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Chhagan Lal
Division of Plant Breeding and Genetics, Rajasthan Agricultural Research Institute, S.K.N. Agriculture University, Durgapura (Jaipur), Rajasthan, India

AS Shekhawat
Division of Plant Breeding and Genetics, Rajasthan Agricultural Research Institute, S.K.N. Agriculture University, Durgapura (Jaipur), Rajasthan, India

Jogendra Singh
Division of Plant Breeding and Genetics, Rajasthan Agricultural Research Institute, S.K.N. Agriculture University, Durgapura (Jaipur), Rajasthan, India

Pawan Kumar
Division of Plant Breeding and Genetics, Rajasthan Agricultural Research Institute, S.K.N. Agriculture University, Durgapura (Jaipur), Rajasthan, India

Vinod Kumar
Department of Genetics and Plant Breeding, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, India

Correspondence
Chhagan Lal
Division of Plant Breeding and Genetics, Rajasthan Agricultural Research Institute, S.K.N. Agriculture University, Durgapura (Jaipur), Rajasthan, India

GCA and SCA effects analysis for grain yield and related traits in barley (*Hordeum vulgare* L.) in early and normal sowing conditions

Chhagan Lal, AS Shekhawat, Jogendra Singh, Pawan Kumar and Vinod Kumar

Abstract
The study was aimed for estimating GCA and SCA effects of 10 parents and 45 F_1 hybrids of six-rowed barley in Rajasthan area. The experimental data recorded for two different environments showed that the out of 45 crosses, five parents each in early sowing (E_1) for both the generations while one parent for F_1 generation and four parents for F_2 generation in normal sowing (E_2) showed positive significant GCA effects. Whereas, eight and twelve crosses for F_1 generation while eleven and eighteen crosses for F_2 generation in early and normal sown conditions, respectively showed positive significant SCA effects. Over all appraisal of present investigation manifested that the parent BH 959 and RD 2786 emerged as good general combiners 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 in all the three environments and therefore, above study could be useful in developing desirable genotypes/hybrids/varieties with better yield or other associated traits under crop improvement.

Keywords: Barley, combining ability, half diallel, GCA, SCA

Introduction

The production of barley can be increased either by increasing cultivated area or by increasing yield per unit area. Currently, it is nearly impossible to increase area under barley crop due to competition with other crops, restricted irrigation water supply. Therefore, the only alternative left is to increase yield per unit area by introducing high yielding varieties along with resistance against environmental stresses and better crop management techniques. Expanding the cultivated area of barley in India is only possible in rainfed areas, in some part of Rajasthan, Utter Pradesh, Haryana, Punjab and the newly reclaimed lands, where irrigation resources are poor.

A thorough understanding of the genetics and related aspects of a crop is necessary for improvement of yield and quality parameters. Progress in yield improvement and quality traits of a crop requires information about the nature of combining ability of parents to be involved in the hybridization program along with the nature of gene effects operative in the inheritance of different traits. General and specific combining ability effects are very important in designing and execution of a breeding programme.

Estimation of combining ability of the parents is requisite to recognize superior parental combinations that can yield useful segregants. It has been established from the prior studies that different parental combinations perform non-identically i.e. superiority of different parental combinations vary cross to cross. Some combinations possess superior progeny while others produce inferior. Therefore, combining ability analysis is a convenient approach to fulfill this objective.

Allard (1960) [1] reported that the ability of parents to combine well depends on complex interaction among genes for trait of interest which can't be adjusted by mere yield and yield adaptation of the parents. The improvement in the productivity of a crop involves multidirectional approaches including thorough understanding of the genetics and related aspect of crop under consideration. Identification of genetically superior parents is an important pre-requisite for developing promising strains. For this, combining ability analysis provides useful information to select the suitable parents for a hybridization programme (Kakani *et al*., 2007) [7].

Therefore, the present research investigation was carried out to understand the effect of yield contributing attributes under early sown conditions and identification of early sown condition genotypes.

Material Method

The present investigation was carried out to study combining ability in 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 (Rabi 2015-16) 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 in three environments created by three different dates of sowing i.e. early sown (5th November) and timely sown (20th November)with three replications in a randomized block design during Rabi 2016-17 at Agricultural Research Farm of RARI Durgapura, Jaipur. Each replication contained two parts. First part consisted 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 (Panse and Sukhatme, 1967) [9], combining ability (Griffing's method 2, Model I).

The generalized model to estimate the general and specific combining ability effects ofijklth observations is given below (according to Griffing, 1956) [3].

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

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

Result and Discussion

The combining ability analysis in the individual environment revealed significant mean squares due to GCA and SCA for all the characters (Table 1) 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 by Sultan *et al.* (2016) [12] and Pesaraklu *et al.* (2016) [10].

