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Research Article

Combining ability analysis over environments in bread wheat

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Abstract
Thirty-eight genotypes of wheat including 8 parents, their 28 F_1s and 2 checks evaluated in 4 different environments *i.e.* early sown, normal sown, late sown and very late sown conditions was undertaken to study the combining ability in bread wheat for grain yield and its component traits. From pooled analysis, it was found that mean square due to GCA and SCA were significant for all characters which revealed difference between parents for GCA and difference between crosses for SCA. Significant mean square for GCA x E and SCA x E for proline content, chlorophyll content, chlorophyll stability index and heat injury was observed. In addition, SCA x E for grain yield was also significant. This suggested that additive and non-additive genetic components were sensitive to environments. Variance for GCA was higher than their respective SCA variance for grain yield per plant, leaf canopy temperature, proline content and chlorophyll stability index which suggested that additive component was less stable over the environment than dominant component. Parents HD 2987 was good general combiners for grain yield over different environments. Cross HI 1544 x HD 2987 was the best specific combiner for grain yield per plant followed by HI 1544 x RAJ 4079.

Key words
Bread wheat, diallel analysis, GCA, SCA, combining ability.

Introduction

Bread wheat is the second most important cereal crop after rice in India where it meets the basic food requirements of more than half of the human population. It is popularly known as ‘stuff of life or king of cereals’ because of the acreage occupied, high productivity and the prominent position it holds in the international food grain trade. It is grown in temperate, irrigated to dry and high-rain-fall areas and in warm, humid to dry, cold environments. In India, area and production of wheat during the year 2014-15 was 30.97 million ha and 88.94 million tonnes with an average productivity of 2872 kg ha^{-1} (DAC and FW, 2015). Recent climate change research predicts significant increase in rainfall as well as temperature. The temperature in South Asia is projected to rise by 3-4 ^{0}C by the end of the century (DEFRA, 2005). In this way, heat stress has been given top research needs in significant wheat-growing regions. Generation of information on the effect of high temperature stress on various traits may be helpful for developing thermo-tolerance wheat cultivars. Hence, now breeding for heat tolerance has become an integral component of wheat improvement. For further progress, it is necessary to further develop knowledge of breeding behaviour, especially combining ability and type of gene action for the different traits. An indication of the relative magnitude of genetic variance can be given by the estimates of combining ability variances and effects. Besides making haphazard crosses, only high - performance crosses must be executed. Combining ability in this context provides a guideline for selecting elite parents and desirable cross combinations to be used for rapid improvement in the formulation of a systematic breeding programme. This information enables the breeder to evaluate and classify selected parental material for their utility in development of high yielding F_1 hybrids in wheat.

Materials and Methods

Experimental material consisted of 8 diverse genotypes (Table 1) which were crossed in half diallel fashion resulting in 28 F_1s at Research Farm, Rajasthan College of Agriculture, Udaipur (Rajasthan) during the year 2014-15. These eight parents and their 28 F_1s were grown in a randomized block design with three replications under early (E_1), normal (E_2), late (E_3) and very late (E_4) sown conditions. Row-to-row and plant-to-plant distances were 30cm and 10cm respectively in each environment. Recommended plant protection procedures were followed for raising the crop in all the environments.

The observations were recorded on seven distinct characters *viz.* grain yield per plant, leaf canopy temperature, proline content, chlorophyll content, chlorophyll stability index, heat injury and total protein content in grain for statistical analysis. The mean value of the recorded observations was subjected to analysis of variance (ANOVA) using the standard procedures of Panse and Sukhatme (1985). Combining ability analysis was done by using Griffing's (1956) Method II (parents and one set of F_1s without reciprocals), Model I (fixed effect).

Results and Discussion

From pooled analysis of variance for combining ability (Table 2), it was found that variance due to GCA and SCA were significant for all characters which revealed difference between parents for GCA and difference between crosses for SCA. Similar results were also reported by Dholariya *et al.* (2014) and Kumar and Kerkhi (2015). Significant mean square for GCA x E for proline content, chlorophyll content, chlorophyll stability index and heat injury suggested that additive genetic component was sensitive to environments. Similarly, significant mean square for SCA x E for grain yield, proline content, chlorophyll content, chlorophyll stability index and heat injury suggested that non-additive genetic component was also sensitive to environments. Variance for GCA was higher than their respective SCA variance for grain yield per plant, leaf canopy temperature, proline content and chlorophyll stability index which suggested that additive component was less stable over the environments than dominant component. The results were in agreement with finding of Nayeem and Veer (2000), Joshi *et al.* (2002) and Verma *et al.* (2006).

