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COMBINING ABILITY ANALYSIS IN BREAD WHEAT (*TRITICUM AESTIVUM* (L.) EM. THELL) UNDER DIFFERENT ENVIRONMENTAL CONDITIONS

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Abstract

Pooled analysis of 8 genotypes of wheat of diverse origin, their 28 F_1s and 2 checks was carried out in 4 different environments to study the combining ability in bread wheat for grain yield and its component traits. On pooled basis, analysis of variance due to GCA and SCA was significant for all characters revealed difference between parents for GCA and difference between crosses for SCA. Similarly, mean square due to GCA × E was significant for number of effective tillers per plant and flag leaf area revealed influence of environment on GCA. Whereas SCA × E was also significant for number of effective tillers per plant and grain yield per plant revealed influence of environment on SCA. The variance due to GCA was higher than their respective SCA for all characters except number of grains per spike indicating that additive type of gene action played role in the expression of all these traits. Significant GCA effects for grain yield and its component traits were exhibited by the parents HD 2987, Lok 1 and HI 1544. Fourteen crosses recorded showed significant SCA effects for grain yield and related traits.

Introduction

Bread wheat (2n = 6x = 42) an annual self-pollinated crop belonging to *Poaceae* family and *Triticum* genus is most widely consumed cereal crop in India where it meets the basic food requirements of human population. It is popularly known as 'Stuff of life or King of the 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-rainfall areas and in warm, humid to dry, cold environments. In India, area and production of wheat during year 2015 - 2016 were recorded 30.22 million ha and 93.50 million tonnes respectively with an average productivity of 3093 kg/ha (DAC & FW 2016).

Wheat is a thermo sensitive crop mostly grown in temperate environment. However, it is predominantly consumed in tropical and subtropical regions of the world. In subtropical regions it is cultivated in winter season, but it exposed to high temperature stress at the end of the season i.e. at grain filling stage. Exposure to higher temperature (> 35ºC) or heat stress during the grain-filling period reduces the yield and decreases quality. Generation of information on the effect of high temperature stress on various traits may be helpful for developing thermo-tolerance wheat variety. Hence, now breeding for heat tolerance has become an integral component of wheat improvement. For further progress, knowledge of breeding behavior, particularly of combining ability and type of gene action for the various traits is necessary. The estimates of combining ability variances and effects provide useful information regarding the selection of suitable parents for effective hybridization programme and at the same time elucidates the nature and magnitude of different types of gene action. Since, the nature of gene action with genetic architecture of population involved in

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hybridization, it is necessary to evaluate the parents for their combining ability. 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.

According to Braun *et al.* (1996), large scale testing and crossing programmes using diverse gene pool will most likely have high chances of identifying widely adapted germplasm, break genetic linkage and pyramid desired genes that testing in a narrow environmental range restricts genetic diversity in the crossing programmes. Ceccarelli (1989) suggested that environments used to test breeding material often differ widely in their effect on crop yield. By exposing a number of genotypes in a set of contrasting environments, it is possible to identify genotypes with high average yield and low G × E interaction.

Keeping the above fact in mind, the present investigation was carried out predict the performance of these varieties in hybrid combinations for components of grain yield and heat tolerance under four different environments through half diallel crosses and to evaluate the type of gene action involved in yield and its contributing traits.

Materials and Methods

Experimental materials consisting of 8 diverse genotypes (Table 1) selected on the basis of broad range of genetic diversity for major yield components, geographical origin, heat tolerance and their suitability for different yield traits, 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 8 parents and their 28 F_1s were grown in a randomized block design with 3 replications under early sown (E_1), normal sown (E_2), late sown (E_3) and very late sown (E_4) conditions. The environments were created by four different date of sowings (Table 2). Row-to-row and plant-to-plant distances were 30 and 10 cm, respectively in each environment. Recommended plant protection procedures were followed for raising the crop in all the environments.

Table 1. Particulars of wheat parent materials used.

Sl. No.	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. The detail of the four environments created.

Environment	Date of sowing
E_1 (Early sown)	October 27, 2015
E_2 (Normal sown)	November 17, 2015
E_3 (Late sown)	December 07, 2015
E_4 (Very late sown)	December 27, 2015

The observation was recorded on five randomly selected competitive plants from each plot in each replication in case of parents, F_1s and checks in all the four environments separately on 11 distinct morphological characters, except days to 50% flowering and days to maturity, where it was observed on complete plot basis. The data on days to heading, days to maturity, plant height, number of effective tillers per plant, spike length, number of grains per spike, flag leaf area, 1000 grain weight, biological yield per plant, grain yield per plant and harvest index were recorded for statistical analysis.