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 for both the generations in normal as well as early sowing condition; days to heading and number of effective tillers per plant in early sown condition and 1000-grain weight in normal sown condition for F_1 generation 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*. (2016) [12] and Ram and Shekhawat (2017) [11].

Present investigation indicated that parent BH 959 for days to heading, number of effective tillers per plant, flag leaf area, number of grains per spike, grain yield per plant and harvest index; parent BH 946 for 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 whereas RD 2786 for days to maturity, number of effective tillers per plant, number of grains per spike, 1000-grain weight, grain yield per plant and harvest index emerged as good general combiner in case of early sown condition.

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 (1958) [5] 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.

The top three crosses for two or more characters which were significant in early sown condition for F_1 generation only (Table 2), are as follows: BHS 400 x BH 959 and BG 105 x PL 426 for days to heading and grain yield per plant; PL 426 x RD 2552 for days to heading and flag leaf area; BH 400 x BH 946 for days to maturity and number of effective tillers per plant; BH 959 x RD 2786 for days to heading and days to maturity; PL 426 x BH 959 for number of effective tillers, number of grains per spike and grain yield per plant; RD 2715 x RD 2552 for flag leaf area and harvest index; BHS 400 x BH 902 for flag leaf area and number of grains per spike; BG 105 x BH 959 for 1000-grain weight and malt score; and BHS 400 x PL 426 for grain yield per plant and harvest index.

The top three crosses for two or more characters which were significant in normal sown condition for F_1 generation only (Table 2), are as follows: BHS 400 x BH 959 for days to heading and plant height; 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 and number of effective tillers per plant; BHS 400 x BH 946 and PL 426 x BH 959 for number of effective tiller per plant and number of grains per spike; and BH 902 x RD 2552 for 1000-grain weight and malt score.

The top three crosses for two or more characters which were significant in early sown condition for F_2 generation only (Table 2), are as follows: BHS 400 x BH 959 days to heading and plant height; PL 426 x RD 2552 for days to heading, days to maturity, flag leaf area and grain yield per plant; BG 105 x PL 426 for days to heading and grain yield per plant; BHS 400 x BH 902 for days to maturity and number of grains per spike; BG 105 x BH 959 for days to maturity and 1000-grain weight; BH 959 x RD 2786 for flag leaf area and grain yield per plant; and BH 946 x BH 959 for harvest index and malt score.

The top three crosses for two or more characters which were significant in normal sown condition for F_2 generation only (Table 2), 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 per plant; BH 959 x RD 2786 for flag leaf area and grain yield per plant; and RD 2715 x RD 2552 for harvest index and malt score.

On the basis of GCA effects and *per se* performance, an overall evaluation across the environment showed that the parent BH 959 for both generations while RD 2786 in both the early as well as normal sowing conditions for F_2 generation only 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, some crosses *viz*., BH 959 x RD 2786 for both generations in both the environments, BG 105 x PL 426, BHS 959 x RD 2786 and PL 426 x RD 2552 in normal sown condition for F_2 generation, BHS 400 x BH 959 in early sown condition for F_1 generation; and BG 105 x RD 2715 in normal sown condition for F_1 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.

An overall appraisal revealed that the cross BHS 400 x BH 959 and BH 959 x RD 2786 for both generations in both the environments emerged as good specific cross combinations for grain yield with simultaneous consideration of other characters. 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.The present findings are supported by Amiruzzaman *et al.* (2008) [2] and Madic *et al.* (2014) [8].

As non-additive gene action was found to be more dominant in the present investigation, so that in addition to conventional breeding methods some non-conventional breeding methods such as diallel selective mating (Jensen, 1970) [4], biparental mating in early segregating generations (Joshi and Dhawan, 1966) [6] or reciprocal recurrent selection followed by selection or multiple crosses might prove to be effective alternative approach for appreciable progress in grain yield of barley.

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 (Jensen, 1970) [4], bi-parental mating in early segregating generations (Joshi and Dhawan, 1966) [6] 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 in early (E_1) and normal (E_2) sown environment for yield and its attributes

Characters	Env.	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	E_1	123.36**	135.09**	7.91**	16.24**	1.23	1.30	1.52	0.75
	E_2	121.00**	131.58**	13.11**	15.02**	0.22	0.12	0.78	0.74
Days to maturity	E_1	26.55**	37.39**	20.53**	54.67**	0.22	1.13	0.11	0.06
	E_2	17.75**	15.27**	14.70**	13.86**	0.13	0.12	0.10	0.09
Number of effective tillers per plant	E_1	11.45**	10.10**	1.01**	2.46**	0.14	0.15	1.09	0.36
	E_2	8.02**	8.42**	0.85**	1.76**	0.14	0.13	0.92	0.42
Flag leaf area	E_1	37.54**	26.69**	5.56**	5.77**	0.38	0.34	0.60	0.40
	E_2	36.04**	29.56**	4.94**	7.03**	1.85	1.72	0.92	0.44
Number of grains per spike	E_1	244.00**	197.59**	14.75**	10.34**	0.33	0.41	1.41	1.65
	E_2	246.89**	279.05**	10.93**	23.26**	0.31	0.39	1.93	1.02
1000-grain weight	E_1	55.84**	56.27**	5.02**	13.23**	0.31	0.33	0.98	0.36
	E_2	61.21**	48.99**	3.01**	14.62**	0.45	0.36	1.98	0.28
Grain yield per plant	E_1	15.06**	22.58**	3.47**	6.93**	0.45	0.45	0.40	0.28
	E_2	11.03**	19.08**	5.86**	10.01**	1.19	0.70	0.18	0.16
Harvest index	E_1	91.17**	150.17**	8.45**	17.77**	0.33	0.69	0.93	0.73
	E_2	57.73**	94.57**	9.65**	17.78**	0.31	0.34	0.51	0.45