The estimate of general combining ability effects of the parents for seven characters for individual and pooled environments are presented in Table 3 to Table 5. General combining effect revealed that parent HD 2987 for grain yield per plant, parent HD 2932 for chlorophyll content and RAJ 4037 for proline content and heat injury were consistently good general combiners in all the four environments including pooled. For leaf canopy temperature, none of the parents was significant whereas negative GCA was observed in E_2. Parent Raj 4079 (in E_1 and E_3) and HD 2987 in E_4 were good general combiners. Highest GCA effects for chlorophyll stability index was observed in parent HD 2987 (in E_1), Raj 4079 (in E_2), and Raj 4079 (in E_3, E_4 and pooled). Similarly, highest GCA effects for total protein content in grain was observed in parent Lok1 (in E_1) and HI 1544 (in E_2, E_3, E_4 and pooled). These results were in agreement with Nayeem and Veer (2000) and Ramani *et al.* (2014).

The data on GCA effects of different parents indicated that the effects varied significantly for different characters and in different environments. The good general combiners had fixable component of variance like additive and additive × additive epistasis component; therefore, these parents offer the best possibilities of exploitation for development of improved high yielding lines with heat tolerance in bread wheat. It was further noted that involvement of these parents would result into hybrids expressing useful heterosis for various traits.

Sprague and Tatum (1942) reported that the specific combining ability is an important parameter for judging and selecting superior cross combinations, which might be exploited through heterosis breeding. The crosses which showed highest significant positive SCA effects for different characters are presented in Table 3 to Table 5. Among the hybrids on pooled basis, the highest value of SCA effects for grain yield per plant were recorded in the crosses, HI 1544 x HD 2987 followed by HI 1544 x RAJ 4079, PBW 175 x HD 2987. Cross, GW 366 x PBW 175 followed by HD 2932 x Lok 1 had highest SCA effects in negative direction for leaf canopy temperature. Cross, HD 2932 x HD 2987 show highest SCA effects in positive direction for proline content. Similarly, for chlorophyll content, cross HD 2932 x HD 2987 show highest SCA effects. For chlorophyll stability index, the highest SCA effects were exhibited by the cross, Raj 4037 x HD 2987. The cross Raj 4037 x HI 1544 for heat injury and Raj 4037 x Lok 1 for total protein content possessed highest SCA effects in negative direction. Similar results were also reported by Singh and Yadav (2011) and Punia *et al.* (2011).

The estimates of SCA effects revealed that none of the hybrids was consistently superior for all the traits. The significant SCA effects might be due to the presence of intra or inter allelic interaction and can be easily exploited in cross pollinated crops and in self-pollinated crops where commercial hybrid seed production is possible. However, if its parents are good general combiners the h igh SCA might be due to accumulation of dominant alleles from both the parents, if so it can be easily exploited in self-pollinated crops by selecting transgressive segregants in segregating generations.

In the present investigation, parents HD 2987 was good general combiner for grain yield over different environments. Therefore, this parent offers the best possibilities of exploitation for development of improved high yielding lines with heat tolerance in bread wheat. The cross HI 1544 x HD 2987 was the best specific combiner for grain yield per plant followed by HI 1544 x RAJ 4079. They produced significant and desirable SCA effects and heterosis for most of the traits studied indicating potential for exploiting hybrid vigour in breeding programme.

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Table 1. Particulars of wheat parent material used

S.N.	Name of cultivar	Pedigree
1.	HD 2932 (PUSA WHEAT 111)	KAUZ/STAR//HD 2643
2.	GW 366	DL 802-3/GW 232
3.	Raj 4037	DL 788-2 / RAJ 3717
4.	PBW 175	HD 2160 /WG 1025
5.	HI 1544 (PURNA)	HINDI 62/BOBWHITE/ CPAN 2099
6.	Raj 4079	UP 2363/WH 595
7.	HD 2987 (PUSA BAHAR)	HI1011/HD2348//MENDOS//IWP 72/DL 153-2
8.	LOK 1	S-308 / S 331

Table 2. Combining ability mean square and error mean square over the environments for different character

