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Combining ability analysis for yield and some of its associated characters in late sown condition in bread wheat (*Triticum aestivum* L. em. Thell)

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Abstract
The present study was conducted to assess the general combining ability effects of parents and specific combining ability effects of crosses for yield and yield related traits. 42 F_1s developed by line x tester were evaluated. The ratio of sca/gca variance revealed that there was preponderance of additive gene action in the expression of yield and yield contributing characters. The maximum GCA effects were exhibited by parent DBW-179 for grain yield per plant (3.83) and harvest index (8.33) in late sown environment. The maximum SCA effects (3.20) were depicted by cross KBRL 82-2 x RAJ 4079 in late sown environment for this trait.

Keywords: general combining ability, specific combining ability, bread wheat

Introduction
Bread wheat [*Triticum aestivum* (L.) em. Thell] is the most important food crop in the world which belongs to genus *Triticum* and family Poaceae. The species of genus *Triticum* to which the cultivated wheat belongs are divided into diploid, tetraploid and hexaploid groups, with chromosome number 2n=14, 28 and 42, respectively. These 21 chromosomes of the hexaploid wheat have been divided into seven homeologous group, each homeologous group having a partially homologous chromosome from each of the A, B, and D genomes. Plant breeders are always interested in production of superior wheat varieties by using good general combining genotypes in crossing programs and selecting promising transgressive segregants from resulting crosses for grain yield and its related traits (Akbar *et al.*, 2009) [1]. It plays a key role to pick the parents of choice for crosses and it assists to take decision about breeding approaches to be followed to select promising genotypes (Salgotra *et al.*, 2009) [17]. Line × Tester analysis, is an important mating design for envisaging the general combining ability (GCA) of parental lines and choosing the appropriate parents and their subsequent F_1 crosses with high specific combining ability (SCA).

Method and material
The experimental material comprised of seventeen wheat genotypes (14 lines and 3 testers) and two check varieties *viz.*, MP 3288 and HI 1544. The genotypes were selected on the basis of their origin, adaptability, diversity and morpho-physiological characters *viz.*, earliness, high yield potential and heat tolerance. These genotypes were crossed in Line × Tester design to develop a total forty-two crosses during *rabi* 2016-17. All the 61 genotypes (17 parents, 42 crosses and 2 checks) were evaluated in a randomized block design with three replications in three different environments during *rabi* 2017-18 at Department of Plant Breeding and Genetics, Rajasthan College of Agriculture (RCA), MPUAT, Udaipur. Each genotype was accommodated in one row plot of 3 meter length. Row to row and plant to plant distances were 22.5 cm and 10 cm, respectively. The combining ability analysis for individual environment as well as over environments was performed to determine the general and specific combining ability effects for line x tester mating design was performed as per method suggested by Kempthorne (1957) [11].

Result and discussion
The analysis of variance in each environment revealed that mean squares due to general combining ability (GCA) lines were significant for all the characters in late sown environment while mean squares due to general combining ability (GCA) testers were significant for all the characters in late sown environment except spike length and biological yield per plant in late

Sown environment. Likewise, mean squares due to specific combining ability (SCA) l x t were significant for all the characters in late sown environment except 1000-grain weight.

1. Number of effective tillers per plant
Among 17 parents, only one parent KBRL 82-2 exhibited significant GCA effects (2.12) for number of effective tillers per plant in late sown environment. Among 28 crosses, 4 crosses exhibited significant positive SCA effects in late sown environment. The cross DBW-93 x RAJ 4120 was found maximum significant and positive SCA effects (2.00) in late sown environment for this trait.

2. Spike length
The significant positive GCA effects (0.92) were expressed by line PBW-107 in late sown environment. While, 2 crosses HPW-360 x RAJ 4120 (1.93) and VL 1003 x RAJ 4120 (1.59) were exhibited significant positive SCA effects in late sown environment.

3. Number of spikelets per plant
The positive, significant and maximum GCA effects (44.22) were expressed by line KBRL 82-2 in late sown environment for number of spikelets per plant. The 4 crosses in late sown environment showed significant positive magnitude of SCA effect. The maximum SCA effects (40.56) were observed by PBW-701 x RAJ 4120 in late sown environment for this character.

4. Length of awns
The positive and significant GCA effects were recorded by 4 parents in late sown environment for length of awns. Line DBW-129 showed significant and positive GCA effects (0.47) in late sown environment. 3 crosses in late sown environment showed significant positive SCA effects. The maximum positive and significant SCA was observed by HPW-368 x RAJ 4120 (1.62) in late sown environment for this trait.

5. Number of grains per spike
The positive and significant GCA effects for number of grains per spike were expressed by 3 parents. The positive significant magnitude of GCA effects were maximum for three lines, KBRL 82-2 (5.24) followed by PBW-701 (3.57) and GW-463 (2.68) in late sown environment. Cross HPW-360 x RAJ 4079 showed significant positive SCA effects (4.02) in late sown environment for number of grains per spike.