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

Table 2: Estimates of GCA and SCA effects of various characters

Parents / Crosses	Days to heading				Days to maturity				Number of effective tillers per plant				Flag leaf area			
	E_1		E_2		E_1		E_2		E_1		E_2		E_1		E_2	
	F_1	F_2	F_1	F_2	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	4.09**	4.26**	3.49**	4.21**	1.58**	0.90**	2.16**	2.19**	-0.50**	-0.45**	-0.33**	-0.43**	-0.61**	-0.37*	-0.97*	-0.86*
BG 105	-1.13**	-0.69*	-1.28**	-1.26**	0.42**	1.01**	0.35**	-0.08	0.95**	0.62**	0.85**	0.12	-0.85**	0.54**	-1.00**	0.12
PL 426	-2.85**	-3.08**	-2.60**	-2.33**	0.64**	-1.68**	-0.68**	-1.39**	-1.17**	-0.57**	-1.09**	-0.60**	3.41**	3.03**	3.37**	3.40**
BHS 380	2.32**	2.34**	2.00**	2.55**	1.75**	1.84**	1.24**	1.08**	-0.93**	-0.82**	-0.70**	-0.62**	-1.80**	-1.35**	-1.63**	-1.41**
BH 902	1.76**	0.95**	2.58**	0.92**	-0.69**	-1.27**	-0.43**	0.42**	0.62**	0.44**	0.30**	0.63**	1.28**	0.81**	1.64**	0.94*
BH 946	0.48	0.70*	0.38**	1.00**	-2.31**	-0.52	-0.15	-1.67**	0.74**	0.04	0.52**	0.05	0.87**	0.37*	0.47	0.13
BH 959	-6.99**	-7.69**	-7.14**	-7.72**	-0.03	1.29**	-0.40**	-0.64**	0.56**	0.85**	0.41**	0.96**	1.64**	0.85**	1.58**	1.10**
RD 2715	-1.10**	-0.49	-0.99**	-0.61**	1.72**	2.21**	1.02**	0.19*	-0.73**	-0.85**	-0.43**	-0.69**	-1.46**	-0.82**	-1.33**	-0.69
RD 2786	2.65**	2.14**	2.49**	2.01**	-1.19**	-3.38**	-1.15**	-0.31**	1.52**	1.80**	1.39**	1.59**	-0.28	-0.61**	-0.17	-0.46
RD 2552	0.76*	1.56**	1.07**	1.23**	-1.89**	-0.41	-1.96**	0.19*	-1.06**	-1.06**	-0.93**	-1.02**	-2.21**	-2.46**	-1.96**	-2.25**
SE (gi)±	0.3	0.31	0.13	0.1	0.13	0.29	0.1	0.09	0.1	0.1	0.1	0.1	0.17	0.16	0.37	0.36
SE (gi-gj)±	0.45	0.47	0.19	0.14	0.19	0.43	0.15	0.14	0.15	0.16	0.15	0.15	0.25	0.24	0.55	0.54
SCA effects																
BHS 400 x BG 105	2.92**	4.29**	2.73**	4.89**	0.48	6.25**	0.39	4.31**	-0.5	1.21**	-0.69*	0.86*	1.64**	2.08**	2.37	1.42
BHS 400 x PL 426	3.98**	3.68**	2.05**	1.64**	2.26**	7.61**	2.09**	2.62**	0.33	-0.11	0.11	-0.57	-1.38*	-0.02	-1.13	-0.83
BHS 400 x BHS 380	0.15	-0.41	6.56**	-0.25	3.15**	3.42**	0.84*	-3.19**	-0.36	1.16**	-0.31	0.82*	-3.07**	0.74	-2.09	-0.5
BHS 400 x BH 902	0.7	0.32	1.98**	3.72**	-4.74**	-16.80**	-4.83**	-0.52	-0.88*	-1.95**	-0.66	-1.56**	3.50**	-1.11*	2.58*	-2.36
BHS 400 x BH 946	-0.02	0.23	-0.93*	0.97**	-8.46**	-2.89**	-1.78**	-3.77**	2.06**	-0.54	2.13**	-0.67*	-0.53	0.44	-0.82	-0.7
BHS 400 x BH 959	-10.55**	-12.71**	-11.74**	-11.31**	-5.07**	-4.03**	-3.86**	-6.13**	-0.04	2.89**	-0.42	2.38**	-1.58**	1.54**	-2.78*	2.42*
BHS 400 x RD 2715	0.9	3.43**	-0.23	1.91**	4.18**	2.73**	2.06**	1.70**	1.03**	-0.71*	0.74*	-0.91**	3.15**	1.21*	3.94**	1.75