S.N.	Characters	Source							
		Env	GCA	SCA	GCA x E	SCA x E	Pooled Error	GCA Variance	SCA Variance
		[3]	[7]	[28]	[21]	[84]	[280]		
1	Grain yield per plant (g)	127.67**	13.89**	20.22**	0.77	0.90**	0.55	10.59	2.33
2	Leaf canopy temperature (^{0}C)	93.44**	1.48**	1.52**	0.11	0.15	0.16	7.77	0.23
3	Proline content (µg)	749.83**	135.38**	11.20**	0.97**	2.16**	0.13	62.47	23.67
4	Chlorophyll content (mg/g)	0.56**	1.17**	0.25**	0.005**	0.004**	0.00	0.05	0.21
5	Chlorophyll stability index	52.44**	24.76**	34.40**	0.52**	0.74**	0.20	4.35	4.30
6	Heat injury (%)	220.38**	407.40**	44.51**	1.61**	1.93**	0.73	18.30	71.17
7	Total Protein content in grain (%)	1.14**	1.38**	1.22**	0.011	0.010	0.02	0.09	0.24

*,** Significant at 5 and 1 percent respectively (Model I)

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Table 3. GCA and SCA effects for grain yield per plant and leaf canopy temperature

S.N.	Genotype	Grain yield per plant					Leaf canopy temperature (^{0}C)				
		E_1	E_2	E_3	E_4	Pooled	E_1	E_2	E_3	E_4	Pooled
1	HD 2932	-0.00	-0.13	-0.08	0.17	-0.01	-0.05	-0.05	0.16	0.05	0.03
2	GW 366	-0.93**	-0.28	-0.61**	-0.55**	-0.59*	-0.03	-0.07	-0.00	-0.04	-0.03
3	Raj 4037	-0.62*	-0.81**	-0.31	0.02	-0.43*	0.00	0.10	0.06	0.28*	0.11
4	PBW 175	-0.56*	0.05	-0.24	-0.54**	-0.32*	-0.19	-0.05	-0.11	0.02	-0.08
5	HI 1544	0.59*	0.21	0.26	0.10	0.29**	0.41**	0.24	0.33**	0.28*	0.32**
6	Raj 4079	-0.46	-0.80**	-0.51*	-0.14	-0.48*	-0.28*	-0.12	-0.27*	-0.28*	-0.24*
7	HD 2987	1.37**	1.33**	1.01**	0.89**	1.15**	-0.23	-0.22	-0.19	-0.34**	-0.24*
8	Lok1	0.62*	0.43	0.47*	0.06	0.39**	0.36**	0.18	0.02	0.03	0.15*
9	HD 2932 x GW 366	1.14	1.49	0.74	1.00*	1.09**	0.56	0.30	0.43	-0.21	0.27
10	HD 2932 x Raj 4037	1.97*	0.37	1.32*	1.18**	1.21**	0.31	-0.11	-0.81*	-0.17	-0.20
11	HD 2932 x PBW 175	0.23	1.13	-0.03	-0.61	0.18	0.69	0.94*	0.80*	0.33	0.69**
12	HD 2932 x HI 1544	-1.80*	-1.86*	-2.98**	-1.73**	-2.09**	0.80*	0.73	0.52	0.82*	0.72**
13	HD 2932 x Raj 4079	3.89**	2.59**	3.57**	3.16**	3.30**	-0.64	-0.31	0.22	-1.00*	-0.43*