The mean value of the recorded observation 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), and pooled analysis over environments was done according to method suggested by Singh (1973).

Results and Discussion

A pooled analysis over environments was computed to obtain less biased estimates of the various types of variances and their interactions with the environments is presented in Table 3. The variances for GCA and SCA were highly significant for all the characters revealed difference between parents for GCA and difference between crosses for SCA. Variance for GCA × E significant for number of effective tillers per plant and flag leaf area revealed influence of environment on GCA. Similarly, SCA × E was significant for number of effective tillers per plant and grain yield per plant revealed influence of environment on SCA. Variance for GCA was higher than their respective SCA variance for all the characters except number of grains per spike indicating additive type of gene action played role in the expression of all these traits. Similar finding has been reported by Joshi *et al*. 2002, Sharma *et al*. 2003, Singh and Yadav 2011.

Table 3. Combining ability mean square and error mean square over the environments for different characters.

Sl. No.	Characters	Source							
		Env	GCA	SCA	GCA × E	SCA × E	Pooled Error	GCA Variance	SCA Variance
		[3]	[7]	[28]	[21]	[84]	[280]		
1	Days to flowering	26.10**	27.95**	8.19**	0.49	0.66	1.23	2.07	4.68
2	Days to maturity	298.43**	12.29**	7.29**	2.65	1.79	2.05	24.70	1.79
3	Plant height	269.37**	108.27**	17.09**	2.75	2.24	4.70	22.06	18.13
4	No. of effective tillers per plant	10.82**	4.47**	5.74**	0.39	0.23	0.27	0.88	0.73
5	Spike length	4.52**	3.36**	3.20**	0.11	0.07	0.43	0.34	0.51
6	No. of grains per spike	15.18*	31.13**	39.77**	0.45	0.56	4.81	0.86	22.10
7	Flag leaf area	8.80**	40.23**	41.70**	0.48	0.27	1.32	0.62	6.81
8	1000 grain weight (g)	27.88**	7.45**	25.65**	0.16	0.25	0.85	2.25	1.15
9	Biological yield per plant	404.11**	168.68**	172.59**	3.45	1.61	6.71	33.12	28.34
10	Grain yield per plant	85.82**	13.56**	22.28**	0.65	0.52	0.76	7.09	2.24
11	Harvest index	17.08*	19.49**	14.16**	4.72	3.47	4.53	1.05	2.62

*,** Significant at 5 and 1 per cent, respectively (Model I).

The estimate of general combining ability effects of the parents for 11 characters for individual and pooled environments is presented in Tables 4, 5, 6 and 7.

Table 4. GCA and SCA effects for days to heading, days to maturity and plant height.

