Weight
	Lines									
1	EC-667377	0.88	-4.02**	-0.61**	0.24	-2.43*	-0.23	-0.60	-1.20*	-1.52*
2	EC-667365	-0.12	-1.02	-0.06	-0.05	-1.81*	1.03	0.78*	1.29*	1.98**
3	EC-667526	-1.29	-0.86	0.24	0.53*	-0.57	-0.23	0.14	0.87	0.31
4	EC-667458	1.05	1.48*	0.00	0.10	-0.07	0.81	0.24	-0.12	-1.35*
5	EC-667498	-0.12	2.81**	-0.09	-0.52	1.05	-0.23	0.24	-0.26	-0.02**
6	EC-667509	0.05	0.14	0.34*	-0.29	2.06*	-1.52*	-0.728	0.24	2.95**
7	EC-667454	-0.45	1.48*	0.19	-0.01	1.76*	0.36	-0.06	-0.82	-2.35
	CD @95%	1.37	1.30	0.29	0.53	1.46	1.50	0.60	0.88	1.00
	Testers									
1	RD-2552	-0.29	0.02	0.18	0.12	-1.18*	-0.28	-0.19	-0.59*	0.09
2	NDB-3	0.79	-1.33*	-0.08	-0.02	2.76**	0.22	0.09	0.62*	0.46
3	Azad	-0.50	1.31*	-0.10	-0.11	-1.57*	0.06	0.09	-0.03	-0.54
	CD @95%	0.90	0.85	0.19	0.35	0.96	0.98	0.39	0.57	0.65

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

The combining ability analysis for various yield and quality traits was accomplished by the method suggested by Kempthorne (1957). The significance of GCA (General Combining Ability) and SCA (Specific Combining Ability) effects were evaluated by t-test.

The analysis of variance of combining ability revealed that the line and tester effect was significant only for days to 75 per cent maturity. ANOVA for Line x Tester effect and crosses were significant for all the traits except ear length (**Table 1**). SCA variance was significant for all the traits while GCA variance was significant only for days to 75 per cent maturity, grains per spike and harvest index.

GCA variance ($\sigma^2 g$) was less than SCA variance ($\sigma^2 s$) for all the traits indicating role of non-additive gene action in inheritance of those traits (**Table 1**). However, days to 75 per cent maturity $\sigma^2 g$ was more than $\sigma^2 s$, indicating the role of additive gene action in inheritance of days to maturity trait. Similar findings have been observed in work of Hockett*et al.*(1993); Briggs, (1994); Yilmoz and Konak, (2000); Singh *et al.*(2013) and Patial*et al.*(2018) and Sharma and Jaiswal(2020).

When a line is crossed with several other lines, then the mean performance of that particular line can be measured; called as General Combining Ability (GCA) of the line (Falconer and Mackay,1996). GCA, primarily a function of additive gene action, is used to recognize combining ability of genotypes and hence indirectly assist in predicting genetic worth of genotypes.

Two genotypes had significant high GCA effect in desirable direction for three traits *viz*., grain yield per plant, harvest index, 1000-grain weight in EC-667365 and productive tillers per plant, grains per spike and 1000-grain weight in EC-667509. Kumari*et al*. (2020) had recorded only parent which showed a high GCA for yield per plant in their experimental findings. Among testers, only NDB-3 was found to be desirable combiner for days to 75 per cent maturity, grains per spike and harvest index (**Table 2**). Other two testers did not record high GCA

Table 3. Estimates of specific combining ability (*sca*) effects of crosses among nine traits in barley