14	HD 2932 x HD 2987	-1.64*	-1.60	-1.69**	-2.28**	-1.80**	-0.60	-0.33	-0.44	-0.27	-0.41*
15	HD 2932 x Lok1	-2.14**	-3.81**	-2.22**	-1.00*	-2.29**	-1.37**	-0.78*	-1.54**	-0.59	-1.07**
16	GW 366 x Raj 4037	0.92	3.21**	2.01**	0.03	1.54**	1.17**	0.89*	1.48**	0.66	1.05**
17	GW 366 x PBW 175	0.10	0.91	1.65*	0.68	0.83*	-1.16**	-1.39**	-1.51**	-0.22	-1.07**
18	GW 366 x HI 1544	-2.80**	-3.62**	-2.88**	-1.57**	-2.72**	-0.31	-0.43	-0.78*	-0.56	-0.52**
19	GW 366 x Raj 4079	-2.83**	-3.68**	-2.49**	-1.98**	-2.75**	0.73	0.99*	1.17**	0.91*	0.95**
20	GW 366 x HD 2987	-0.87	-1.00	-1.63*	-0.90*	-1.10**	0.01	-0.31	-0.03	-0.64	-0.24
21	GW 366 x Lok1	1.11	1.87*	1.23	0.58	1.20**	0.32	0.28	0.29	0.70	0.40*
22	Raj 4037 x PBW 175	0.88	1.06	0.16	-0.22	0.47	-0.26	-0.54	0.11	-0.36	-0.26
23	Raj 4037 x HI 1544	0.67	1.40	1.94**	-0.66	0.84*	-0.09	-0.32	-0.56	0.81*	-0.04
24	Raj 4037 x Raj 4079	-1.87*	-2.27**	-1.61*	0.25	-1.38**	0.35	0.10	-0.03	-0.20	0.06
25	Raj 4037 x HD 2987	3.48**	2.85**	3.22**	4.11**	3.42**	0.05	-0.41	-0.63*	-0.85*	-0.46*
26	Raj 4037 x Lok1	-1.28	-0.49	-0.76	-1.60**	-1.03**	0.43	0.26	0.76*	-0.23	0.31
27	PBW 175 x HI 1544	-5.48**	-7.19**	-5.48**	-2.89**	-5.26**	0.17	-0.10	0.26	-1.01*	-0.17
28	PBW 175 x Raj 4079	1.80*	1.50	2.56**	0.58	1.61**	0.06	0.19	-0.03	0.37	0.15
29	PBW 175 x HD 2987	2.98**	3.33**	2.32**	0.79	2.35**	0.54	0.07	0.21	0.94*	0.44*
30	PBW 175 x Lok1	2.73**	2.57**	1.99**	0.93*	2.06**	0.75	0.55	0.57	0.66	0.63**
31	HI 1544 x Raj 4079	2.98**	3.57**	2.42**	0.07	2.26**	0.38	0.10	0.06	0.51	0.26
32	HI 1544 x HD 2987	4.02**	2.92**	3.58**	3.77**	3.57**	-0.50	0.25	0.29	-0.41	-0.09
33	HI 1544 x Lok1	0.55	0.11	0.66	2.38**	0.92**	-0.77	-0.75	-0.65*	-0.85*	-0.75**
34	Raj 4079 x HD 2987	-1.02	0.02	-0.35	-1.41**	-0.69*	1.43**	0.52	0.40	1.12**	0.87**
35	Raj 4079 x Lok1	0.74	1.40	0.43	-0.39	0.55	-0.56	-0.91*	-0.98**	-1.26**	-0.93**
36	HD 2987 x Lok1	-0.59	-1.30	-0.55	-0.20	-0.66	0.09	-0.05	-0.31	0.31	0.01

