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Combining Ability Analysis for Grain Yield and Its Attributing Traits in Six- rowed Barley (*Hordeum vulgare* L.)

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ABSTRACT

To enhance productivity in barley crop, varieties having good combining ability are required. Because, the choice of the most suitable breeding method depends mainly on the combining ability behaviour vis-a-vis nature of gene action involved in the control of the trait of interest to the breeder. Therefore, the present research investigation was carried out with 10 parent half diallel set consisting of parents, F_1's and F_2's to estimate the general and specific combining ability variances and effects. Overall appraisal of present investigation manifested that the parent BH 959 and RD 2786 emerged as good general combiners for yield and its attributing traits, while among the crosses BHS 400 x BH 959, BH 959 x RD 2786 and PL 426 x RD 2552 emerged as good crosses for grain yield per plant as well as for other yield contributing characters. Parents BH 946, BH 902 and BH 959 has high yield coupled with high malt quality hence can be also used for malting quality purpose.

Key words: *Barley, Combining Ability, Half Diallel, GCA, SCA.*

INTRODUCTION

Barley is a cereal grain crop, originated from of the Near East and Ethiopian High lands, but now cultivated worldwide. Among cereals, it is an important food grain crop and stands fourth position next to wheat, rice and maize in India. Increased yield of crops had been a prime concern in breeding programmes. Barley breeding programmmes mostly involve hybridization, evaluation and selection of desirable genotypes. The assessment of combining ability and determining gene action are elementary tools for selection of ideal genotypes. Advancement in the yield of this important crop species requires adequate information regarding the nature of combining ability of the parents available in a wide array of genetic material to be used in the hybridization programme and also the nature of gene actions involved in the expression of quantitative and qualitative traits of economic importance. Diallel mating design has been extensively used to analyze the combining ability effects of barley genotypes and also to provide information regarding genetic mechanism controlling grain yield and other traits.

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Combining ability analysis provides useful information to select the suitable parents for a hybridization programme[6]. Therefore, the present research investigation was carried out to understand the effect of yield contributing attributes under high temperature conditions and identification of tolerant genotypes suitable for such environment.

MATERIAL AND METHODS

The present investigation was carried out to study combining ability in six-rowed barley (*Hordeum vulgare* (L.) em. Boweden). Ten genetically diverse parents namely BHS 400, BG 105, PL 426, BHS 380, BH 902, BH 946, BH 959, RD 2715, RD 2786 and RD 2552 were selected for present study and crossed in half-diallel fashion (excluding reciprocals) in Rabi 2015-16. Next year (Summer 2016) F_1 seed was grown to advance the generation. Finally, ten genotypes along with their 45 F_1's and 45 F_2's were evaluated at timely sown condition (20th November) with three replications in a randomized block design during Rabi 2016-17 at Agricultural Research Farm, RARI Durgapura, Jaipur. Each replication contained two parts. First part consist ten parents and 45 F_1's sown in two rows plot while the plots of second part consisted four rows of 45 F_2's. Row length was kept 3 meters. Row to row and plant to plant distance was kept 30 cm and 10 cm, respectively. Observations were recorded for days to heading, days to maturity, number of effective tillers per plant, flag leaf area, number of grains per spike, 1000-grain weight, grain yield per plant and harvest index, 10 randomly selected plants in each of the F_1's progenies along with each parent, while 30 plants were selected in F_2's population from each replication. The data obtained were subjected to statistical analysis to get information on significance of differences[1] and combining ability (Griffing's method 2, Model I).

The generalized model to estimate the general and specific combining ability effects of ijklth observations is given below[2].

$$Xijk=\mu+gi+gj+sij+ 1/bc\Sigma k\Sigma\ ieijkl$$

Where,

μ= Population means

gi= gca effect of ith male parent

gj= gca effect of jth female parent

sij= sca effect of ijth combinations

eijk= error associated with the observation Xijk

i= number of male parents

j= number of female parents

k= no of replications

RESULTS AND DISCUSSION

The combining ability analysis revealed significant mean squares due to GCA and SCA for all the characters indicating that both additive and non-additive gene effects played an important role in the genetic control of the traits studied similar results were also observed Sultan *et al.*[7] and Pesaraklu *et al.*[8], consequently established the circumstances that the characters manifested the presence of ample genetic diversity among the parents (Table 1).

The GCA/SCA variance ratio was less than unity indicated the importance of non-additive gene action for all the characters under investigation except number of grains per spike in both the generations and 1000-grain weight in F_1 generation only where predictability ratio was more than unity, which showed preponderance of additive gene action. These findings were corroborative with the results obtained by Sultan *et al.*[7] and Ram and Shekhawat[9] (Table 1).