BHS 400 x RD 2786	0.15	-2.55*	0.30	-1.71**	10.10**	-14.03**	8.22**	-0.80*	0.90*	0.07	0.63	0.02	-0.51	-4.18**	-0.46	-3.21**
BHS 400 x RD 2552	-0.96	1.04	-1.95**	0.63	-2.54**	5.67**	-2.30**	2.37**	-0.98**	-0.18	-0.64	0.37	-0.99	0.15	-1.97	1.45
BG 105 x PL 426	-5.46**	-8.38**	-2.51**	-4.90**	-0.24	-7.83**	1.22**	-7.77**	0.81*	-0.57	1.14**	-0.13	3.28**	1.48**	3.04*	3.20**
BG 105 x BHS 380	-0.63	2.87**	-8.78**	3.89**	-4.68**	-2.69**	-3.69**	-1.24**	-0.78*	-1.22**	-0.21	-1.98**	0.43	-1.57**	-1.46	-0.87
BG 105 x BH 902	1.92	1.26	5.54**	-0.11	2.10**	7.09**	2.97**	0.42	1.02**	1.20**	-0.21	0.86*	-2.79**	0.01	-1.12	1.17
BG 105 x BH 946	-2.13*	-3.82**	-1.49**	-3.23**	1.04*	-3.00**	0.70*	-1.16**	0.1	0.09	0.17	-0.6	-1.23*	0.23	-0.07	-1.84
BG 105 x BH 959	-5.33**	-7.43**	-4.96**	-7.10**	-3.90**	-16.14**	-5.72**	-5.85**	0.95**	0.15	0.51	-0.03	1.70**	3.32**	1.81	2.58*
BG 105 x RD 2715	-0.21	1.04	0.88*	1.05**	-1.99**	-5.72**	-4.14**	-5.02**	-0.80*	-1.35**	-0.58	-1.17**	2.98**	4.96**	2.58*	5.02**
BG 105 x RD 2786	1.7	3.07**	2.30**	-0.76*	6.26**	10.53**	6.70**	5.81**	1.37**	1.63**	0.91**	1.79**	-1.34*	0.22	-1.53	0.35
BG 105 x RD 2552	0.92	1.98	1.94**	0.88**	1.62**	5.89**	2.50**	5.31**	-0.37	-0.59	0.72*	-0.49	-1.74**	-2.63**	-1.36	-2.95*
PL 426 x BHS 380	-3.24**	-0.74	-3.13**	2.30**	2.10**	1.34	1.67**	0.4	-1.31**	-1.12**	-1.69**	-0.97**	0.23	-4.06**	-0.35	-4.83**
PL 426 x BH 902	-0.02	1.65	3.07**	0.93**	-3.46**	-2.89**	-2.66**	5.40**	-0.04	3.97**	-0.46	2.40**	-0.89	-1.05	0.3	-1.95
PL 426 x BH 946	0.59	-0.1	-2.84**	-0.49	1.82**	2.03*	2.72**	1.15**	1.28**	-0.54	0.76*	-0.78*	-0.45	-1.82**	-1.87	1.53
PL 426 x BH 959	2.06*	6.29**	2.02**	5.90**	-1.79**	-7.11**	-4.69**	-8.22**	1.48**	1.59**	1.63**	1.23**	-0.55	-0.59	-2.75*	-2.80*
PL 426 x RD 2715	1.84	3.09**	1.20**	2.46**	6.79**	3.98**	5.22**	4.29**	-0.95**	-0.52	-0.38	-0.34	-0.27	0.61	-1.02	0.13
PL 426 x RD 2786	3.42**	1.46	3.06**	0.84*	2.04**	4.23**	-1.28**	-1.55**	1.02**	3.02**	0.51	2.66**	-2.39**	0.14	0.86	0.17
PL 426 x RD 2552	-5.69**	-10.96**	-6.53**	-12.38**	-5.27**	-15.08**	-2.80**	-2.05**	-0.17	-0.80*	-0.19	0.14	3.80**	4.78**	1.65	3.56**
BHS 380 x BH 902	-0.52	-3.43**	-0.64	-2.95**	3.43**	4.92**	0.42	1.92**	-0.57	-1.79**	-0.51	-1.55**	-3.67**	-0.33	-1.06	-0.2
BHS 380 x BH 946	-0.91	-1.18	0.22	0.3	-4.29**	5.17**	-1.19**	-0.66*	1.11**	1.57**	1.02**	1.91**	-0.87	-0.07	-1.8	0.91
BHS 380 x BH 959	1.56	0.87	-1.25**	0.36	3.76**	1.03	2.39**	1.31**	0.91**	3.85**	-0.45	3.29**	2.02**	-1.61**	0.38	-3.47**
BHS 380 x RD 2715	2.34*	-0.66	3.26**	-1.76**	1.68**	-0.22	3.97**	0.15	0.35	0.5	0.28	0.02	-2.83**	-0.19	-1.04	0.42