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Table 4. GCA and SCA effects for proline content, chlorophyll content and chlorophyll stability index

S.N.	Genotype	Proline content (µg)					Chlorophyll content (mg/g)					Chlorophyll stability index				
		E_1	E_2	E_3	E_4	Pooled	E_1	E_2	E_3	E_4	Pooled	E_1	E_2	E_3	E_4	Pooled
1	HD 2932	2.44**	2.10**	2.01**	1.58**	2.03**	0.22**	0.24**	0.20**	0.20**	0.21**	-0.37**	0.08	-0.25	-0.24	-0.20*
2	GW 366	-1.20**	-1.08**	-1.50**	-1.33**	-1.28*	-0.25**	-0.26**	-0.24**	-0.21**	-0.24*	0.34*	-0.00	0.35*	-0.10	0.15*
3	Raj 4037	2.79**	2.67**	2.63**	2.73**	2.71**	0.18**	0.22**	0.20**	0.17**	0.19**	-0.77**	-0.61**	-0.58**	-0.32*	-0.57*
4	PBW 175	-1.10**	-1.07**	-1.44**	-1.30**	-1.23*	-0.06**	-0.07**	-0.07**	-0.05**	-0.06*	-0.94**	-1.10**	-1.04**	-0.81**	-0.97*
5	HI 1544	-1.96**	-2.07**	-1.74**	-2.09**	-1.96*	-0.21**	-0.23**	-0.22**	-0.16**	-0.21*	0.07	-0.08	0.00	-0.15	-0.04
6	Raj 4079	1.15**	1.59**	1.45**	1.29**	1.37**	0.11**	0.14**	0.12**	0.12**	0.12**	1.27**	1.26**	1.30**	1.20**	1.26**
7	HD 2987	0.03	0.27*	-0.17	0.62**	0.19**	0.03**	0.00	0.04**	0.01	0.02**	1.33**	1.26**	0.79**	0.64**	1.01**
8	Lok1	-2.15**	-2.42**	-1.24**	-1.49**	-1.83*	-0.02**	-0.06**	-0.03**	-0.07**	-0.05*	-0.93**	-0.81**	-0.56**	-0.23	-0.63*
9	HD 2932 x GW 366	1.76**	1.87**	0.66*	1.36**	1.41**	-0.11**	-0.14**	-0.03	-0.02	-0.07**	-7.58**	-8.40**	-7.10**	-5.00**	-7.02**
10	HD 2932 x Raj 4037	0.35	1.06**	0.84**	4.06**	1.58**	-0.01	-0.10**	-0.05	0.01	-0.04**	-5.17**	-5.25**	-4.89**	-4.04**	-4.84**
11	HD 2932 x PBW 175	-0.45	-0.61	-1.96**	-1.05**	-1.02**	-0.04	-0.01	-0.02	-0.11**	-0.05**	2.31**	3.42**	2.77**	2.53**	2.76**
12	HD 2932 x HI 1544	-0.79*	-0.82*	-2.77**	-1.95**	-1.58**	-0.22**	-0.25**	-0.21**	-0.23**	-0.23**	1.46**	1.58**	1.21*	0.13	1.10**
13	HD 2932 x Raj 4079	-0.44	-1.52**	0.45	1.30**	-0.05	0.19**	0.13**	0.21**	0.22**	0.19**	1.16**	0.58*	1.47**	1.38**	1.15**
14	HD 2932 x HD 2987	3.11**	3.07**	2.03**	2.45**	2.66**	0.55**	0.48**	0.56**	0.56**	0.54**	0.40	0.81**	-0.37	-1.81**	-0.24
15	HD 2932 x Lok1	2.56**	1.90**	2.34**	0.35	1.79**	-0.20**	-0.21**	-0.22**	-0.08**	-0.18**	3.98**	3.89**	3.95**	3.50**	3.83**
16	GW 366 x Raj 4037	0.04	0.87*	-0.38	-0.39	0.04	-0.17**	-0.22**	-0.21**	-0.23**	-0.21**	3.52**	3.23**	3.78**	2.60**	3.28**
17	GW 366 x PBW 175	0.58	0.15	0.81**	0.66	0.55**	-0.02	-0.03	-0.02	-0.07*	-0.04**	1.93**	2.19**	1.17*	0.59	1.47**