In self-pollinated crops like barley, SCA effects have relatively less applicability as they are consequences of non-additive gene effects excepting those arising from complementary gene action or linkage effects and cannot be fixed in the end product i.e. pure line. Jinks and Jones[3] emphasized that the superiority of the hybrids might not indicate their ability to yield transgressive segregants, rather SCA would provide satisfactory criteria. However, if a cross combination exhibiting high SCA as well as high *per se* performance having at least one parent as good general combiner for a specific trait, it is expected that this cross combination may provide desirable transgressive segregants in later generations (Table 2 and 3).

The top three cross combinations which were significant and good for two or more characters in F_1 only (Table 4), are as follows: BHS 400 x BH 959 for days to heading, plant height and biomass per plant; BG 105 x BHS 380 for days to heading and number of grains per spike; BG 105 x BH 959 for days to maturity and 1000-grain weight; BHS 400 x BH 902 for days to maturity, number of effective tillers per plant; BHS 400 x BH 946 for number of effective tillers per plant and grain yield per plant; PL 426 x BH 959 for number of effective tiller per plant and number of grains per spike; BH 902 x RD 2552 for 1000-grain weight and malt score.

The top three cross combinations which were significant and good for two or more characters in F_2 only (Table 4), are as follows: PL 426 x RD 2552 for days to heading, flag leaf area and grain yield per plant; BHS 400 x BH 959 for days to heading and grain yield per plant; BG 105 x BH 959 for days to heading and 1000-grain weight; PL 426 x BH 959 for days to maturity and number of grains per spike; BHS 380 x BH 959 for plant height and number of effective tillers; BH 959 x RD 2786 for flag leaf area and grain yield per plant; RD 2715 x RD 2552 for harvest index and malt score.

On the basis of GCA effects and *per se* performance (Table 5), an overall evaluation showed that the parent BH 959 for both generations and RD 2786 for F_2 generation emerged as good general combiners for grain yield with simultaneous consideration of other characters. Therefore, these parents could be intensively used in the hybridization programme to develop lines with several desirable characters for further tangible advancement of barley yield.

On the basis of SCA effects and *per se* performance (Table 5), some crosses *viz*., BG 105 x RD 2715 in F_1 generation and, BH 959 x RD 2786 and PL 426 x RD 2552 in F_2 generation were identified as good specific cross combinations for grain yield and some associated traits. These crosses have great potential for improvement of barley and may be utilize in multiple crossing programme.

SCA effects of best crosses and GCA effects of their parents indicated that the good specific cross combinations were the result of good x good, good x poor or poor x poor combinations. These crosses hold great promise in improving the grain yield in future breeding programme of barley. The crosses involving good × good general combiner may be utilize to develop pureline.

Conclusively, an overall evaluation showed that the parent BH 959 and RD 2786 emerged as good general combiners while among the cross BHS 400 x BH 959, BH 959 x RD 2786 and PL 426 x RD 2552 emerged as good crosses for grain yield per plant as well as for other yield contributing characters in all the environments. As non-additive gene actions were found to be more dominant in the present investigation and heterosis may not be worthwhile in a crop like barley so that In addition to conventional breeding methods some non-conventional breeding methods such as diallel selective mating[4], bi-parental mating in early segregating generations[5] or reciprocal recurrent selection followed by selection or multiple crosses might prove to be effective alternative approach for advancement of grain yield in barley.

Table 1: Analysis of variance for combining ability for yield and its attributes

Characters	Source of variation							
	GCA (df = 9)		SCA (df = 45)		Error (df =110)		GCA/SCA Ratio	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
Days to heading	121.00**	131.58**	13.11**	15.02**	0.22	0.12	0.78	0.74
Days to maturity	17.75**	15.27**	14.70**	13.86**	0.13	0.12	0.10	0.09
Plant height	84.44**	95.21**	11.92**	15.39**	0.37	0.36	0.61	0.53
Number of effective tillers per plant	8.02**	8.42**	0.85**	1.76**	0.14	0.13	0.92	0.42
Flag leaf area	36.04**	29.56**	4.94**	7.03**	1.85	1.72	0.92	0.44
Number of grains per spike	246.89**	279.05**	10.93**	23.26**	0.31	0.39	1.93	1.02
1000-grain weight	61.21**	48.99**	3.01**	14.62**	0.45	0.36	1.98	0.28
Biomass per plant	110.44**	165.31**	49.62**	64.19**	6.32	3.9	0.20	0.22
Grain yield per plant	11.03**	19.08**	5.86**	10.01**	1.19	0.70	0.18	0.16
Harvest index	57.73**	94.57**	9.65**	17.78**	0.31	0.34	0.51	0.45
Malt score	31.46**	37.75**	4.24**	7.55**	0.24	0.27	0.65	0.43

