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Research Article

Combining ability analysis for yield and its components in bread wheat (*Triticum aestivum* L.)

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Abstract
Combining ability was analyzed using a line × tester (8 × 4) analysis in bread wheat (*Triticum aestivum* L.). Combining ability analysis, revealed the importance of both additive as well as non-additive genetic variances for control of various traits. The potence ratio (σ^2gca/ σ^2sca) suggested the preponderance of additive gene actions for number of effective tillers per plant, length of main spike, number of spikelets per main spike, number of grains per main spike and 100-grain weight and non-additive gene actions for rest of the traits. Parent MP 3288 was the best general combiner, whereas crosses MP 3288 × GW 496 and MP 3288 × GW 366 were found to be the best specific combiners for grain yield per plant and some of the yield contributing traits. However, on the basis of *per se* performance and significant SCA effects for grain yield per plant and some of its important components, hybrids MP 3288 x GW 366, MP 3288 x HI 1544 and GW 173 x GW 451 were considered to be the most promising for further exploitation in breeding programmes.

Key words
Triticum aestivum L., General combining ability, Specific combining ability, additive genetic variance, non-additive genetic variance.

Introduction

Since the dawn of civilization, wheat has been a major crop to feed the human society in every part of the world. Wheat was used not only for local feeding but also in trade for exchange of goods. It is believed that wheat developed from a type of wild grass native to the arid lands of Asia Minor. Cultivation of wheat is thought to have originated in Euphrates Valley as early as 10,000 B.C., making it one of the world's oldest cereal crops. In the Mediterranean region, centuries before recorded history, wheat was an important food. Wheat played such a dominant role in the Roman Empire that at the time it often was referred to as a "Wheat Empire". Wheat is a unique gift of nature to the mankind as it contains starch (60-68%), protein (6-21%), fat (1.5-2.0%), cellulose (2.0-2.5%), minerals (1.8%) and vitamins (Das, 2008). Bread wheat is consumed in India mainly as chapatti. Its other preparations include bread, biscuits, noodles, cakes, pizzas, doughnuts, etc. It is also milled as semolina, locally known as rava or sooji, to prepare different food products like *upma, halwa etc*.

The combining ability study is a powerful tool to discriminate good as well as poor combiners for choosing appropriate parental material in plant breeding programme. Moreover, information regarding general and specific combing ability enables the plant breeders to evaluate parental material and to decide a suitable breeding procedure for character improvement. The knowledge of nature and magnitude of fixable and non-fixable types of gene effects governing the yield and its components is essential in order to formulate an efficient and a sound breeding programme to achieve the maximum genetic improvement.

Materials and Methods

The present study was conducted at Wheat Research Station, Junagadh Agricultural University, Junagadh (Gujarat), during *Rabi* 2017-18. The experimental material of the study consisted of eight lines i.e., GW 11, GW 173, GJW 463, HD 2932, J 11-04, Lok 1, MP 3288, Raj 4238 and four testers i.e. GW 366, GW 451, GW 496, HI 1544, one standard check (GW 366) and their 32 F_1s. The F_1s were made by crossing eight lines with four testers in line × tester mating design during *Rabi* 2016-17. These crosses were then evaluated along with the parents and check during *Rabi* 2017-18. The experimental material was tested in randomized block design with three replications during *Rabi* 2017-18. A single row plot of 2.5 meters was allotted randomly to each entry. The row-to-row and plant-to-plant distance was kept 22.5 cm and 10 cm, respectively. Twelve morphological characters namely, days to heading, days to maturity, plant height (cm), number of effective tillers per plant, length of main spike

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(cm), number of spikelets per main spike, grain filling period (days), number of grains per main spike, 100-grain weight (g), grain yield per plant (g), biological yield per plant (g) and harvest index (%). Analysis of variance for combining ability was carried-out according to the method suggested by Kempthorne (1957).