Cross	Days to 50% Ear Emergence	Days to 75% maturity	Productive Tillers/ Plant	Ear Length	Grains/ Spike	Biological Yield/ Plant	Grain Yield/ Plant	Harvest Index	1000 Grain Weight
EC-667377×RD-2552	-0.88	-1.69	-0.06	0.46	2.75*	-0.17	0.01	-0.40	-1.25
EC-667377×NDB-3	0.05	-0.83	-0.20	0.34	1.91	1.05	-0.04	0.02	0.38
EC-667377×Azad	0.83	2.52*	0.26	-0.81	-4.66**	-0.88	0.03	0.39	0.88
EC-667365×RD-2552	-1.38	-1.19	-0.11	0.70	-1.12	-2.19	-0.64	0.55	3.25**
EC-667365×NDB-3	0.05	1.17	0.45	0.13	1.69	2.41	1.04	0.40	-2.12*
EC-667365×Azad	1.33	0.02	-0.34	-0.82	-0.58	-0.22	-0.40	-0.96	-1.12
EC-667526×RD-2552	1.29	0.14	-0.51	-0.28	0.29	0.51	0.15	-0.27	-1.09
EC-667526×NDB-3	-0.29	-2.00*	0.25	0.00	-2.45	-0.38	0.45	1.47	3.54**
EC-667526×Azad	-1.00	1.86	0.26	0.28	2.16	-0.13	-0.60	-1.20	-2.46**
EC-667458×RD-2552	-0.55	0.31	0.62*	-o.25	5.12**	1.57	0.34	-0.51	1.58
EC-667458×NDB-3	-2.12**	0.17	-0.22	-0.47	-0.60	-2.98*	-0.73	0.03	-0.79
EC-667458×Azad	2.67*	-0.48	-0.40	0.73	-4.52**	1.40	0.39	0.48	-0.79
EC-667498×RD-2552	-1.88	0.98	-0.16	-0.57	-7.00**	-1.31	-0.74	-0.08	-0.25
EC-667498×NDB-3	0.05	1.33	-0.63*	0.48	2.14	-1.30	-0.76	-1.22	0.88
EC-667498×Azad	1.83	-2.31*	0.79**	0.08	4.87**	2.62*	1.50**	1.30	-0.62
EC-667509×RD-2552	0.45	0.14	-0.40	-0.16	0.50	0.45	0.31	-1.03	-2.81**
EC-667509×NDB-3	0.88	1.50	0.14	-0.40	-2.47	-1.28	-0.44	0.96	-0.59
EC-667509×Azad	-1.33	-1.64	0.26	0.56	1.97	0.83	0.13	0.07	3.41**
EC-667454×RD-2552	2.95*	1.31	0.64*	0.11	-0.54	1.14	0.58	1.74*	0.58
EC-667454×NDB-3	1.38	-1.33	0.20	-.0.07	-0.22	2.48	0.48	-1.65*	-1.29
EC-667454×Azad	-4.33**	0.02	-0.84**	-0.32	0.76	-3.62**	-1.06*	-0.09	0.71
CD @95%	2.39	2.26	0.52	0.92	2.54	2.61	1.05	1.53	1.74

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

effects in desirable direction for any trait. These findings are in congruence with results obtained by Zeng and Chen (2001); Singh *et al*. (2005);Arabi(2005) and Sayed *et al*. (2008).

The 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. The promising F_1s exhibiting significant SCA effects in desirable direction can be incorporated in future barley improvement program. Results revealed that, none of the crosses showed significant SCA effects in desirable direction for all the traits. Several crosses exhibited significant and desirable SCA effects for one or more traits but none of them emerged as good specific combination for more than five traits. In the present study 12 out of 21 crosses did not record significant high SCA effect in desirable direction for any of the traits (**Table 3**). Among the 12 crosses which showed the significant desirable SCA effect, only one cross EC-667498×Azad displayed a significant and positive SCA effect for grain yield. Five crosses showed significant SCA effect for one trait only, *viz*., cross EC-667377 x RD-2552 for grains per spike; EC-667365 x RD-2552 and EC-667509 x Azad for 1000-grain weight; EC-667458 x NDB-3 and EC-667454 x Azad for days to fifty per cent ear emergence. Cross EC-667458 x RD-2552 recorded high SCA effect in desirable direction for two traits *viz*., effective tillers per plant and grains per spike. Similarly cross EC-667454 x RD-2552 recorded a high SCA effect in desirable direction for two traits *viz*., effective tillers per plant and harvest index. Similar findings have been recorded in work of Singh *et al.*(2005), Saad*et al.* (2005), Sayed*et al.* (2008), and Verma*et al.* (2009). The SCA effect of the crosses is an estimate for making selection of best cross combinations. The high specific combining ability denotes, undoubtedly a high heterotic response, however this, does not mean high performance of the hybrids as well. The best crosses on the basis of SCA effect and the mean performance was reported in **Table 4**.