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

Table 2: Estimates of GCA and SCA effects for yield related attributes

Parents / Crosses	Days to heading		Days to maturity		Plant height		Number of effective tillers per plant		Flag leaf area		Number of grains per spike	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
GCA effects												
BHS 400	3.49**	4.21**	2.16**	2.19**	1.83**	1.79**	-0.33**	-0.43**	-0.97*	-0.86*	-5.78**	-5.67**
BG 105	-1.28**	-1.26**	0.35**	-0.08	-0.83**	-0.66**	0.85**	0.12	-1.00**	0.12	-0.11	-0.1
PL 426	-2.60**	-2.33**	-0.68**	-1.39**	-1.77**	-2.46**	-1.09**	-0.60**	3.37**	3.40**	-5.40**	-4.83**
BHS 380	2.00**	2.55**	1.24**	1.08**	-0.26	-0.80**	-0.70**	-0.62**	-1.63**	-1.41**	-4.55**	-4.65**
BH 902	2.58**	0.92**	-0.43**	0.42**	2.38**	2.50**	0.30**	0.63**	1.64**	0.94*	2.68**	4.45**
BH 946	0.38**	1.00**	-0.15	-1.67**	3.09**	2.58**	0.52**	0.05	0.47	0.13	5.26**	6.37**
BH 959	-7.14**	-7.72**	-0.40**	-0.64**	-5.23**	-5.68**	0.41**	0.96**	1.58**	1.10**	5.03**	5.40**
RD 2715	-0.99**	-0.61**	1.02**	0.19*	2.71**	3.38**	-0.43**	-0.69**	-1.33**	-0.69	-0.02	-2.45**
RD 2786	2.49**	2.01**	-1.15**	-0.31**	-2.44**	-1.79**	1.39**	1.59**	-0.17	-0.46	5.78**	4.96**
RD 2552	1.07**	1.23**	-1.96**	0.19*	0.50**	1.16**	-0.93**	-1.02**	-1.96**	-2.25**	-2.89**	-3.47**
SE (gi)±	0.13	0.1	0.1	0.09	0.17	0.16	0.1	0.1	0.37	0.36	0.15	0.17
SE (gi-gj)±	0.19	0.14	0.15	0.14	0.25	0.24	0.15	0.15	0.55	0.54	0.23	0.26
SCA effects												
BHS 400 x BG 105	2.73**	4.89**	0.39	4.31**	4.07**	2.39**	-0.69*	0.86*	2.37	1.42	-5.28**	-8.42**
BHS 400 x PL 426	2.05**	1.64**	2.09**	2.62**	-0.67	-0.11	0.11	-0.57	-1.13	-0.83	-1.91**	1.29*
BHS 400 x BHS 380	6.56**	-0.25	0.84*	-3.19**	-0.95	-0.57	-0.31	0.82*	-2.09	-0.5	1.24*	0.97
BHS 400 x BH 902	1.98**	3.72**	-4.83**	-0.52	2.32**	0.79	-0.66	-1.56**	2.58*	-2.36	8.05**	3.99**
BHS 400 x BH 946	-0.93*	0.97**	-1.78**	-3.77**	2.05**	1.28*	2.13**	-0.67*	-0.82	-0.7	1.54**	2.08**
BHS 400 x BH 959	-11.74**	-11.31**	-3.86**	-6.13**	-8.80**	-7.71**	-0.42	2.38**	-2.78*	2.42*	2.66**	-0.42
BHS 400 x RD 2715	-0.23	1.91**	2.06**	1.70**	2.19**	5.44**	0.74*	-0.91**	3.94**	1.75	3.01**	-2.46**
BHS 400 x RD 2786	0.3	-1.71**	8.22**	-0.80*	-7.72**	-4.32**	0.63	0.02	-0.46	-3.21**	-7.03**	4.54**
BHS 400 x RD 2552	-1.95**	0.63	-2.30**	2.37**	3.80**	-5.76**	-0.64	0.37	-1.97	1.45	1.62**	5.16**
BG 105 x PL 426	-2.51**	-4.90**	1.22**	-7.77**	-5.85**	-4.89**	1.14**	-0.13	3.04*	3.20**	2.31**	6.30**
BG 105 x BHS 380	-8.78**	3.89**	-3.69**	-1.24**	0.55	-3.19**	-0.21	-1.98**	-1.46	-0.87	5.03**	8.51**
BG 105 x BH 902	5.54**	-0.11	2.97**	0.42	-1.15*	-2.23**	-0.21	0.86*	-1.12	1.17	1.48**	0.34
BG 105 x BH 946	-1.49**	-3.23**	0.70*	-1.16**	-1.04	-0.58	0.17	-0.6	-0.07	-1.84	-4.42**	3.35**
BG 105 x BH 959	-4.96**	-7.10**	-5.72**	-5.85**	-3.87**	-6.14**	0.51	-0.03	1.81	2.58*	-2.45**	-7.88**
BG 105 x RD 2715	0.88*	1.05**	-4.14**	-5.02**	1.20*	-0.79	-0.58	-1.17**	2.58*	5.02**	3.54**	0.26
BG 105 x RD 2786	2.30**	-0.76*	6.70**	5.81**	-2.37**	-0.65	0.91**	1.79**	-1.53	0.35	2.27**	5.62**