S.N.	Genotype	Days to heading					Days to maturity					Plant height				
		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	0.81*	1.12**	1.14**	0.78*	0.96**	-0.19	0.55	0.65	0.38	0.35	2.38**	1.64*	1.91**	3.09**	2.26**
2	GW 366	0.64	0.75*	0.41	0.55	0.59**	0.94*	1.02*	0.82	0.12	0.72**	2.08**	1.28	0.90	1.76**	1.50**
3	Raj 4037	-0.89**	-0.82*	-0.73*	-0.65*	-0.77*	-0.49	-0.22	-0.05	0.15	-0.15	-1.68*	-1.30	-1.16	-1.13*	-1.32*
4	PBW 175	0.18	-0.22	0.41	0.02	0.10	-0.42	-0.65	0.25	-0.32	-0.29	2.10**	1.38	1.47*	0.22	1.30**
5	HI 1544	0.07	-0.22	-0.26	0.12	-0.07	-0.36	0.08	-0.35	-0.68	-0.33	-0.75	-0.35	-0.13	-0.61	-0.46
6	Raj 4079	-0.02	0.05	0.11	-0.02	0.03	-0.42	-0.52	0.02	0.02	-0.23	-3.05**	-2.40**	-2.19**	-2.87**	-2.63*
7	HD 2987	0.57	0.65	1.01**	0.72*	0.74**	1.71**	0.62	0.52	0.15	0.75**	-1.51*	-1.09	-0.79	-0.52	-0.98*
8	Lok1	-1.36**	-1.32**	-2.09**	-1.52**	-1.57*	-0.76	-0.88	-1.85**	0.18	-0.83*	0.42	0.83	-0.01	0.06	0.33
9	HD 2932 × GW 366	1.52	0.49	0.98	2.13*	1.28*	3.44**	2.45	1.14	-0.70	1.58*	1.42	-2.43	-3.69	-2.97	-1.92
10	HD 2932 × Raj 4037	0.72	1.05	2.44*	1.33	1.39**	-0.12	-0.31	2.01	1.93	0.88	-2.16	-1.87	-1.00	0.48	-1.14
11	HD 2932 × PBW 175	0.99	0.45	0.64	1.66	0.94	1.81	1.12	1.38	1.40	1.43*	-2.68	-0.57	-0.58	0.21	-0.91
12	HD 2932 × HI 1544	0.09	-1.21	-1.69	-1.77	-1.15*	-2.26	0.72	0.98	-0.57	-0.28	-2.13	-1.43	-1.00	0.35	-1.05
13	HD 2932 × Raj 4079	-0.14	0.52	-0.06	-1.30	-0.25	-0.86	-2.35	-1.72	-0.27	-1.30*	-1.35	-1.14	-2.18	0.16	-1.13
14	HD 2932 × HD 2987	1.92	1.92	1.71	2.30*	1.96**	-0.66	-1.48	0.78	1.93	0.14	4.08	2.47	2.18	0.84	2.39*
15	HD 2932 × Lok1	3.52**	3.89**	2.81**	2.53**	3.19**	-1.19	-1.31	-1.19	-2.44*	-1.53*	2.59	1.07	2.05	1.69	1.85
16	GW 366 × Raj 4037	-1.44	0.09	-0.82	-0.10	-0.57	-0.92	0.55	1.18	-0.80	0.00	0.76	2.67	2.95	2.98	2.34*
17	GW 366 × PBW 175	0.49	0.49	2.04*	1.56	1.15*	2.01	0.65	1.88	-0.34	1.05	0.03	-0.73	-0.21	0.30	-0.15
18	GW 366 × HI 1544	0.59	1.49	0.04	-0.87	0.31	-1.06	0.25	0.81	0.03	0.01	2.48	1.27	0.46	-0.78	0.86
19	GW 366 × Raj 4079	-0.31	1.22	1.34	1.26	0.88	-2.32	-0.15	0.11	1.33	-0.26	0.69	2.28	-1.19	-0.24	0.39
20	GW 366 × HD 2987	-0.24	-0.71	-0.22	-0.14	-0.33	1.54	2.05	-0.06	0.53	1.02	-1.16	-0.68	-0.17	-1.28	-0.82
21	GW 366 × Lok1	0.69	0.59	-0.79	-0.57	-0.02	2.68*	0.89	-0.36	2.83*	1.51*	-3.94	-3.72	-4.07*	0.25	-2.87**
22	Raj 4037 × PBW 175	1.02	0.39	0.18	0.76	0.59	2.11	-0.11	1.08	2.30	1.34*	4.71*	2.31	2.24	0.12	2.35*
23	Raj 4037 × HI 1544	0.12	1.05	0.51	0.33	0.50	2.04	0.82	0.01	-1.00	0.47	0.21	-0.11	-0.07	-1.24	-0.30
24	Raj 4037 × Raj 4079	0.56	-0.21	0.14	0.46	0.24	2.78*	2.09	1.31	1.63	1.95**	1.02	1.38	0.31	0.12	0.71
25	Raj 4037 × HD 2987	-1.71	-1.15	-0.76	-0.27	-0.97	-3.69**	-0.71	-0.19	-1.84	-1.61*	0.10	-0.73	-0.84	0.33	-0.28
26	Raj 4037 × Lok1	-0.78	0.15	1.01	1.96*	0.59	2.11	0.79	-0.82	2.13	1.05	-0.54	-0.35	1.36	3.68*	1.04
27	PBW 175 × HI 1544	0.06	-0.55	-0.62	0.33	-0.20	-2.69*	-1.75	-0.62	0.13	-1.23	-7.28**	-6.84**	-5.44**	-2.64	-5.55**
28	PBW 175 × Raj 4079	-0.51	0.52	1.34	0.13	0.37	-0.96	-0.48	-0.66	-0.24	-0.58	0.12	1.57	0.88	1.26	0.96
29	PBW 175 × HD 2987	1.56	2.25	1.78	-0.94	1.16*	0.58	2.05	-0.16	-0.70	0.44	0.02	1.53	1.91	2.17	1.41
30	PBW 175 × Lok1	1.82	-0.45	-0.79	-0.37	0.05	-1.62	-0.11	-1.12	-0.07	-0.73	4.69*	5.07*	2.76	-3.06*	2.36*
31	HI 1544 × Raj 4079	0.92	-0.48	1.01	1.70	0.79	1.98	2.79*	0.94	0.80	1.63*	-0.52	-1.25	-1.12	0.38	-0.63
32	HI 1544 × HD 2987	-1.01	-0.41	-0.56	-0.37	-0.59	3.51**	1.65	0.11	-0.67	1.15	2.78	2.97	1.92	3.85*	2.88**
33	HI 1544 × Lok1	-0.41	1.22	1.88	1.53	1.05*	-0.02	0.49	1.14	-1.70	-0.02	0.60	0.54	0.97	1.60	0.93
34	Raj 4079 × HD 2987	-0.91	-0.68	-1.26	-0.24	-0.77	1.24	0.59	0.74	-2.04	0.13	1.18	0.98	0.81	0.80	0.94
35	Raj 4079 × Lok1	1.02	1.29	0.18	-0.34	0.54	1.38	-0.58	-1.22	0.60	0.04	-2.59	-3.31	-2.98	-4.03*	-3.23**
36	HD 2987 × Lok1	0.09	-0.65	0.28	0.26	-0.00	-0.09	2.29	3.61*	2.46*	2.07**	-1.88	-1.44	0.34	-2.35	-1.33