BHS 380 x RD 2786	0.26	2.04	0.01	0.62	-1.74**	-13.97**	-0.53	3.65**	0.91**	-1.03**	1.75**	-0.53	-0.33	3.04**	-0.49	2.28
BHS 380 x RD 2552	0.48	-0.38	1.20**	-4.00**	4.62**	0.73	2.61**	-0.85**	0.80*	-0.34	0.63	0.08	2.79**	0.19	2.99*	1.55
BH 902 x BH 946	0.31	-0.13	2.76**	0.26	2.15**	-12.05**	0.47	0.01	-1.78**	-1.67**	-1.02**	-0.58	2.36**	-2.29**	1.22	-3.45**
BH 902 x BH 959	1.45	-1.07	-0.82	-3.02**	5.87**	1.48	6.72**	-0.02	1.32**	-1.21**	0.92**	-0.15	1.18*	0.15	0.46	0.35
BH 902 x RD 2715	-0.44	-2.27*	-1.98**	-2.13**	3.79**	7.23**	4.97**	3.48**	0.59	0.16	0.21	0.07	1.17*	0.76	-0.28	-1
BH 902 x RD 2786	-1.52	0.09	-2.12**	-1.42**	-5.29**	-0.53	-3.19**	-7.02**	0.44	1.64**	0.57	1.52**	-1.66**	-2.30**	-2.57*	-1.66
BH 902 x RD 2552	1.37	3.01**	-1.37**	3.37**	-0.27	4.17**	-1.05**	-0.85**	1.34**	0.48	1.46**	0.86*	-1.67**	1.46**	-2.54*	2.59*
BH 946 x BH 959	2.73**	3.84**	2.37**	2.57**	1.15**	4.06**	3.78**	1.73**	-0.12	0.44	-0.14	0.43	1.33*	-4.65**	1.32	-4.52**
BH 946 x RD 2715	-1.16	1.32	-0.79	1.13**	-3.27**	-3.19**	-3.64**	-2.77**	-0.61	-1.05**	-1.24**	0.02	-2.40**	2.41**	-1.77	2.56*
BH 946 x RD 2786	1.76	0.68	0.19	0.5	7.65**	7.73**	5.20**	3.06**	-0.86*	0.12	-1.23**	-0.48	3.05**	1.50**	1.94	-0.05
BH 946 x RD 2552	-0.35	0.26	0.16	-1.05**	3.35**	1.75	1.34**	-0.44	-0.16	-0.15	-0.19	-0.62	-4.89**	-1.76**	-3.84**	-2.21
BH 959 x RD 2715	0.31	0.04	0.41	-0.82*	4.46**	5.00**	5.28**	5.20**	-0.13	-1.11**	1.07**	-0.54	-3.81**	-4.19**	-2.43	-0.97
BH 959 x RD 2786	-2.77**	-6.27**	-0.73	-4.44**	-8.29**	2.59**	-6.55**	1.70**	-0.51	-1.44**	-1.26**	-2.24**	2.36**	3.73**	3.04*	5.82**
BH 959 x RD 2552	4.12**	6.65**	8.24**	7.94**	2.07**	7.95**	2.59**	4.87**	-1.29**	-1.39**	-1.19**	-1.22**	0.11	1.56**	3.38**	0.44
RD 2715 x RD 2786	-0.66	-0.46	-0.11	0.78*	0.96*	4.00**	-0.3	1.20**	-0.94**	-0.24	-0.5	-0.01	-1.48*	-2.63**	-1.41	-2.82*
RD 2715 x RD 2552	-0.44	-1.21	-0.47	-0.1	1.98**	-1.97*	0.17	-2.30**	-0.36	2.10**	-0.23	1.45**	4.13**	-0.11	4.67**	0.02
RD 2786 x RD 2552	-1.52	0.15	-3.50**	1.94**	-2.77**	-9.05**	-1.33**	-0.13	0.06	-0.17	-1.45**	-1.75**	1.95**	-1.55**	1.03	-2.29
SE (Sij)±	1.02	1.05	0.43	0.32	0.44	0.98	0.33	0.31	0.35	0.35	0.34	0.33	0.57	0.54	1.25	1.21
SE (Sij-Sik)±	1.5	1.55	0.64	0.47	0.64	1.44	0.48	0.46	0.51	0.52	0.51	0.49	0.83	0.79	1.84	1.78
SE (Sij-Ski)±	0.37	1.89	0.21	0.19	0.37	1.89	0.21	0.19	0.24	0.24	0.23	0.22	0.63	0.57	3.08	2.86

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

Conti.