18	GW 366 x HI 1544	-0.96**	-1.53**	-0.13	0.07	-0.64**	0.16**	0.19**	0.17**	0.14**	0.16**	0.50	1.29**	1.04*	0.11	0.74**
19	GW 366 x Raj 4079	0.93**	0.58	-0.73*	-0.75	0.01	-0.09**	-0.13**	-0.11**	-0.09**	-0.11**	0.16	0.42	0.26	-0.66	0.04
20	GW 366 x HD 2987	0.89**	3.43**	0.57	0.19	1.27**	-0.23**	-0.19**	-0.23**	-0.20**	-0.21**	0.26	0.25	-1.42**	-1.73**	-0.66**
21	GW 366 x Lok1	-1.80**	-2.30**	0.39	0.35	-0.84**	-0.14**	-0.12**	-0.15**	-0.07*	-0.12**	0.66	1.19**	0.79	0.33	0.74**
22	Raj 4037 x PBW 175	-1.61**	1.20**	-1.33**	-1.35**	-0.77**	-0.33**	-0.36**	-0.30**	-0.20**	-0.30**	-3.91**	-5.03**	-3.70**	-2.32**	-3.74**
23	Raj 4037 x HI 1544	0.01	1.75**	-0.05	0.88*	0.65**	-0.36**	-0.41**	-0.42**	-0.36**	-0.39**	5.19**	4.45**	3.06**	1.86**	3.64**
24	Raj 4037 x Raj 4079	0.13	-0.74*	1.25**	0.52	0.29	0.41**	0.34**	0.42**	0.46**	0.41**	2.32**	2.86**	2.56**	2.12**	2.47**
25	Raj 4037 x HD 2987	1.34**	0.63	3.73**	2.82**	2.13**	0.27**	0.39**	0.43**	0.46**	0.39**	3.77**	3.51**	4.56**	3.93**	3.94**
26	Raj 4037 x Lok1	-0.61*	2.16**	-0.25	0.26	0.39*	0.27**	0.25**	0.24**	0.27**	0.26**	-2.80**	-2.50**	-2.78**	-2.21**	-2.57**
27	PBW 175 x HI 1544	3.19**	2.94**	1.08**	1.64**	2.21**	0.28**	0.33**	0.27**	0.24**	0.28**	2.64**	2.45**	3.27**	3.04**	2.85**
28	PBW 175 x Raj 4079	-1.05**	0.04	-1.27**	-1.48**	-0.94**	-0.09**	-0.08**	-0.06	-0.04	-0.07**	1.69**	2.15**	1.57**	0.19	1.40**
29	PBW 175 x HD 2987	-2.02**	-2.69**	1.78**	0.34	-0.65**	-0.00	0.01	-0.05	-0.09**	-0.03*	1.90**	1.25**	-0.33	-0.31	0.63**
30	PBW 175 x Lok1	-0.59	-1.21**	3.40**	4.11**	1.43**	-0.11**	-0.08**	-0.11**	-0.05	-0.09**	0.44	1.65**	0.70	0.07	0.71**
31	HI 1544 x Raj 4079	0.75*	1.82**	-0.13	0.66	0.77**	0.07**	0.00	0.06*	0.11**	0.06**	0.95*	0.74**	0.46	-0.06	0.52*
32	HI 1544 x HD 2987	1.76**	0.92**	-0.54	-1.20**	0.23	-0.24**	-0.18**	-0.19**	-0.23**	-0.21**	2.32**	1.68**	2.36**	2.45**	2.20**
33	HI 1544 x Lok1	-1.97**	-2.37**	-2.40**	-2.34**	-2.27**	0.25**	0.20**	0.22**	0.19**	0.22**	-2.59**	-1.52**	-2.34**	-1.54**	-2.00**
34	Raj 4079 x HD 2987	-0.07	1.84**	0.97**	6.36**	2.28**	-0.16**	-0.23**	-0.20**	-0.04	-0.16**	-3.58**	-3.44**	-3.58**	-2.52**	-3.28**
35	Raj 4079 x Lok1	0.27	1.09**	0.18	1.55**	0.77**	-0.39**	-0.39**	-0.41**	-0.33**	-0.38**	1.92**	2.42**	1.00*	1.04*	1.60**
36	HD 2987 x Lok1	-2.72**	-3.52**	-4.47**	-2.71**	-3.36**	-0.22**	-0.25**	-0.26**	-0.19**	-0.23**	-1.08*	-0.56*	-0.40	-0.29	-0.58**