BG 105 x RD 2552	1.94**	0.88**	2.50**	5.31**	0.87	4.45**	0.72*	-0.49	-1.36	-2.95*	-0.41	-3.61**
PL 426 x BHS 380	-3.13**	2.30**	1.67**	0.4	4.46**	3.84**	-1.69**	-0.97**	-0.35	-4.83**	-0.91	-2.72**
PL 426 x BH 902	3.07**	0.93**	-2.66**	5.40**	-1.23*	0.68	-0.46	2.40**	0.3	-1.95	-0.37	1.48*
PL 426 x BH 946	-2.84**	-0.49	2.72**	1.15**	1.80**	-3.65**	0.76*	-0.78*	-1.87	1.53	3.10**	1.14
PL 426 x BH 959	2.02**	5.90**	-4.69**	-8.22**	1.08	-3.28**	1.63**	1.23**	-2.75*	-2.80*	7.34**	7.07**
PL 426 x RD 2715	1.20**	2.46**	5.22**	4.29**	-1.16*	-1.33*	-0.38	-0.34	-1.02	0.13	-1.77**	-0.62
PL 426 x RD 2786	3.06**	0.84*	-1.28**	-1.55**	2.47**	-1.04	0.51	2.66**	0.86	0.17	1.51**	4.57**
PL 426 x RD 2552	-6.53**	-12.38**	-2.80**	-2.05**	1.53**	4.77**	-0.19	0.14	1.65	3.56**	1.36**	-3.18**
BHS 380 x BH 902	-0.64	-2.95**	0.42	1.92**	-0.64	1.88**	-0.51	-1.55**	-1.06	-0.2	0.91	5.91**
BHS 380 x BH 946	0.22	0.3	-1.19**	-0.66*	0.15	-1.61**	1.02**	1.91**	-1.8	0.91	2.21**	-5.97**
BHS 380 x BH 959	-1.25**	0.36	2.39**	1.31**	-4.14**	-8.91**	-0.45	3.29**	0.38	-3.47**	-5.59**	2.81**
BHS 380 x RD 2715	3.26**	-1.76**	3.97**	0.15	-1.30*	1.52**	0.28	0.02	-1.04	0.42	0.74	-0.45
BHS 380 x RD 2786	0.01	0.62	-0.53	3.65**	1.63**	-0.8	1.75**	-0.53	-0.49	2.28	0.85	-4.77**
BHS 380 x RD 2552	1.20**	-4.00**	2.61**	-0.85**	-2.09**	-1.38*	0.63	0.08	2.99*	1.55	-2.52**	-0.39
BH 902 x BH 946	2.76**	0.26	0.47	0.01	-2.36**	-0.58	-1.02**	-0.58	1.22	-3.45**	-2.94**	1
BH 902 x BH 959	-0.82	-3.02**	6.72**	-0.02	2.30**	-0.2	0.92**	-0.15	0.46	0.35	-4.38**	1.98**
BH 902 x RD 2715	-1.98**	-2.13**	4.97**	3.48**	-1.56**	-4.32**	0.21	0.07	-0.28	-1	-3.03**	-0.15
BH 902 x RD 2786	-2.12**	-1.42**	-3.19**	-7.02**	2.48**	5.12**	0.57	1.52**	-2.57*	-1.66	4.31**	3.11**
BH 902 x RD 2552	-1.37**	3.37**	-1.05**	-0.85**	6.38**	1.17*	1.46**	0.86*	-2.54*	2.59*	-2.78**	-6.98**
BH 946 x BH 959	2.37**	2.57**	3.78**	1.73**	4.88**	5.05**	-0.14	0.43	1.32	-4.52**	-2.29**	-2.74**
BH 946 x RD 2715	-0.79	1.13**	-3.64**	-2.77**	1.85**	0.25	-1.24**	0.02	-1.77	2.56*	2.50**	0.87
BH 946 x RD 2786	0.19	0.5	5.20**	3.06**	-0.8	-0.32	-1.23**	-0.48	1.94	-0.05	0.02	0.35
BH 946 x RD 2552	0.16	-1.05**	1.34**	-0.44	-2.53**	-2.61**	-0.19	-0.62	-3.84**	-2.21	-0.59	5.88**
BH 959 x RD 2715	0.41	-0.82*	5.28**	5.20**	1.64**	1.78**	1.07**	-0.54	-2.43	-0.97	-0.96	-6.49**
BH 959 x RD 2786	-0.73	-4.44**	-6.55**	1.70**	-0.18	0.2	-1.26**	-2.24**	3.04*	5.82**	2.74**	0.42
BH 959 x RD 2552	8.24**	7.94**	2.59**	4.87**	-5.68**	-0.08	-1.19**	-1.22**	3.38**	0.44	0.91	7.10**
RD 2715 x RD 2786	-0.11	0.78*	-0.3	1.20**	-0.2	-3.29**	-0.5	-0.01	-1.41	-2.82*	-0.92	0.07
RD 2715 x RD 2552	-0.47	-0.1	0.17	-2.30**	1.79**	3.14**	-0.23	1.45**	4.67**	0.02	1.07*	5.79**
RD 2786 x RD 2552	-3.50**	1.94**	-1.33**	-0.13	2.35**	0.65	-1.45**	-1.75**	1.03	-2.29	0.11	-10.98**
SE (Sij)±	0.43	0.32	0.33	0.31	0.56	0.55	0.34	0.33	1.25	1.21	0.51	0.58
SE (Sij-Sik)±	0.64	0.47	0.48	0.46	0.82	0.81	0.51	0.49	1.84	1.78	0.75	0.85
SE (Sij-Ski)±	0.21	0.19	0.21	0.19	0.61	0.6	0.23	0.22	3.08	2.86	0.51	0.66