Parents / Crosses	Number of grains per spike				1000-grain weight				Grain yield per plant				Harvest index			
	E_1		E_2		E_1		E_2		E_1		E_2		E_1		E_2	
	F_1	F_2	F_1	F_2	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	-6.42**	-5.55**	-5.78**	-5.67**	-0.66**	-0.72**	-0.3	-1.37**	-1.61**	-1.82**	-0.96**	-1.50**	-1.83**	-3.86**	-0.74**	-0.40*
BG 105	1.11**	-0.13	-0.11	-0.1	3.65**	3.01**	3.93**	3.03**	-0.35	0.07	0.1	-0.19	0.73**	1.59**	1.06**	1.82**
PL 426	-5.28**	-5.29**	-5.40**	-4.83**	0.61**	1.48**	1.02**	0.97**	0.59**	0.64**	0.52	0.86**	-3.79**	-3.43**	-2.53**	-2.58**
BHS 380	-3.34**	-2.33**	-4.55**	-4.65**	-4.03**	-3.20**	-4.08**	-3.12**	-1.90**	-1.78**	-1.63**	-1.73**	-3.03**	-3.16**	0.56**	0.15
BH 902	2.54**	2.23**	2.68**	4.45**	2.27**	2.96**	2.39**	2.50**	-0.16	-0.79**	-0.60*	-1.09**	2.85**	4.19**	3.07**	3.46**
BH 946	5.68**	5.27**	5.26**	6.37**	0.53**	-0.34*	0.27	0.03	1.10**	0.46*	0.39	0.07	3.26**	3.39**	1.28**	1.45**
BH 959	4.71**	4.59**	5.03**	5.40**	-2.42**	-1.71**	-2.58**	-1.78**	1.66**	2.65**	1.97**	2.14**	1.82**	2.77**	1.42**	2.52**
RD 2715	-0.23	0.01	-0.02	-2.45**	-0.27	-1.26**	-0.11	-0.76**	-0.33	-0.96**	0.18	-0.62**	-2.06**	-3.09**	-2.69**	-4.10**
RD 2786	5.07**	4.44**	5.78**	4.96**	0.38*	1.73**	-0.06	1.81**	0.58**	0.97**	0.03	1.15**	3.54**	4.41**	1.89**	2.07**
RD 2552	-3.85**	-3.24**	-2.89**	-3.47**	-0.06	-1.94**	-0.48*	-1.32**	0.42*	0.57**	-0.01	0.92**	-1.49**	-2.79**	-3.32**	-4.39**
SE (gi)±	0.16	0.17	0.15	0.17	0.15	0.16	0.18	0.16	0.18	0.18	0.3	0.23	0.16	0.23	0.15	0.16
SE (gi-gj)±	0.24	0.26	0.23	0.26	0.23	0.24	0.27	0.24	0.27	0.27	0.44	0.34	0.23	0.34	0.23	0.24
SCA effects																
BHS 400 x BG 105	-7.98**	-4.34**	-5.28**	-8.42**	-6.01**	-8.37**	-1.68**	-10.17**	-1.53*	-1.84**	-1.74	-3.74**	-0.72	-3.08**	-1.56**	-4.40**
BHS 400 x PL 426	-2.41**	-0.21	-1.91**	1.29*	-0.53	-2.57**	0.66	-2.11**	3.39**	2.39**	2.94**	2.57**	4.65**	1.19	1.97**	3.51**
BHS 400 x BHS 380	0.45	2.96**	1.24*	0.97	-3.69**	-2.28**	-2.03**	-2.35**	0.65	1.22	4.22**	1.53	-1.36*	0.84	1.30*	2.40**
BHS 400 x BH 902	5.92**	4.15**	8.05**	3.99**	0.66	-2.22**	0.94	-2.00**	-1.67**	-0.58	-4.31**	-3.40**	-1.78**	-0.51	-1.32*	-0.76
BHS 400 x BH 946	1.40**	-0.63	1.54**	2.08**	0.34	1.98**	-1.02	1.50**	0.13	0.39	3.93**	3.85**	-0.57	-2.06**	-2.27**	-1.57**