Results and Discussion

The analysis of variance for combining ability for all the twelve characters is presented in Table 1. [It was carried out according to the line × tester design proposed by Kempthorne (1957) which is analogous to North Carolina Design-II of Comstock and Robinson (1948, 1952).] Mean squares due to lines, testers and their interactions (line × tester) were first tested against the error mean squares. If line × tester interaction mean squares were found to be significant, and then more stringent test of significance was applied and the mean squares of lines and testers were further tested against line × testers means squares.

The magnitude of gca variance was higher than the sca variance for the characters, *viz*., number of effective tillers per plant, length of main spike, number of spikelets per main spike, number of grains per main spike and 100-grain weight, which indicated preponderance of additive gene action in the inheritance of these traits. Therefore, selection for these traits in early generations would be effective for developing the superior varieties in wheat breeding programme. Preponderance of additive variance in expression of these traits in wheat have also been reported by Pansuriya *et al*. (2014) for number of effective tillers per plant; Vanpariya *et al.* (2006) for length of main spike; Ahmad *et al.* (2017) for number of spikelets per main spike; Yadav *et al.* (2017) for number of grains per main spike and Ahmad *et al.* (2017) for 100-grain weight.

The magnitude of sca variance was higher than gca variance for the characters, *viz.*, days to heading, days to maturity, plant height, grain filling period, grain yield per plant, biological yield per plant and harvest index, which indicated preponderance of non-additive gene action in the inheritance of these traits. Therefore, heterosis breeding is used if commercially feasible. Similar findings were also reported by Murugan and Kannan (2017) for days to heading, days to maturity and plant height; Yadav *et al*. (2017) for grain filling period and grain yield per plant; Kerkhi *et al.* (2015) for biological yield per plant and Pansuriya *et al.* (2014) for harvest index.

The summary of general combining ability effects of the parents revealed that none of the parents was found to be good general combiner for all the characters. General combining ability effects of the parents revealed that lines GW 173, HD 2932, Lok 1 and GW 11, testers HI 1544 and GW 366 were found to be good general combiners for days to heading. For days to maturity, female parents GW 173, Lok 1, J 11-04, HD 2932 and GW 11 and male parents HI 1544 and GW 366 were registered as good general combiners. The good general combining ability effect was expressed by the female parent GW 173 and male parent GW 451 for plant height. The estimate of general combining ability effect revealed that female parents MP 3288 and GW 11 and male parents GW 451 and GW 496 have good general combining ability effects for number of effective tillers per plant. Female parents MP 3288, GJW 463 and J 11-04 and male parents GW 496 and HI 1544 showed significant positive general combining ability effects for length of main spike. For number of spikelets per main spike, female parents MP 3288, J 11-04 and GJW 463 and male parent HI 1544 registered as good general combiners. For grain filling period, female parents J 11-04, GJW 463 and MP 3288 and male parents HI 1544, GW 366 and GW 496 showed significant negative general combining ability effects. Female parents MP 3288, J 11-04 and GJW 463 and male parent HI 1544 were considered as good general combiners for number of grains per main spike. For 100-grain weight, female parent Lok 1 and GW 11 and male parent GW 366 emerged with good general combining ability. For grain yield per plant, female parents MP 3288 and GW 11 and male parent GW 451 showed significant positive general combining ability effect. For biological yield per plant, female parents MP 3288 and GW 11 and male parent GW 451 showed significant positive general combining ability effect. Female parents HD 2932 and GW 173 and male parent HI 1544 were observed as good general combiners for harvest index (Table 2).