Table 3: Estimates of GCA and SCA effects for yield and related attributes

Parents / Crosses	1000-grain weight		Biomass per plant		Grain yield per plant		Harvest index		Malt score	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
GCA effects										
BHS 400	-0.3	-1.37**	-1.88**	-3.54**	-0.96**	-1.50**	-0.74**	-0.40*	-0.98**	-0.55**
BG 105	3.93**	3.03**	-0.84	-2.29**	0.1	-0.19	1.06**	1.82**	0.37**	1.36**
PL 426	1.02**	0.97**	3.40**	4.14**	0.52	0.86**	-2.53**	-2.58**	2.14**	1.74**
BHS 380	-4.08**	-3.12**	-4.38**	-4.07**	-1.63**	-1.73**	0.56**	0.15	-0.2	0.47**
BH 902	2.39**	2.50**	-4.19**	-5.15**	-0.60*	-1.09**	3.07**	3.46**	1.86**	1.21**
BH 946	0.27	0.03	0.52	0.12	0.39	0.07	1.28**	1.45**	0.52**	0.19
BH 959	-2.58**	-1.78**	3.11**	1.83**	1.97**	2.14**	1.42**	2.52**	1.34**	1.46**
RD 2715	-0.11	-0.76**	2.93**	2.34**	0.18	-0.62**	-2.69**	-4.10**	-2.21**	-2.15**
RD 2786	-0.06	1.81**	-1.67*	0.54	0.03	1.15**	1.89**	2.07**	-0.11	0.1
RD 2552	-0.48*	-1.32**	2.99**	6.08**	-0.01	0.92**	-3.32**	-4.39**	-2.74**	-3.83**
SE (gi)±	0.18	0.16	0.69	0.54	0.3	0.23	0.15	0.16	0.13	0.14
SE (gi-gj)±	0.27	0.24	1.03	0.81	0.44	0.34	0.23	0.24	0.2	0.21
SCA effects										
BHS 400 x BG 105	-1.68**	-10.17**	-2.69	-4.63*	-1.74	-3.74**	-1.56**	-4.40**	-1.50**	-3.02**
BHS 400 x PL 426	0.66	-2.11**	4.89*	2.43	2.94**	2.57**	1.97**	3.51**	-2.00**	-2.08**
BHS 400 x BHS 380	-2.03**	-2.35**	8.09**	1.47	4.22**	1.53	1.30*	2.40**	-0.15	-3.62**
BHS 400 x BH 902	0.94	-2.00**	-8.41**	-6.53**	-4.31**	-3.40**	-1.32*	-0.76	4.07**	3.48**
BHS 400 x BH 946	-1.02	1.50**	10.33**	8.55**	3.93**	3.85**	-2.27**	-1.57**	0.19	2.06**
BHS 400 x BH 959	1.31*	4.06**	12.04**	16.48**	2.96**	5.72**	-4.58**	-3.33**	2.27**	4.13**
BHS 400 x RD 2715	1.53*	0.27	-6.87**	-8.02**	-2.04*	-2.43**	2.06**	2.56**	-0.96*	0.2
BHS 400 x RD 2786	0.68	3.43**	2.69	1.09	-0.13	-0.38	-3.41**	-2.11**	0.73	2.31**
BHS 400 x RD 2552	-1.13	2.28**	-7.95**	-8.14**	-1.77	-2.12**	4.08**	3.56**	3.49**	4.02**
BG 105 x PL 426	-1.80**	-0.26	8.08**	9.04**	3.24**	4.63**	-0.67	0.78	1.52**	0.69
BG 105 x BHS 380	1.94**	1.85**	-4.5	-4.40*	-2.28*	-1.79*	-0.97	0.8	-2.10**	2.33**
BG 105 x BH 902	1.18	2.05**	-1.24	5.34**	0.69	3.56**	2.99**	2.00**	0.98*	1.56**
BG 105 x BH 946	0.83	1.34*	-9.55**	-10.31**	-2.23*	-2.57**	4.52**	5.61**	-0.01	1.98**
BG 105 x BH 959	3.50**	5.78**	0.34	5.61**	1.79	5.01**	2.67**	4.65**	1.73**	-0.03
BG 105 x RD 2715	0.34	-2.84**	8.63**	6.41**	3.83**	2.13**	-0.11	-1.69**	0.27	1.33**
BG 105 x RD 2786	0.83	2.09**	-2.21	-8.99**	0.18	-2.69**	2.42**	4.96**	0.41	0.81
BG 105 x RD 2552	-2.40**	-0.78	10.95**	1.14	0.09	-2.43**	-8.13**	-6.31**	-1.74**	-2.48**