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Table 5. GCA and SCA effects for heat injury and total protein content in grain

S.N.	Genotype	Heat injury (%)					Total protein content in grain (%)				
		E_1	E_2	E_3	E_4	Pooled	E_1	E_2	E_3	E_4	Pooled
1	HD 2932	-3.90**	-4.43**	-3.62**	-4.04**	-4.00*	-0.09	-0.08	-0.06	0.02	-0.05*
2	GW 366	2.48**	3.25**	2.48**	2.96**	2.79**	0.15**	0.13**	0.11*	0.07*	0.12**
3	Raj 4037	-4.44**	-5.42**	-5.27**	-4.85**	-5.00*	-0.26**	-0.27**	-0.23**	-0.19**	-0.24*
4	PBW 175	1.85**	2.62**	2.47**	2.95**	2.47**	0.15**	0.15**	0.13**	0.09**	0.13**
5	HI 1544	3.66**	4.02**	3.68**	3.42**	3.70**	0.17**	0.17**	0.15**	0.16**	0.16**
6	Raj 4079	-1.43**	-1.61**	-1.04**	-1.32**	-1.35*	-0.31**	-0.30**	-0.28**	-0.36**	-0.31*
7	HD 2987	0.66**	0.73*	0.76**	1.06**	0.80**	0.00	0.03	0.01	0.07*	0.03
8	Lok1	1.12**	0.85**	0.54*	-0.17	0.58**	0.18**	0.17**	0.15**	0.15**	0.16**
9	HD 2932 x GW 366	-1.59*	-2.54**	-3.96**	-1.29	-2.34**	0.19	0.19	0.16	0.02	0.14*
10	HD 2932 x Raj 4037	0.22	0.06	3.11**	2.24**	1.41**	-0.39**	-0.38*	-0.47**	-0.32**	-0.39**
11	HD 2932 x PBW 175	1.87**	1.09	1.24	1.81*	1.50**	0.74**	0.74**	0.72**	0.85**	0.77**
12	HD 2932 x HI 1544	3.06**	5.09**	5.20**	5.86**	4.80**	0.65**	0.63**	0.61**	0.68**	0.64**
13	HD 2932 x Raj 4079	-3.13**	-3.87**	-4.73**	-5.86**	-4.40**	-0.28	-0.23	-0.21	-0.30**	-0.26**
14	HD 2932 x HD 2987	-4.57**	-3.77**	-1.17	-0.73	-2.56**	0.75**	0.72**	0.69**	1.08**	0.81**
15	HD 2932 x Lok1	-3.39**	-4.38**	-5.42**	-5.66**	-4.71**	-0.94**	-0.94**	-0.97**	-1.12**	-0.99**
16	GW 366 x Raj 4037	5.19**	5.04**	5.36**	7.35**	5.73**	-0.27	-0.26	-0.30*	-0.12	-0.24**
17	GW 366 x PBW 175	-2.30**	-2.15*	-3.05**	-4.81**	-3.08**	0.29	0.30*	0.32*	0.64**	0.39**
18	GW 366 x HI 1544	-1.03	-0.65	0.41	-0.67	-0.49	-0.58**	-0.58**	-0.56**	-0.59**	-0.58**
19	GW 366 x Raj 4079	1.49*	5.17**	4.76**	3.33**	3.69**	0.39**	0.40**	0.37*	0.31**	0.37**
20	GW 366 x HD 2987	-0.12	0.47	0.57	3.31**	1.06**	0.00	-0.03	-0.02	-0.27**	-0.08
21	GW 366 x Lok1	-1.00	-0.59	0.02	1.50*	-0.01	0.47**	0.41**	0.43**	0.29**	0.40**
22	Raj 4037 x PBW 175	-3.39**	-4.06**	-1.90*	-2.11**	-2.87**	0.12	0.13	0.09	0.26**	0.15*
23	Raj 4037 x HI 1544	-4.96**	-7.04**	-6.60**	-3.45**	-5.51**	-0.47**	-0.47**	-0.52**	-0.46**	-0.48**
24	Raj 4037 x Raj 4079	-5.25**	-3.57**	-2.81**	-3.78**	-3.85**	0.10	0.10	0.03	0.05	0.07
25	Raj 4037 x HD 2987	-4.50**	-5.05**	-4.95**	-6.26**	-5.19**	-0.24	-0.31*	-0.29*	-0.37**	-0.30**
26	Raj 4037 x Lok1	2.36**	1.91*	2.93**	2.43**	2.41**	1.34**	1.37**	1.34**	1.26**	1.33**
27	PBW 175 x HI 1544	-0.95	-0.55	-1.39	-2.93**	-1.46**	-0.20	-0.20	-0.19	-0.20*	-0.20**
28	PBW 175 x Raj 4079	2.06**	0.51	-0.51	5.14**	1.80**	0.05	0.05	0.02	-0.23**	-0.03
29	PBW 175 x HD 2987	2.68**	3.82**	2.63**	1.84*	2.74**	-0.51**	-0.54**	-0.53**	-0.51**	-0.52**
30	PBW 175 x Lok1	0.92	0.84	1.33	1.88*	1.24**	-0.98**	-0.98**	-0.96**	-1.07**	-1.00**
31	HI 1544 x Raj 4079	3.45**	2.43*	3.01**	2.30**	2.80**	-0.12	-0.13	-0.16	-0.40**	-0.20**
32	HI 1544 x HD 2987	2.29**	1.68	1.67*	3.01**	2.16**	0.58**	0.56**	0.57**	0.45**	0.54**
33	HI 1544 x Lok1	2.78**	2.10*	2.90**	2.72**	2.62**	0.69**	0.77**	0.79**	0.56**	0.70**
34	Raj 4079 x HD 2987	-1.18	-2.26*	0.63	2.29**	-0.13	0.08	0.05	0.01	0.00	0.04
35	Raj 4079 x Lok1	3.02**	2.77**	2.49**	1.99**	2.57**	0.32*	0.28	0.25	0.49**	0.33**
36	HD 2987 x Lok1	-1.09	-1.20	-2.55**	-2.82**	-1.92**	-0.34*	-0.36*	-0.36*	-0.23**	-0.32**

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Table 6. GCA and SCA effects for grain yield per plant and harvest index