As regard to specific combining ability effects (Table 3), eight crosses exhibited significant positive specific combining ability effects for grain yield per plant. The highest *sca* effect for grain yield per plant was exhibited by the cross MP 3288 × GW 366 (good × average) followed by MP 3288 × HI 1544 (good × poor), GW 173 × GW 451 (poor × good). Considering the desired *sca* effects, the best cross combination were MP 3288 × GW 451 for days to heading, MP 3288 × GW 496 for days to maturity, MP 3288 × GW 451 for plant height, J 11-04 × GW 496 for number of effective tillers per plant, GW 11 × GW 451 for length of main spike, MP 3288 × GW 496 for number of spikelets per main spike, MP 3288 × GW 496 for grain filling period, MP 3288 × GW 496 for number of grains per main spike, HD 2932 × GW 496 for 100-grain weight, MP 3288 × GW 366 for grain yield per plant, J 11-04 × GW 496 for biological yield per plant and MP 3288 × GW 496 for harvest index.

The present study revealed that both additive and non-additive components were important for inheritance of different characters. The presence of additive gene action would enhance the chances of making improvement through simple selection. The prevalence of both additive and non-additive gene actions suggested the simultaneous exploitation of these gene actions by adopting selective intermating and selection, which could accumulate more of additive genetic variability. The non-additive gene action can be exploited by the breeding procedures involving biparental mating followed by selection and heterosis breeding.

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Table 1. Analysis of variance for combining ability and variance components for different characters in bread wheat

Source	d.f.	Days to heading	Days to maturity	Plant height	Number of effective tillers per plant	Length of main spike	Number of spikelets per main spike
Replications	2	0.594	2.573	0.299	1.003	0.075	0.781
Lines	7	113.970**++	44.487**+	117.757**+	13.792**++	4.937**++	14.247**++
Testers	3	66.681**	119.816**++	102.302**	27.865**++	3.540**++	3.384**
Lines× Testers	21	22.911**	16.427**	35.659**	2.762**	0.447*	1.752*
Error	62	0.798	0.960	12.154	0.724	0.244	0.925
Variance Components							
$\sigma^2 l$		9.431	3.627	8.800	1.089	0.391	1.110
$\sigma^2 t$		2.745	4.952	3.756	1.131	0.137	0.103
$\sigma^2 lt$		7.371	5.156	7.835	0.680	0.068	0.276
$\sigma^2 gca$		4.974	4.511	5.438	1.117	0.222	0.438
$\sigma^2 sca$		7.371	5.156	7.835	0.680	0.068	0.276
$\sigma^2 gca / \sigma^2 sca$		**0.675**	**0.875**	**0.694**	**1.643**	**3.265**	**1.587**

Source	d.f.	Grain filling period	Number of grains per main spike	100-grain weight	Grain yield per plant	Biological yield per plant	Harvest index
Replications	2	0.948	1.595	0.234	11.256*	84.118	12.635
Lines	7	75.952**++	141.411**++	0.915**+	37.423**	414.504**+	44.075**
Testers	3	18.556**	24.791**	2.056**++	35.135**	466.569**+	33.069**
Lines× Testers	21	17.135**	12.060	0.263*	19.210**	135.202**	23.355**
Error	62	1.335	7.205	0.132	3.182	30.800	6.275
Variance Components							
$\sigma^2 l$		6.218	11.184	0.065	2.853	31.975	3.150
$\sigma^2 t$		0.717	0.733	0.080	1.331	18.157	1.116
$\sigma^2 lt$		5.267	1.618	0.044	5.343	34.800	5.693
$\sigma^2 gca$		2.551	4.217	0.075	1.839	22.763	1.794
$\sigma^2 sca$		5.267	1.618	0.044	5.343	34.800	5.693
$\sigma^2 gca / \sigma^2 sca$		**0.484**	**2.606**	**1.705**	**0.344**	**0.654**	**0.315**

*,** Significant at 5% and 1% against error, respectively

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Table 2. General combining ability effects of parents for different characters in bread wheat