PL 426 x BHS 380	-0.15	-5.48**	6.46**	5.21**	2.44*	2.14**	-0.86	-0.65	-0.7	-2.07**
PL 426 x BH 902	0.71	-2.16**	5.76*	4.01*	1.74	0.89	-2.33**	-3.11**	-1.09*	0.87
PL 426 x BH 946	2.05**	-2.90**	-4.82*	-3.58	-2.04*	-1.95*	-1.07*	-2.72**	0.39	-1.11*
PL 426 x BH 959	0.41	4.30**	-5.95*	-13.05**	-1.6	-5.08**	1.83**	2.33**	-1.46**	1.26*
PL 426 x RD 2715	-0.63	4.57**	1.00	3.39	1.6	2.65**	2.75**	3.05**	-0.71	0.03
PL 426 x RD 2786	0.99	4.41**	-6.67**	-5.31**	-3.29**	-3.33**	-1.48**	-2.72**	0.55	3.15**
PL 426 x RD 2552	0.67	2.22**	11.10**	17.85**	2.76**	6.31**	-1.93**	-0.19	2.17**	-4.01**
BHS 380 x BH 902	-0.92	1.73**	8.78**	6.58**	3.46**	2.28**	-1.74**	-2.63**	-0.17	3.61**
BHS 380 x BH 946	2.20**	6.18**	8.38**	6.38**	0.36	-0.35	-8.37**	-9.07**	3.84**	3.78**
BHS 380 x BH 959	2.47**	2.97**	-7.40**	-1.84	-3.08**	-0.95	0.32	-0.08	1.68**	2.99**
BHS 380 x RD 2715	-0.25	1.32*	1.02	4.43*	-0.42	0.77	-2.35**	-2.94**	-0.15	-2.45**
BHS 380 x RD 2786	1.51*	3.30**	-6.96**	-11.23**	-1.89	-3.58**	4.01**	5.82**	1.43**	1.40**
BHS 380 x RD 2552	-2.24**	-3.25**	-5.03*	0.69	0.11	2.14**	5.50**	3.75**	-2.87**	-2.86**
BH 902 x BH 946	-1.58*	-1.63**	-5.69*	-10.44**	-0.88	-2.71**	3.67**	6.06**	-3.26**	-2.30**
BH 902 x BH 959	-0.1	2.29**	-2.02	-9.19**	-0.05	-2.76**	1.40**	6.23**	-3.53**	-6.95**
BH 902 x RD 2715	0.6	5.61**	-2.67	-4.71*	-0.64	-2.06**	0.58	-1.20*	-0.28	-1.26*
BH 902 x RD 2786	0.41	-0.08	2.53	3.22	2.27*	3.82**	2.23**	4.66**	2.76**	1.55**
BH 902 x RD 2552	3.25**	-1.01	-4.77*	-2.64	-2.27*	-1.91*	-1.03*	-3.02**	5.23**	1.24*
BH 946 x BH 959	-1.58*	-5.11**	-7.30**	-11.45**	-1.22	-3.88**	3.34**	3.10**	-1.08*	-2.95**
BH 946 x RD 2715	0.6	-2.68**	4.70*	2.03	2.74**	2.78**	0.22	2.40**	-0.8	-0.56
BH 946 x RD 2786	2.23**	6.34**	-5.62*	-2.32	-0.84	2.07**	3.03**	5.56**	0.92*	-2.59**
BH 946 x RD 2552	1.89**	1.52**	4.51	11.66**	1.41	2.35**	-2.05**	-5.46**	-2.04**	-1.84**
BH 959 x RD 2715	-1.34*	-4.99**	9.13**	1.78	1.53	-1.12	-2.53**	-3.83**	-0.32	-1.10*
BH 959 x RD 2786	0.4	0.96	6.49**	11.50**	1.31	6.12**	0.47	0.27	-1.47**	0.58
BH 959 x RD 2552	-0.67	-2.75**	5.09*	2.65	2.59*	1.53*	0.61	0.83	-0.89	-0.84
RD 2715 x RD 2786	-0.59	-3.98**	1.36	7.61**	-1.38	-1.55*	-4.85**	-9.45**	-1.17*	-4.17**
RD 2715 x RD 2552	1.54*	1.83**	-12.06**	-13.85**	-3.56**	-3.03**	3.51**	6.96**	0.51	4.27**
RD 2786 x RD 2552	0.31	-2.30**	0.06	2.11	-0.25	-0.37	-1.10*	-2.74**	-1.94**	-0.31
SE (Sij)±	0.62	0.55	2.32	1.82	1	0.77	0.51	0.54	0.45	0.48
SE (Sij-Sik)±	0.91	0.81	3.4	2.67	1.48	1.13	0.76	0.79	0.67	0.71
SE (Sij-Ski)±	0.75	0.59	10.53	6.49	1.98	1.17	0.52	0.56	0.4	0.46