Table 5. GCA and SCA effects for effective tillers per plant, spike length and number of grains per spike.

S.N.	Genotype	No. of effective tillers per plant					Spike length					No. of grains per spike				
		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	0.08	-0.18	-0.37*	-0.24	-0.18*	0.21	0.38	0.29	0.24	0.28**	-0.07	-0.16	-0.39	-0.17	-0.20
2	GW 366	-0.18	-0.12	-0.10	-0.26	-0.16*	-0.10	-0.27	-0.17	-0.11	-0.16	0.77	0.57	0.78	1.09	0.80*
3	Raj 4037	-0.22	-0.13	0.27	0.05	-0.01	-0.46*	-0.61**	-0.42*	-0.23	-0.43*	1.43*	1.38	1.06	1.56*	1.36**
4	PBW 175	-0.65**	-0.39*	-0.13	-0.17	-0.33*	0.18	0.15	0.24	0.22	0.19*	1.37*	1.42*	1.77**	1.56*	1.53**
5	HI 1544	-0.47**	-0.31	-0.37*	-0.34*	-0.37*	0.30	0.43	0.15	0.07	0.24*	1.97**	2.18**	2.39**	2.17**	2.18**
6	Raj 4079	0.01	0.07	0.08	0.25	0.10	0.37	0.34	0.30	0.18	0.30**	-0.50	-0.66	-0.37	-0.91	-0.61
7	HD 2987	0.58**	0.60**	0.52**	0.45**	0.54**	-0.43*	-0.27	-0.34	-0.30*	-0.33*	-2.06**	-2.15**	-2.21**	-2.58**	-2.25*
8	Lok1	0.85**	0.45**	0.10	0.26	0.42**	-0.08	-0.14	-0.05	-0.07	-0.08	-2.91**	-2.58**	-3.04**	-2.72**	-2.81*
9	HD 2932 × GW 366	-2.19**	-1.17*	-1.52**	-1.37**	-1.56**	0.09	-0.09	0.37	0.49	0.21	3.99	3.03	3.46	4.13*	3.66**
10	HD 2932 × Raj 4037	-0.01	0.01	-0.02	0.40	0.09	-0.55	-0.81	-0.08	-0.18	-0.41	2.70	1.83	0.74	0.16	1.36
11	HD 2932 × PBW 175	-0.74	-0.73	-0.15	0.01	-0.40	0.26	-0.03	-0.59	-0.36	-0.18	-4.12*	-4.18	-3.46	-2.76	-3.63**
12	HD 2932 × HI 1544	-3.53**	-3.38**	-2.68**	-2.27**	-2.97**	-0.71	-0.88	-0.77	-0.68	-0.76*	-1.08	-1.22	-0.91	-1.00	-1.05
13	HD 2932 × Raj 4079	-0.78	-0.57	-0.42	-0.40	-0.54*	-1.07	-1.40*	-0.96	-1.09*	-1.13**	2.93	3.18	3.96*	2.08	3.04**
14	HD 2932 × HD 2987	2.96**	1.31**	1.15*	1.70**	1.78**	-0.62	0.20	-0.16	-0.02	-0.15	-0.73	-0.70	-0.58	-0.99	-0.75
15	HD 2932 × Lok1	0.50	-0.23	1.00*	-0.16	0.28	0.54	1.20	0.32	0.04	0.53	-2.17	-2.49	-1.76	-2.85	-2.32*
16	GW 366 × Raj 4037	1.45**	1.41**	1.14*	0.54	1.14**	-0.87	-0.77	-0.57	-0.67	-0.72*	-0.57	-0.67	-1.82	-0.36	-0.86
17	GW 366 × PBW 175	-2.79**	-3.16**	-2.41**	-2.06**	-2.61**	-0.00	-0.01	0.36	0.25	0.15	-1.44	-1.36	-1.08	-0.45	-1.08
18	GW 366 × HI 1544	0.26	0.32	0.38	0.25	0.30	-1.31*	-1.47*	-1.50*	-1.31**	-1.40**	-0.64	-0.68	-0.93	-1.29	-0.89