6. Flag leaf area
Line DBW-17 expressed positive and significant GCA effects (4.69) followed by DBW-179 (2.51) and HUW-677 (2.11) in late sown environment for flag leaf area. The 2 crosses, DBW-129 x RAJ 4120 (4.69) and HS 547 x RAJ 4037 (3.39) in late sown environment exhibited significant positive SCA effects for this trait.

7. 1000- grain weight
The 5 parents exhibited significant positive GCA effects in late sown environment. The GCA effects were positive and significant by line DBW-17 (2.61) followed by DBW-129 (2.42) and DBW-179 (2.31) in late sown environment. None of the crosses showed significant positive SCA effects.

8. Biological yield per plant
The significant positive GCA effect for biological yield per plant was exhibited by 4 parents in late sown environment. The maximum significant positive GCA effects (3.92) were showed by HPW 360 in late sown environment. Significant positive SCA effects were exhibited by 3 crosses in late sown environment. The maximum SCA effects (3.33) were exhibited by cross DBW-129 x RAJ 4120 in late sown environment for this trait.

9. Grain yield per plant
Seven parents were exhibited significant positive GCA effects for grain yield per plant. The maximum GCA effects (3.83) were exhibited by parent DBW-179 in late sown environment. 7 crosses showed significant positive SCA effects in late sown environment for grain yield per plant. The maximum SCA effects (3.20) were depicted by cross KBRL 82-2 x RAJ 4079 in late sown environment for this trait.

10. Harvest index
Among the parents, 5 parents exhibited significant positive GCA effects in late sown environment. The parent DBW 179 in late sown environment showed maximum GCA effects (8.33) for harvest index. The significant positive SCA effects were exhibited by 4 crosses in late sown environment. Significant positive SCA effects (6.25) were exhibited by cross HPW-368 x RAJ 4079 in late sown environment for this trait.

Similar findings were obtained in earlier by Kumar *et al.* 2011 [13], Punia *et al.* 2011 [15], Jain and Sastry 2012 [8], Srivastava *et al.* 2012 [19], Desale and Mehta, 2013 [5]; Barot *et al.* 2014 [3], Dholariya *et al.* 2014 [6], Lohithaswa *et al.* 2014 [14], Kalhoro *et al.* 2015 [9], Kandil *et al.* 2016 [10], Verma *et al.* 2016 [20], Kumar *et al.* 2017 [12], Choudhary *et al.* 2018 [4] and Ingle *et al.* 2018 [7].

Table 1: Analysis of variance for combining ability

SN	Characters	Rep	Genotype	GCA T	GCA Lines	SCA L X T	Error
1	Number of effective tillers per plant	0.59	4.72**	4.67*	5.85**	4.97**	1.17
2	Spike length (cm)	0.02	3.16*	0.9	2.29*	4.05**	1.1
3	Number of spikelets per plant	286.17	1634.2**	1666.04**	2179.63**	1465.98**	301
4	Length of awns (cm)	0.01	1.65*	1.59*	1.79**	1.43**	0.37
5	Number of grains per spike	5.97	63.97**	38.17*	97.88**	15.95**	8.06
6	Flag leaf area (cm2)	0.39	24.57**	25.39*	55.36**	11.68**	5.85
7	1000-grain weight (g)	5.75	18.87*	40.96**	36.42**	8.2	5.22
8	Biological yield per plant (g)	2.09	21.47**	5.71	41.95**	13.74**	3.9
9	Grain yield per plant (g)	0.32	19.15**	6.04**	45.08**	10.56**	0.95
10	Harvest index (%)	0.7	78.33**	31.72*	175.03**	49.21**	7.66

Table 2: Abstract table of GCA and SCA effects for number of effective tillers per plant, spike length, number of spikelets per plant, length of awns and number of grains per spike in late sown environment