In general, maximum contribution to the total variance due to females was higher than the males for all the nine traits except grains per spike. The maximum contribution of females (lines) was recorded for days to 75 per cent maturity followed by1000-grain weight, harvest index, grain yield per plant, ear length productive tillers per plant, biological yield per plant, the number of grains per spike. The lowest contribution of total variance by female line was recorded for days to 50 per cent ear emergence. The maximum contribution of testers was recorded for the number of grains per spike followed by days to 75 per cent maturity, harvest index, days to fifty per cent ear emergence, productive tillers per plant ear length, grain yield per plant, 1000-grain weight. The lowest contribution of males was recorded for biological yield.

Proportional contribution of lines × testers were found maximum for biological yield per plant followed by days to 50 per cent ear emergence, ear length, productive tillers per plant, grain yield per plant, grains per spike, 1000-grain weight and harvest index. While the lowest contribution of lines × tester interaction was recorded for days to 75 per cent maturity. Similar findings have been recorded by Bhatnagar*et al.* (2001), Yadav*et al.*(2002), Ved Prakash *et al.* (2006) and Verma*et al.* (2009). The best crosses on the basis of SCA effect and *per se* performance was depicted in **Table 5**

The hybrids recording positive and significant SCA effects in the present study need to be further tested in observational/multiplication trials to exploit their heterotic potential at commercial level. Moreover, the cross combinations which show non-significant SCA effects but originated from parental lines having high GCA effects can be used for recombination breeding with an easy selection of desirable segregants, particularly for developing the better performing pure lines.

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

S. No.	Character	Contribution (%)		
		Lines	Testers	Lines × Testers
1	Days to 50% Ear Emergence	14.70	8.65	76.66
2	Days to 75% Maturity	59.60	16.10	24.33
3	Productive Tillers/ Plant	29.81	5.69	64.50
4	Ear Length	32.74	3.05	64.20
5	Grains/ Spike	16.93	25.28	57.79
6	Biological Yield/ Plant	17.69	1.21	81.10
7	Grain Yield/ Plant	35.77	2.75	61.40
8	Harvest Index	39.04	14.12	46.83
9	1000 Grain Weight	49.17	2.61	48.21

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Table 5. Ranking of desirable crosses on the basis of per se performance and sca effects