19	GW 366 × Raj 4079	0.49	0.83	0.35	0.42	0.52*	-0.43	-0.34	-0.82	-0.56	-0.54	-0.83	-0.58	-0.22	-2.58	-1.05
20	GW 366 × HD 2987	0.85*	0.75	0.22	0.41	0.56*	1.54*	1.40*	1.29*	0.81	1.26**	4.95*	5.28*	4.96*	4.72*	4.98**
21	GW 366 × Lok1	1.21**	-0.51	0.12	-0.38	0.11	-1.29*	-1.35*	-1.03	-0.84	-1.13**	-5.78**	-6.10**	-6.25**	-6.25**	-6.09**
22	Raj 4037 × PBW 175	-0.57	-0.65	0.20	-0.58	-0.40	-0.15	-0.15	0.30	-0.03	-0.01	-0.35	-0.36	0.45	-1.87	-0.53
23	Raj 4037 × HI 1544	0.54	0.34	0.06	0.22	0.29	-0.16	-0.35	-0.24	-0.31	-0.27	-0.85	-0.99	-1.43	-0.68	-0.99
24	Raj 4037 × Raj 4079	-0.14	-0.10	-0.24	-0.25	-0.18	0.13	-0.08	0.01	0.06	0.03	2.57	2.79	2.00	3.06	2.61*
25	Raj 4037 × HD 2987	-0.71	0.26	-0.06	0.30	-0.05	-0.17	-0.47	-0.26	0.16	-0.18	5.09*	5.31*	4.52*	4.73*	4.91**
26	Raj 4037 × Lok1	-0.51	-1.46**	-0.86	-0.52	-0.84**	0.45	0.42	0.44	0.58	0.48	2.09	2.90	3.37	3.27	2.91**
27	PBW 175 × HI 1544	-0.39	-0.93	-1.47**	-0.97	-0.94**	0.44	0.74	0.74	0.94*	0.71*	0.71	0.50	0.75	-0.47	0.37
28	PBW 175 × Raj 4079	-0.21	0.52	0.14	-0.16	0.07	-0.36	-0.33	-0.20	-0.41	-0.32	-0.05	0.02	-1.50	-1.60	-0.78
29	PBW 175 × HD 2987	1.86**	1.71**	1.95**	1.27*	1.70**	-0.68	-1.02	-0.84	-0.90*	-0.86**	-0.86	-0.96	-0.40	-2.40	-1.15
30	PBW 175 ×Lok1	1.39**	0.50	0.67	1.22*	0.95**	-0.29	-0.43	-0.20	0.05	-0.22	-0.94	-0.73	-2.05	-1.50	-1.30
31	HI 1544 × Raj 4079	0.43	-0.03	0.74	0.40	0.38	-0.28	0.58	-0.31	-0.26	-0.07	-1.04	-1.18	-0.82	-0.99	-1.01
32	HI 1544 × HD 2987	-0.93*	-1.32**	-0.46	-0.47	-0.80**	-0.87	-1.34*	-1.05	-0.57	-0.96**	2.22	2.07	0.97	1.05	1.58
33	HI 1544 × Lok1	-0.15	0.85	0.14	0.37	0.30	1.81**	1.66*	1.82**	1.31**	1.65**	-3.20	-1.83	-1.68	-2.84	-2.39*
34	Raj 4079 × HD 2987	-1.07*	-1.20*	-0.25	-0.51	-0.76**	0.09	0.14	-0.13	-0.34	-0.06	-3.81	-3.70	-3.20	-4.15*	-3.72**
35	Raj 4079 × Lok1	0.17	-0.03	-0.49	-0.48	-0.21	-1.73**	-2.03**	-1.53*	-1.18**	-1.62**	-1.43	-2.65	-2.89	-2.12	-2.27*
36	HD 2987 × Lok1	-1.88**	-1.45**	-1.27*	-0.70	-1.32**	0.15	0.17	0.41	0.09	0.20	-0.87	-1.35	-2.00	-1.82	-1.51

Table 6. GCA and SCA effects for flag leaf area, 1000 grain weight and biological yield per plant.