Table 4:Top three of the parents, F_1 and F_2 generation for their mean values, GCA and SCA estimates for yield and its attributes

Characters	High mean			GCA		SCA	
	Parent	F_1	F_2	F_1	F_2	F_1	F_2
Days to heading	BH 959	BHS 400 x RD 2715	BG 105 x BH 946	BH 959	BH 959	BHS 400 x BH 959	PL 426 x RD 2552
	PL 426	BHS 400 x BH 959	PL 426 x BHS 380	PL 426	PL 426	BG 105 x BHS 380	BHS 400 x BH 959
	RD 2715	BG 105 x RD 2715	BH 959 x RD 2786	BG 105	BG 105	PL 426 x RD 2552	BG 105 x BH 959
Days to maturity	RD 2786	BH 959 x RD 2786	PL 426 x BH 959	RD 2552	BH 946	BH 959 x RD 2786	PL 426 x BH 959
	RD 2715	BG 105 x BH 946	BH 902 x BH 959	RD 2786	PL 426	BG 105 x BH 959	BG 105 x PL 426
	RD 2552	PL 426 x BH 959	BG 105 x BH 946	PL 426	BH 959	BHS 400 x BH 902	BH 902 x RD 2786
Plant height	PL 426	BHS 400 x BH 902	BHS 380 x RD 2715	BH 959	BH 959	BHS 400 x BH 959	BHS 380 x BH 959
	BH 959	BH 959 x RD 2715	BG 105 x BH 946	RD 2786	PL 426	BHS 400 x RD 2786	BHS 400 x BH 959
	RD 2786	BG 105 x BH 946	PL 426 x BH 959	PL 426	RD 2786	BG 105 x PL 426	BG 105 x BH 959
Number of effective tillers per plant	RD 2786	BG 105 x BHS 380	BH 902 x BH 959	RD 2786	RD 2786	BHS 400 x BH 946	BHS 380 x BH 959
	BH 946	BHS 380 x BH 946	PL 426 x BH 902	BG 105	BH 959	BHS 380 x RD 2786	PL 426 x RD 2786
	BG 105	BHS 400 x BH 946	BHS 380 x RD 2715	BH 946	BH 902	PL 426 x BH 959	PL 426 x BH 902
Flag leaf area	PL 426	BG 105 x RD 2552	BH 959 x RD 2786	PL 426	PL 426	RD 2715 x RD 2552	BH 959 x RD 2786
	BH 902	PL 426 x RD 2786	PL 426 x RD 2715	BH 902	BH 959	BHS 400 x RD 2715	BG 105 x RD 2715
	BH 946	BH 959 x RD 2786	PL 426 x BHS 380	BH 959	BH 902	BH 959 x RD 2552	PL 426 x RD 2552
Number of grains per spike	BH 959	BH 959 x RD 2786	BH 902 x BH 959	RD 2786	BH 946	BHS 400 x BH 902	BG 105 x BHS 380
	BH 946	BH 902 x BH 959	BH 902 x RD 2786	BH 946	BH 959	PL 426 x BH 959	BH 959 x RD 2552
	RD 2786	BH 946 x RD 2715	BH 902 x RD 2552	BH 959	RD 2786	BG 105 x BHS 380	PL 426 x BH 959
1000-grain weight	BG 105	BG 105 x RD 2715	BH 946 x RD 2715	BG 105	BG 105	BG 105 x BH 959	BH 946 x RD 2786
	BH 902	BH 902 x BH 946	BH 902 x RD 2715	BH 902	BH 902	BH 902 x RD 2552	BHS 380 x BH 946