S.no.	Genotype	Number of effective tillers per plant	Spike length	Number of spikelets per plant	Length of Awns	Number of grains per spike
1	RAJ 4120	0.33	0.02	6.06	-0.18	-0.93
2	RAJ 4037	0	0.13	0.46	-0.03	-0.05
3	DBW-129	0.34	-0.35	3.19	0.47*	0.57
4	DBW-17	0.34	0.15	4.37	-0.06	1.24
5	DBW-93	0.45	0.31	11.43	0.63**	-0.32
6	HPW-368	0.12	-0.47	2.99	0.13	-1.65
7	DBW-179	0.12	0.2	5.15	0.64**	0.57
8	KBRL 82-2	2.12**	0.65	44.22**	-0.48*	5.24**
9	GW-463	-0.99**	-0.58	-16.44**	-0.31	2.68**
10	HUW-677	0.12	-0.1	-4.4	0.44*	-5.21**
11	HPW-360	-0.77*	0.46	-6.22	-0.14	1.9
12	PBW-701	-0.55	0.92*	-6.85	-0.70**	3.57**
13	DBW-129 x RAJ 4120	-0.56	-0.69	0.97	-0.05	0.93
14	DBW-17 x RAJ 4120	1.44	1.31	26.35*	-1.19**	-0.07
15	DBW-93 x RAJ 4120	2.00**	-1.36	33.44**	-0.04	-0.52
16	HPW-368 x RAJ 4120	-1	-0.91	-23.11	1.62**	0.15
17	HS-595 x RAJ 4120	0	0.64	-6.81	-0.14	-0.74
18	HUW-677 x RAJ 4120	-2.00**	0.72	-25.28*	0.15	-0.96
19	VL-1003 x RAJ 4120	1	1.59*	-4.51	-0.72	0.15
20	HPW-360 x RAJ 4120	-1.44	1.93**	-24.70*	-0.28	-1.07
21	PBW-701 x RAJ 4120	1.67*	0.03	40.56**	0.41	1.6
22	DBW-179 x RAJ 4037	-0.33	0.31	-13.04	0.13	2.38
23	GW-463 x RAJ 4037	-0.89	0.75	-12.97	0.24	-2.06
24	HS-547 x RAJ 4037	0.33	0.09	6.91	-0.05	0.05
25	HUW-677 x RAJ 4037	1.67*	-0.39	22.96	-0.01	-1.17
26	DBW-17 x RAJ 4079	-1.89*	-0.34	-28.17*	0.93*	0.69
27	HPW-368 x RAJ 4079	0.67	0.93	18.22	-0.53	-3.09
28	KBRL 82-2 x RAJ 4079	-1.33	0.16	-27.01*	-0.15	-0.64
29	VL-1003 x RAJ 4079	0.33	-0.73	13.62	1.33**	-2.42
30	HPW-360 x RAJ 4079	1.89*	-2.15**	30.07*	0.24	4.02*

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

Table 3: Abstract table of GCA and SCA effects for flag leaf area, 1000-grain weight, biological yield per plant, grain yield per plant and harvest index in late sown environment

SN	Genotype	Flag leaf area	1000-grain weight	Biological yield per plant	Grain yield per plant	Harvest index
1	RAJ 4120	0.48	1.09**	-0.38	-0.36*	-0.63
2	RAJ 4037	0.42	-0.82*	0.36	0.40*	0.99*
3	DBW-129	2.09*	2.42**	2.03**	1.51**	1.88
4	DBW-17	4.69**	2.61**	1.07	1.98**	5.33**
5	DBW-93	-3.81**	-2.89**	-2.71**	-3.01**	-6.12**
6	HPW-368	0.48	0.96	1.09	1.21**	2.44*
7	DBW-179	2.51**	2.31**	2.65**	3.83**	8.33**
8	KBRL 82-2	0.79	0.97	1.72*	0.96**	1.21
9	GW-463	-2.38**	-1.55	-2.55**	-2.20**	-4.23**
10	HUW-677	2.11*	-0.17	0.04	-0.13	-0.12
11	HPW-360	-2.35**	2.61**	3.92**	3.45**	5.21**
12	PBW-701	-3.50**	-1.61*	-2.66**	-2.76**	-5.45**
13	DBW-129 x RAJ 4120	4.69**	0.25	3.33*	2.78**	4.07*
14	DBW-17 x RAJ 4120	-0.36	-0.87	-2.12	0.84	5.96**
15	DBW-93 x RAJ 4120	-0.13	-1.54	0.78	0.59	1.07
16	HPW-368 x RAJ 4120	1.31	1.85	-0.91	-0.91	-1.48
17	HS-595 x RAJ 4120	0.92	0.79	2.66	1.54*	0.63
18	HUW-677 x RAJ 4120	0.36	-0.09	1.65	1.49*	3.07
19	VL-1003 x RAJ 4120	-0.56	-0.01	1.5	0.78	0.18
20	HPW-360 x RAJ 4120	-0.99	1.13	-0.63	-0.8	-1.6
21	PBW-701 x RAJ 4120	0.1	-2.32	-0.72	-0.53	-0.93
22	DBW-179 x RAJ 4037	-0.4	0.68	2.23	2.65**	3.67
23	GW-463 x RAJ 4037	-1.28	0.38	2.77*	1.82**	2.56
24	HS-547 x RAJ 4037	3.39*	-0.18	1.97	1.33	2.01
25	HUW-677 x RAJ 4037	-0.22	1.16	0.01	0.09	0.45
26	DBW-17 x RAJ 4079	-0.69	2.49	2.14	1.09	0.7
27	HPW-368 x RAJ 4079	-0.63	-1.52	1.79	2.73**	6.25**
28	KBRL 82-2 x RAJ 4079	0.41	-1.2	2.83*	3.20**	5.81**
29	VL-1003 x RAJ 4079	0.19	2.29	-1.27	-1.13	-2.08
30	HPW-360 x RAJ 4079	1.72	-1.84	0.8	1.13	2.14

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

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