S.N.	Genotype	Flag leaf area					1000 grain weight (g)					Biological yield per plant				
		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	0.04	0.09	0.18	0.31	0.15	-0.42	-0.36	-0.41	-0.30	-0.37*	-1.23	-1.46	-0.82	0.28	-0.81*
2	GW 366	2.57**	1.88**	1.90**	1.41**	1.94**	0.66*	0.73*	0.65*	1.03**	0.77**	-1.44	-1.21	-1.27	-1.73**	-1.42*
3	Raj 4037	-0.49	-0.33	-0.21	-0.22	-0.31	0.16	0.22	0.17	0.31	0.22	-1.44	-1.78*	-1.50	-1.40*	-1.53*
4	PBW 175	0.11	0.19	0.13	0.36	0.19	0.24	0.31	0.24	0.30	0.27*	-1.27	-0.97	-0.64	-0.44	-0.83*
5	HI 1544	-0.14	0.03	-0.13	0.01	-0.06	0.15	0.12	0.16	0.15	0.14	1.27	0.77	0.91	0.49	0.86*
6	Raj 4079	0.28	0.23	0.31	0.43	0.31	-0.45	-0.49	-0.43	-0.64*	-0.50*	-1.76*	-1.78*	-1.48	-0.80	-1.46*
7	HD 2987	-0.70*	-0.54	-0.68*	-0.42	-0.59*	-0.33	-0.27	-0.31	-0.75**	-0.41*	5.18**	5.67**	4.14**	3.14**	4.53**
8	Lok1	-1.67**	-1.54**	-1.48**	-1.88**	-1.64*	0.01	-0.26	-0.08	-0.10	-0.11	0.70	0.76	0.66	0.48	0.65
9	HD 2932 × GW 366	-6.23**	-5.51**	-5.68**	-4.98**	-5.60**	-0.66	-0.73	-0.66	-0.54	-0.65	2.60	3.19	2.40	1.05	2.31
10	HD 2932 × Raj 4037	-2.45*	-2.56*	-2.85**	-2.65*	-2.63**	2.86**	2.86**	2.77**	1.39	2.47**	2.26	0.08	2.08	0.47	1.22
11	HD 2932 × PBW 175	2.55**	2.72*	2.38*	2.30*	2.49**	3.51**	3.51**	3.41**	3.10**	3.38**	2.52	3.01	2.28	0.60	2.10
12	HD 2932 × HI 1544	4.07**	4.18**	3.91**	3.90**	4.01**	-5.72**	-5.79**	-5.59**	-4.97**	-5.52**	-6.07*	-5.55*	-5.12*	-6.53**	-5.82**
13	HD 2932 × Raj 4079	1.01	-0.08	0.17	0.88	0.49	0.40	0.45	0.37	0.08	0.32	10.65**	9.70**	9.58**	9.74**	9.92**
14	HD 2932 × HD 2987	-0.19	-0.22	-0.31	-0.44	-0.29	2.87**	2.87**	2.79**	2.67**	2.80**	-7.17**	-7.26**	-5.99*	-5.35**	-6.44**
15	HD 2932 × Lok1	-0.68	-0.73	1.00	-0.41	-0.20	-4.61**	-4.43**	-4.41**	-3.79**	-4.31**	-5.20*	-5.05	-4.79*	-4.52*	-4.89**
16	GW 366 × Raj 4037	-0.10	0.69	0.29	1.06	0.49	0.31	0.25	0.30	0.32	0.29	5.98*	7.01**	6.27*	3.12	5.60**
17	GW 366 × PBW 175	1.42	2.37*	2.06	2.58*	2.11**	0.84	0.79	0.81	0.91	0.84*	-0.02	-0.31	-0.11	1.79	0.34
18	GW 366 × HI 1544	-1.37	-0.62	-0.71	-0.07	-0.69	-2.13*	-2.14*	-2.08*	-1.85*	-2.05**	-7.81**	-9.09**	-7.17**	-6.59**	-7.67**