	PL 426	BG 105 x BH 959	PL 426 x BH 902	PL 426	RD 2786	BHS 380 x BH 959	BG 105 x BH 959
Biomass per plant	RD 2552	PL 426 x BHS 380	PL 426 x BHS 380	BH 959	BH 959	BHS 400 x BH 959	BHS 400 x BH 959
	RD 2715	BH 959 x RD 2552	BH 946 x BH 959	RD 2552	PL 426	BH 946 x RD 2715	BH 946 x RD 2715
	BH 946	BHS 400 x BH 902	BH 959 x RD 2786	PL 426	RD 2552	BH 959 x RD 2552	PL 426 x RD 2552
Grain yield per plant	RD 2786	BH 959 x RD 2552	BH 959 x RD 2786	BH 959	BH 959	BHS 400 x BHS 380	PL 426 x RD 2552
	BH 959	BG 105 x RD 2715	PL 426 x RD 2552	BH 946	RD 2786	BHS 400 x BH 946	BH 959 x RD 2786
	RD 2552	BHS 400 x BH 959	BG 105 x BH 959	PL 426	RD 2552	BG 105 x RD 2715	BHS 400 x BH 959
Harvest index	BH 902	BH 902 x RD 2552	BH 902 x RD 2786	BH 902	BH 902	BHS 380 x RD 2552	RD 2715 x RD 2552
	RD 2786	BH 902 x BH 959	BH 902 x RD 2552	RD 2786	BH 959	BG 105 x BH 946	BH 902 x BH 959
	BHS 380	BG 105 x RD 2715	BH 902 x BH 959	BH 959	RD 2786	BHS 400 x RD 2552	BH 902 x BH 946
Malt score	PL 426	BHS 400 x BH 959	BHS 380 x RD 2552	PL 426	PL 426	BH 902 x RD 2552	RD 2715 x RD 2552
	BH 959	BH 902 x BH 959	PL 426 x BH 902	BH 902	BH 959	BHS 400 x BH 902	BHS 400 x BH 959
	BH 946	BH 902 x BH 946	BHS 380 x RD 2715	BH 959	BG 105	BHS 380 x BH 946	BHS 400 x RD 2552

Table 5: Best parents or crosses possessing high GCA or SCA effects along with their *per se* performance for grain yield per plant and significant desirable (+) GCA or SCA effects for other characters in F_1 and F_2 generation

Generation in which exhibited high GCA/SCA effect and *per se* performance	F_1	F_2	F_2	F_1	F_2	F_2
Best parents/crosses based on desirable GCA/SCA effect and *per se* performance for grain yield per plant	BH 959	BH 959	RD 2786	BG 105 x RD 2715	BH 959 x RD 2786	PL 426 x RD 2552
Days to heading	+	+	-	-	+	+
Days to maturity	+	+	+	+	-	+
Plant height	+	+	+	-	-	-
Number of effective tillers per plant	+	+	+	-	-	-
Flag leaf area	+	+	-	+	+	+
Number of grains per spike	+	+	+	+	-	-
1000-grain weight	-	-	+	-	-	+
Biomass per plant	+	+	-	+	+	+
Harvest index	+	+	+	-	-	-
Malt Score	+	+	-	-	-	-

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