BHS 400 x BH 959	1.92**	2.50**	2.66**	-0.42	2.50**	4.62**	1.31*	4.06**	5.01**	4.70**	2.96**	5.72**	-1.03	-1.99*	-4.58**	-3.33**
BHS 400 x RD 2715	5.22**	3.82**	3.01**	-2.46**	2.30**	-0.82	1.53*	0.27	-0.69	-1.08	-2.04*	-2.43**	0.72	1.12	2.06**	2.56**
BHS 400 x RD 2786	-5.81**	-3.75**	-7.03**	4.54**	1.19*	3.14**	0.68	3.43**	-1.78**	-1.75**	-0.13	-0.38	2.17**	-2.24**	-3.41**	-2.11**
BHS 400 x RD 2552	5.10**	2.12**	1.62**	5.16**	0.25	3.74**	-1.13	2.28**	-1.02	-1.21	-1.77	-2.12**	2.31**	4.31**	4.08**	3.56**
BG 105 x PL 426	3.78**	-1.98**	2.31**	6.30**	-0.8	0.55	-1.80**	-0.26	3.34**	5.77**	3.24**	4.63**	-1.71**	0.74	-0.67	0.78
BG 105 x BHS 380	6.51**	5.59**	5.03**	8.51**	0.6	2.18**	1.94**	1.85**	0.31	0.57	-2.28*	-1.79*	-5.93**	-8.27**	-0.97	0.8
BG 105 x BH 902	2.88**	2.70**	1.48**	0.34	-0.68	2.17**	1.18	2.05**	1.96**	2.26**	0.69	3.56**	3.95**	5.86**	2.99**	2.00**
BG 105 x BH 946	-2.46**	-2.30**	-4.42**	3.35**	2.66**	1.42**	0.83	1.34*	-1.36*	-2.22**	-2.23*	-2.57**	3.86**	8.34**	4.52**	5.61**
BG 105 x BH 959	-2.36**	-0.59	-2.45**	-7.88**	4.31**	5.24**	3.50**	5.78**	0.46	4.82**	1.79	5.01**	4.06**	1.23	2.67**	4.65**
BG 105 x RD 2715	1.86**	1.24*	3.54**	0.26	1.65**	-2.68**	0.34	-2.84**	-1.08	-0.69	3.83**	2.13**	4.14**	4.56**	-0.11	-1.69**
BG 105 x RD 2786	2.40**	2.31**	2.27**	5.62**	2.48**	1.47**	0.83	2.09**	-0.75	-2.86**	0.18	-2.69**	3.60**	7.94**	2.42**	4.96**
BG 105 x RD 2552	3.12**	-0.53	-0.41	-3.61**	-1.99**	-1.88**	-2.40**	-0.78	-0.45	-2.63**	0.09	-2.43**	-5.54**	-6.83**	-8.13**	-6.31**
PL 426 x BHS 380	-0.94	2.49**	-0.91	-2.72**	0.53	-5.08**	-0.15	-5.48**	-1.03	0.41	2.44*	2.14**	2.18**	2.60**	-0.86	-0.65
PL 426 x BH 902	-0.57	-2.96**	-0.37	1.48*	1.64**	-2.02**	0.71	-2.16**	-0.42	-0.44	1.74	0.89	-2.02**	-3.77**	-2.33**	-3.11**
PL 426 x BH 946	0.4	-1.97**	3.10**	1.14	3.00**	-2.08**	2.05**	-2.90**	0.99	-1.21	-2.04*	-1.95*	-3.74**	-5.10**	-1.07*	-2.72**
PL 426 x BH 959	8.32**	4.91**	7.34**	7.07**	-2.06**	3.63**	0.41	4.30**	-3.14**	-4.61**	-1.6	-5.08**	-0.77	0.59	1.83**	2.33**
PL 426 x RD 2715	-3.72**	4.05**	-1.77**	-0.62	0.19	4.91**	-0.63	4.57**	0.68	0.09	1.6	2.65**	1.14*	0.81	2.75**	3.05**
PL 426 x RD 2786	4.34**	3.99**	1.51**	4.57**	-0.02	5.17**	0.99	4.41**	-1.38*	-2.24**	-3.29**	-3.33**	-4.43**	0.18	-1.48**	-2.72**
PL 426 x RD 2552	0.02	0.18	1.36**	-3.18**	0.33	3.71**	0.67	2.22**	2.22**	5.22**	2.76**	6.31**	2.89**	3.70**	-1.93**	-0.19
BHS 380 x BH 902	2.60**	4.02**	0.91	5.91**	0.43	1.93**	-0.92	1.73**	0.36	0.95	3.46**	2.28**	1.44**	0.05	-1.74**	-2.63**
BHS 380 x BH 946	2.36**	2.18**	2.21**	-5.97**	0.78	4.39**	2.20**	6.18**	-0.55	-1.11	0.36	-0.35	-0.44	0.96	-8.37**	-9.07**