19	GW 366 × Raj 4079	-4.17**	-3.28**	-2.53*	-2.86**	-3.21**	0.44	0.49	0.41	0.83	0.54	-8.39**	-9.31**	-7.97**	-7.74**	-8.35**
20	GW 366 × HD 2987	-3.24**	-2.56*	-2.55*	-2.06	-2.60**	3.44**	3.46**	3.33**	2.57**	3.20**	-4.03	-4.22	-5.86*	-3.76*	-4.47**
21	GW 366 × Lok1	3.78**	4.71**	4.24**	2.15*	3.72**	0.53	0.81	0.61	0.81	0.69	5.94*	6.77*	5.98*	5.56**	6.06**
22	Raj 4037 × PBW 175	7.89**	8.11**	7.57**	7.57**	7.78**	0.54	0.50	0.52	0.88	0.61	-0.01	0.27	-0.04	0.51	0.18
23	Raj 4037 × HI 1544	-1.58	-1.79	-1.82	-1.68	-1.72**	3.12**	3.23**	3.02**	1.33	2.68**	3.91	5.76*	4.71	1.86	4.06**
24	Raj 4037 × Raj 4079	-1.08	-1.04	-1.38	-1.18	-1.17*	-2.51**	-2.52**	-2.47**	-1.75*	-2.31**	-7.03**	-9.06**	-6.30*	-3.08	-6.37**
25	Raj 4037 × HD 2987	1.69	1.59	1.41	1.41	1.52**	-1.84*	-1.93*	-1.81*	-0.89	-1.62**	9.73**	10.11**	10.35**	7.14**	9.33**
26	Raj 4037 × Lok1	-2.06*	-2.29*	-2.48*	-1.77	-2.15**	-1.35	-1.11	-1.22	-0.74	-1.10*	-1.15	-2.80	-2.39	-1.64	-2.00
27	PBW 175 × HI 1544	0.84	0.81	0.82	0.72	0.80	1.12	1.19	1.08	1.60	1.25**	-16.37**	-17.03**	-14.80**	-12.64**	-15.21**
28	PBW 175 × Raj 4079	2.46*	1.71	2.42*	2.33*	2.23**	-0.22	-0.18	-0.22	0.53	-0.02	7.51**	8.28**	6.91**	4.99**	6.92**
29	PBW 175 × HD 2987	1.61	1.61	1.63	1.34	1.55**	-2.82**	-2.93**	-2.76**	-2.40**	-2.73**	7.26**	7.15**	7.79**	7.00**	7.30**
30	PBW 175 × Lok1	-4.12**	-4.32**	-4.30**	-3.79**	-4.13**	-2.24**	-2.01*	-2.09*	-1.50	-1.96**	3.74	4.37	3.91	2.55	3.64**
31	HI 1544 × Raj 4079	3.52**	3.71**	3.46**	2.24*	3.23**	3.42**	2.66**	3.32**	3.07**	3.12**	8.89**	10.90**	9.38**	8.68**	9.46**
32	HI 1544 × HD 2987	-2.29*	-2.53*	-2.29*	-2.37*	-2.37**	-0.44	-0.39	-0.45	-1.63	-0.73	8.30**	8.71**	7.77**	7.66**	8.11**
33	HI 1544 × Lok1	-2.00*	-2.22*	-2.15*	-1.59	-1.99**	-0.67	-0.32	-0.56	0.06	-0.37	1.69	0.19	0.46	3.39	1.43
34	Raj 4079 × HD 2987	-3.44**	-3.47**	-3.41**	-3.49**	-3.45**	2.98**	3.06**	2.90**	0.62	2.39**	-2.68	-4.09	-1.91	-0.08	-2.19
35	Raj 4079 × Lok1	-0.75	-0.70	-1.01	-0.29	-0.69	3.56**	4.00**	3.56**	2.32**	3.36**	-1.13	1.85	2.87	-0.52	0.77
36	HD 2987 × Lok1	3.01**	2.95**	2.73*	3.28**	2.99**	-2.36**	-2.14*	-2.22**	-2.11*	-2.21**	-5.30*	-5.14	-5.53*	-5.64**	-5.41**