Combining ability / Traits	On the basis of *per se* performance	*per se* performance	On the basis of *sca* effects	*sca* effects	On the basis of *per se* performance and *sca* effects
Days to 50% ear emergence	EC-667454×Azad	91.00	EC-667454×Azad	-4.33**	EC-667498×RD-2552
	EC-667526×Azad	93.50	EC-667458×NDB-3	-2.11	EC-667365×RD-2552
	EC-667498×RD-2552	94.00	EC-667498×RD-2552	-1.18	EC-667454×Azad
	EC-667509×Azad	94.50	EC-667365×RD-2552	-1.38	
	EC-667365×RD-2552	94.50	EC-667509×Azad	-1.33	
Days to 75% maturity	EC-667377×NDB-3	120.50	EC-667498×Azad	-2.31*	
	EC-667377×RD-2552	121.00	EC-667526×NDB-3	-2.00	EC-667526×NDB-3
	EC-667526×NDB-3	122.50	EC-667377*RD-2552	-1.69	EC-667377*RD-2552
	EC-667365*RD-2552	124.50	EC-667509×Azad	-1.64	
	EC-667365×NDB-3	125.50	EC-667454×NDB-3	-1.33	
Productive tillers /plant	EC-667454×RD-2552	6.60	EC-667498×Azad	0.79**	
	EC-667458×RD-2552	6.40	EC-667458×RD-2552	0.69	EC-667458×RD-2552
	EC-667498×Azad	6.20	EC-667365×NDB-3	0.45	
	EC-667509×Azad	6.10	EC-667377×Azad	0.26	
	EC-667509×NDB-3	6.00	EC-667526×Azad	0.26	
Ear length (cm)	EC-667377×RD-2552	8.94	EC-667458×Azad	0.73	EC-667377×RD-2552
	EC-667365×RD-2552	8.88	EC-667365×RD-2552	0.70	EC-667365×RD-2552
	EC-667458×Azad	8.83	EC-667498×NDB-3	0.48	
	EC-667526×Azad	8.82	EC-667509×Azad	0.56	
	EC-667526×NDB-3	18.63	EC-667377×RD-2552	0.46	
Grains / spike	EC-667498×NDB-3	60.90	EC-667458×RD-2552	5.12**	EC-667458×RD-2552
	EC-667498×Azad	59.30	EC-667498×Azad	4.86**	EC-667498×Azad
	EC-667454×NDB-3	59.25	EC-667377×RD-2552	2.74*	EC-667498×NDB-3
	EC-667458×RD-2552	58.83	EC-667526×Azad	2.16	
	EC-667365×NDB-3	57.60	EC-667498×NDB-3	2.14	
Biological yield /plant	EC-667365×NDB-3	31.32	EC-667498×Azad	2.61*	EC-667454×NDB-3
	EC-667454×NDB-3	30.72	EC-667454×NDB-3	2.48	EC-667365×NDB-3
	EC-667458×Azad	29.94	EC-667365×NDB-3	2.40	EC-667458×RD-2552
	EC-667458×RD-2552	29.77	EC-667458×RD-2552	1.57	
	EC-667454×RD-2552	28.89	EC-667458×Azad	1.40	
Grain yield / plant (g)	EC-667365×NDB-3	10.49	EC-667498×Azad	1.50**	EC-667498×Azad
	EC-667498×Azad	10.41	EC-667365×NDB-3	1.04	EC-667365×NDB-3
	EC-667458×Azad	9.30	EC-667454×RD-2552	0.58	EC-667454×NDB-3
	EC-667526×NDB-3	9.26	EC-667454×NDB-3	0.48	EC-667526×NDB-3
	EC-667454×NDB-3	9.09	EC-667526×NDB-3	0.45	
Harvest index (%)	EC-667526×NDB-3	34.23	EC-667454×RD-2552	1.74*	EC-667526×NDB-3
	EC-667365×NDB-3	33.59	EC-667526×NDB-3	1.47	EC-667498×Azad
	EC-667509×NDB-3	33.08	EC-667498×Azad	1.30	EC-667509×NDB-3
	EC-667365×RD-2552	32.53	EC-667509×NDB-3	0.96	EC-667365×RD-2552
	EC-667498×Azad	32.28	EC-667365×RD-2552	0.55	
1000-grain weight (g)	EC-667509×Azad	39.00	EC-667526×NDB-3	3.54**	EC-667526×NDB-3
	EC-667365×RD-2552	38.50	EC-667509×Azad	3.41**	EC-667509×Azad
	EC-667526×NDB-3	37.50	EC-667365×RD-2552	3.25**	EC-667365×RD-2552
	EC-667509×NDB-3	36.00	EC-667458×RD-2552	1.54	
	EC-667498×NDB-3	34.50	EC-667377×Azad	0.88	

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