BHS 380 x BH 959	-1.81**	-4.30**	-5.59**	2.81**	2.05**	3.11**	2.47**	2.97**	-1.27*	-1.45*	-3.08**	-0.95	1.25*	1.44	0.32	-0.08
BHS 380 x RD 2715	2.44**	-2.25**	0.74	-0.45	-0.71	0.76	-0.25	1.32*	1.85**	1.18	-0.42	0.77	0.39	0.86	-2.35**	-2.94**
BHS 380 x RD 2786	2.04**	-1.35*	0.85	-4.77**	2.95**	3.12**	1.51*	3.30**	-1.48*	-1.75**	-1.89	-3.58**	2.49**	0.04	4.01**	5.82**
BHS 380 x RD 2552	-5.13**	2.53**	-2.52**	-0.39	-1.25*	-2.67**	-2.24**	-3.25**	0.7	0.59	0.11	2.14**	0.26	2.55**	5.50**	3.75**
BH 902 x BH 946	-3.45**	-1.93**	-2.94**	1	-0.92	-3.44**	-1.58*	-1.63**	-1.26*	-3.38**	-0.88	-2.71**	1.80**	3.97**	3.67**	6.06**
BH 902 x BH 959	-7.33**	-5.58**	-4.38**	1.98**	0.07	3.74**	-0.1	2.29**	-1.61*	-2.18**	-0.05	-2.76**	2.05**	5.00**	1.40**	6.23**
BH 902 x RD 2715	-4.39**	-1.42*	-3.03**	-0.15	0.33	3.02**	0.6	5.61**	0.34	1.29*	-0.64	-2.06**	0.05	-1.97*	0.58	-1.20*
BH 902 x RD 2786	4.11**	0.81	4.31**	3.11**	-3.57**	0.32	0.41	-0.08	0.93	-0.59	2.27*	3.82**	0.5	-0.52	2.23**	4.66**
BH 902 x RD 2552	-0.91	-2.81**	-2.78**	-6.98**	1.34*	-0.97	3.25**	-1.01	0.64	0.03	-2.27*	-1.91*	-0.89	3.68**	-1.03*	-3.02**
BH 946 x BH 959	-1.57**	-3.73**	-2.29**	-2.74**	-2.84**	-5.66**	-1.58*	-5.11**	-3.13**	-1.68**	-1.22	-3.88**	3.66**	5.96**	3.34**	3.10**
BH 946 x RD 2715	2.23**	0.9	2.50**	0.87	-4.04**	-0.3	0.6	-2.68**	1	1	2.74**	2.78**	-0.73	-2.12**	0.22	2.40**
BH 946 x RD 2786	-1.22*	0.38	0.02	0.35	2.40**	6.01**	2.23**	6.34**	3.05**	3.12**	-0.84	2.07**	0.83	3.57**	3.03**	5.56**
BH 946 x RD 2552	0.85	3.34**	-0.59	5.88**	2.60**	-1.32*	1.89**	1.52**	0.21	2.19**	1.41	2.35**	-0.9	-7.92**	-2.05**	-5.46**
BH 959 x RD 2715	2.33**	1.43*	-0.96	-6.49**	-0.82	-5.45**	-1.34*	-4.99**	1.04	-1.1	1.53	-1.12	-3.85**	-1.28	-2.53**	-3.83**
BH 959 x RD 2786	0.58	2.37**	2.74**	0.42	1.35**	0.23	0.4	0.96	0.54	6.48**	1.31	6.12**	1.90**	4.81**	0.47	0.27
BH 959 x RD 2552	1.92**	3.80**	0.91	7.10**	-0.67	-2.26**	-0.67	-2.75**	2.46**	-0.08	2.59*	1.53*	0.73	-2.64**	0.61	0.83
RD 2715 x RD 2786	1.10*	0.51	-0.92	0.07	-0.43	-3.47**	-0.59	-3.98**	-2.38**	-2.61**	-1.38	-1.55*	-1.83**	-3.33**	-4.85**	-9.45**
RD 2715 x RD 2552	0.5	-0.44	1.07*	5.79**	1.83**	0.79	1.54*	1.83**	-3.40**	-2.66**	-3.56**	-3.03**	4.39**	2.94**	3.51**	6.96**
RD 2786 x RD 2552	-0.6	-1.55**	0.11	-10.98**	1.05*	-2.71**	0.31	-2.30**	0.79	1.90**	-0.25	-0.37	1.79**	1.34	-1.10*	-2.74**
SE (Sij)±	0.53	0.59	0.51	0.58	0.51	0.53	0.62	0.55	0.61	0.62	1	0.77	0.53	0.76	0.51	0.54
SE (Sij-Sik)±	0.78	0.86	0.75	0.85	0.75	0.78	0.91	0.81	0.9	0.91	1.48	1.13	0.78	1.12	0.76	0.79
SE (Sij-Ski)±	0.55	0.68	0.51	0.66	0.51	0.56	0.75	0.59	0.74	0.75	1.98	1.17	0.55	1.15	0.52	0.56

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

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