Table 7. 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 × 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 × 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 × 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 × 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 × 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 × 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 × Lok1	-2.90**	-2.91**	-2.55**	-1.66**	-2.50**	-2.26	-1.87	-1.58	0.10	-1.40
16	GW 366 × 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 × 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 × 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 × 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 × 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 × Lok1	1.82	1.78*	1.32	1.13	1.51**	-1.58	-2.24	-2.79	-3.24	-2.46*
22	Raj 4037 × 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 × 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 × 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 × 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 × Lok1	1.51	-0.72	-1.01	-0.85	-0.27	5.61**	0.89	-0.31	-1.31	1.22
27	PBW 175 × 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 × 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 × 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 × Lok1	1.92	2.47**	1.78**	0.89	1.77**	0.77	1.43	0.81	-0.28	0.68
31	HI 1544 × 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 × 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 × Lok1	-0.05	0.37	0.46	0.65	0.36	-2.26	0.67	0.37	-0.77	-0.50
34	Raj 4079 × 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 × Lok1	0.55	1.31	1.66*	0.60	1.03*	3.27**	1.85	1.13	2.74	2.25*
36	HD 2987 × Lok1	-1.51	-1.45	-1.27	0.36	-0.97*	1.41	1.44	2.98	9.14**	3.74**

General combining effect revealed that Raj 4037 in E_1 and in pooled and Lok 1 in remaining three environments showed highest GCA effect for days to heading. For days to maturity, Lok 1 in E_3 and in pooled was the good general combiner. None of the parents had significant GCA effects in E_1, E_2 and E_4 for early maturity. Parent Raj 4079 for plant height, HI 1544 for number of grains per spike, HD 2987 for biological yield per plant and grain yield per plant was the consistently good general combiner in all the four environments including pooled. Highest GCA effects for number of effective tillers per plant was observed in parent HD 2987 in all the 4 environments. In addition, parent Lok 1 was also the best general combiner in E_1 and E_2. The highest positive GCA effects was recorded for parent Raj 4079 in pool, HI 1544 in E_1, Raj 4079 in E_2 and Raj 4079 in E_4 for spike length. None of the parent had significantly positive GCA effects E_3. For flag leaf area, parent HI 1544 in E_4 and GW 366 in remaining environment including pooled was the good general combiner. Parent Raj 4037 in E_1, E_2, pooled and parent GW 366 in E_4 showed highest GCA effect for 1000-grain weight. The highest GCA effects for harvest index were exhibited by parent GW 366 in E_2 and Raj 4037 in E_4.

The data on GCA effects of different parents indicated that the effects varied significantly for different characters and in different environments. Based on estimates of GCA effects on pooled basis for various characters, parents HD 2987, Lok 1 and HI 1544 were good general combiners for grain yield in pool. 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 had resulted into hybrids expressing useful heterosis for various traits.

Sprague and Tatum (1942) reported that the specific combining ability is 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 from Tables 4 to 7.

Among the hybrids on pooled basis, Crosses Raj 4037 × HD 2987 showed highest SCA effects in negative direction for days to heading and days to maturity, whereas showed highest SCA effects in positive direction for number of grains per spike. Crosses PBW 175 × HI 1544 followed by GW 366 × Lok 1 and Raj 4079 × Lok 1had highest SCA effects in negative direction for plant height. Similarly, for number of effective tillers per plant, crosses PBW 175 × HD 2987 followed by Raj4037 × Raj 4079, HD 2932 × HD 2987 showed highest SCA effects. The cross GW 366 × HD 2987, HI 1544 × Lok 1 and PBW 175 × HI 1544 possessed highest positive SCA effects for spike length. For flag leaf area, the highest SCA effects were exhibited by the cross Raj 4037 × PBW 175 followed by HD 2932 × HI 1544, GW 366 × PBW 175 and GW 366 × Lok 1.SCA effects were maximum for 1000-grain weight in the crosses HD 2932 × PBW 175 followed by Raj 4079 × Lok 1. Cross HD 2932 × Raj 4079 followed by Raj 4037 × HD 2987 had highest SCA effects for biological yield per plant. The highest value of SCA effects for grain yield per plant were recorded in the crosses HI 1544 × HD 2987 followed by HI 1544 × RAJ 4079, PBW 175 × HD 2987. SCA effects were maximum for harvest index in the cross GW 366 × Lok 1.

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 high 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 segregates in segregating generations.

In the present investigation, parents HD 2987, Lok 1 and HI 1544 were good general combiners for grain yield over different environments. Therefore, these parents offer the best possibilities of exploitation for development of improved high yielding lines with heat tolerance in bread wheat. The cross HI 1544 × HD 2987 was the best specific combiner for grain yield per plant followed by HI 1544 × RAJ 4079, PBW 175 × HD 2987. They produced significant and desirable SCA effects and heterosis for most of the traits studied indicating potential for exploiting hybrid vigor in breeding programme.

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