S.N.	Genotype	Grain yield per plant					Harvest index				
		E_1	E_2	E_3	E_4	Pooled	E_1	E_2	E_3	E_4	Pooled
1	HD 2932	-0.22	-0.09	-0.30	0.43*	-0.04	0.64	1.11	-0.11	0.87	0.63*
2	GW 366	-0.62	-0.35	-0.24	-0.83**	-0.51*	-0.21	0.03	0.46	-0.97	-0.17
3	Raj 4037	-0.49	-0.75**	-0.60**	-0.20	-0.51*	0.35	-0.04	0.11	1.16	0.40
4	PBW 175	-0.05	-0.02	0.14	-0.46*	-0.10	1.06**	0.74	0.99	-1.39	0.35
5	HI 1544	0.21	0.24	-0.08	0.10	0.12	-0.44	0.17	-1.04	0.33	-0.24
6	Raj 4079	-0.57	-0.87**	-0.50*	-0.16	-0.52*	0.32	-0.27	0.62	1.01	0.42
7	HD 2987	1.32**	1.31**	1.18**	0.93**	1.19**	-1.95**	-2.11**	-1.15	-1.04	-1.56*
8	Lok1	0.42	0.52	0.39	0.20	0.38**	0.24	0.37	0.13	0.02	0.19
9	HD 2932 x GW 366	0.54	1.44	0.10	0.10	0.54	-1.62	0.62	-2.42	-1.23	-1.16
10	HD 2932 x Raj 4037	0.89	0.19	1.20	0.70	0.75	-0.31	-0.08	0.94	2.27	0.70
11	HD 2932 x PBW 175	0.77	1.08	1.19	0.56	0.90*	-0.77	-0.33	1.42	1.10	0.35
12	HD 2932 x HI 1544	-1.71	-2.01*	-2.38**	-1.92**	-2.00**	1.99	0.29	-1.45	1.76	0.65
13	HD 2932 x Raj 4079	3.05**	2.54**	3.14**	3.13**	2.96**	-3.21**	-3.16	-1.97	-2.51	-2.71**
14	HD 2932 x HD 2987	-1.52	-1.71*	-1.61*	-1.63**	-1.62**	3.59**	2.63	1.78	1.47	2.37*
15	HD 2932 x Lok1	-2.90**	-2.91**	-2.55**	-1.66**	-2.50**	-2.26	-1.87	-1.58	0.10	-1.40
16	GW 366 x Raj 4037	2.64**	3.14**	2.98**	0.94	2.42**	0.23	0.50	0.86	-1.11	0.12
17	GW 366 x PBW 175	1.11	0.97	0.94	1.08	1.03*	3.49**	3.11	3.74	1.34	2.92**
18	GW 366 x HI 1544	-2.91**	-3.66**	-3.03**	-1.82**	-2.86**	0.73	-0.03	-0.99	2.44	0.54
19	GW 366 x Raj 4079	-3.21**	-3.62**	-3.50**	-2.61**	-3.24**	0.92	-0.05	-1.74	0.93	0.02
20	GW 366 x HD 2987	-0.97	-0.99	-2.13**	-1.59*	-1.42**	1.49	1.14	0.01	-1.01	0.41
21	GW 366 x Lok1	1.82	1.78*	1.32	1.13	1.51**	-1.58	-2.24	-2.79	-3.24	-2.46*
22	Raj 4037 x PBW 175	-0.27	0.99	0.47	-0.43	0.19	-0.84	2.09	1.10	-2.81	-0.11
23	Raj 4037 x HI 1544	1.41	1.23	1.95**	0.30	1.23**	-1.15	-3.08	-0.34	-2.61	-1.79
24	Raj 4037 x Raj 4079	-3.06**	-2.34**	-1.96**	-0.44	-1.95**	-0.67	3.88	1.38	3.04	1.91
25	Raj 4037 x HD 2987	2.23*	2.73**	2.72**	2.70**	2.59**	-3.47**	-2.48	-2.97	0.60	-2.08*
26	Raj 4037 x Lok1	1.51	-0.72	-1.01	-0.85	-0.27	5.61**	0.89	-0.31	-1.31	1.22
27	PBW 175 x HI 1544	-6.79**	-7.23**	-6.13**	-3.91**	-6.01**	-0.31	-1.18	-1.74	3.71	0.12
28	PBW 175 x Raj 4079	2.90**	1.56	1.54*	0.62	1.65**	-0.65	-4.17*	-3.81	-4.52	-3.29**
29	PBW 175 x HD 2987	3.35**	3.33**	2.81**	2.63**	3.03**	0.75	0.78	-0.95	0.29	0.22
30	PBW 175 x Lok1	1.92	2.47**	1.78**	0.89	1.77**	0.77	1.43	0.81	-0.28	0.68
31	HI 1544 x Raj 4079	3.74**	3.53**	3.13**	1.82**	3.06**	-0.32	-2.36	-1.87	-5.49*	-2.51*
32	HI 1544 x HD 2987	3.28**	3.39**	3.13**	2.47**	3.07**	-0.30	-0.48	0.10	-1.59	-0.57
33	HI 1544 x Lok1	-0.05	0.37	0.46	0.65	0.36	-2.26	0.67	0.37	-0.77	-0.50
34	Raj 4079 x HD 2987	-1.03	0.02	-0.16	-1.05	-0.56	-0.28	3.23	0.63	-4.51	-0.23
35	Raj 4079 x Lok1	0.55	1.31	1.66*	0.60	1.03*	3.27**	1.85	1.13	2.74	2.25*
36	HD 2987 x Lok1	-1.51	-1.45	-1.27	0.36	-0.97*	1.41	1.44	2.98	9.14**	3.74**

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