Sr. No.	Parents	Days to heading	Days to maturity	Plant height	Number of effective tillers per plant	Length of main spike	Number of spikelets per main spike	Grain filling period	Number of grains per main spike	100-grain weight	Grain yield per plant	Biological yield per plant	Harvest index
Lines													
1	GW 11	-2.063**	-1.094**	1.011	1.276**	-0.278	-0.779**	1.292**	-2.394**	0.231*	1.794**	6.020**	-1.089
2	GW 173	-3.813**	-1.594**	-6.847**	-0.026	-0.188	-0.858**	3.042**	-2.360**	-0.268*	-1.245*	-5.371**	1.882**
3	GJW 463	3.354**	0.906**	1.153	-0.816**	0.879**	0.971**	-3.292**	2.406**	-0.160	-0.415	-2.348	1.142
4	HD 2932	-2.813**	-1.010**	-0.997	-0.191	-0.513**	-0.650*	2.375**	-1.935**	-0.012	-0.092	-2.897	3.028**
5	J 11-04	2.021**	-1.344**	4.186**	-1.757**	0.308*	1.188**	-3.708**	3.906**	-0.192	-2.372**	-5.330**	-1.305
6	Lok 1	-2.479**	-1.510**	0.144	0.259	-0.254	-0.621*	1.891**	-2.494**	0.552**	0.235	-0.179	0.464
7	MP 3288	3.771**	3.240**	0.730	1.559**	0.910**	1.702**	-1.125**	5.681**	-0.198	3.170**	11.506**	-2.290**
8	Raj 4238	2.021**	2.406**	0.619	-0.357	-0.864**	-0.954**	0.042	-2.810**	0.047	-1.074*	-1.401	-1.831*
	SE(gi)	**0.258**	**0.283**	**1.006**	**0.246**	**0.143**	**0.278**	**0.334**	**0.692**	**0.105**	**0.515**	**1.602**	**0.723**
	CD at 5%	**0.516**	**0.565**	**2.012**	**0.491**	**0.285**	**0.555**	**0.667**	**1.384**	**0.210**	**1.030**	**3.203**	**1.446**
Testers													
1	GW 366	-1.271**	-0.885**	-1.189	-0.978**	-0.424**	-0.239	-0.667**	-0.369	0.428**	-0.470	-1.292	-0.051
2	GW 451	1.354**	2.365**	-1.950**	1.080**	-0.226*	-0.318	0.833**	-1.048*	-0.078	1.306**	5.092**	-1.230*
3	GW 496	1.521**	1.198**	0.419	0.772**	0.336**	0.044	-0.583*	0.052	-0.230**	0.610	1.528	-0.308
4	HI 1544	-1.604**	-2.677**	2.719**	-0.874**	0.314**	0.513**	-0.917**	1.365**	-0.120	-1.446**	-5.328**	1.589**
	SE(gi)	**0.182**	**0.200**	**0.712**	**0.174**	**0.101**	**0.196**	**0.236**	**0.490**	**0.074**	**0.364**	**1.133**	**0.511**
	CD at 5%	**0.365**	**0.400**	**1.423**	**0.347**	**0.201**	**0.392**	**0.472**	**0.979**	**0.148**	**0.728**	**2.265**	**1.022**

*,** Significant at 5% and 1% against error, respectively

Table 3. Specific combining ability effects of hybrids for different characters in bread wheat

Sr. No.	Hybrids	Days to heading	Days to maturity	Plant height	Number of effective tillers per plant	Length of main spike	Number of spikelets per main spike	Grain filling period	Number of grains per main spike	100-grain weight	Grain yield per plant	Biological yield per plant	Harvest index
1	GW 11 × GW 366	1.771**	2.719**	-1.336	-0.245	0.029	0.089	0.500	-0.440	0.288	-0.864	-1.591	-1.103
2	GW 11 × GW 451	1.146**	-0.865	1.425	0.453	0.491	0.634	-2.333**	2.240	-0.111	2.693**	9.091**	-0.998
3	GW 11 × GW 496	-1.021	0.635	1.222	-0.505	-0.111	-0.594	1.750*	-1.594	-0.011	-0.541	-2.545	0.848
4	GW 11 × HI 1544	-1.896**	-2.490**	-1.311	-0.193	-0.409	-0.129	0.083	-0.206	-0.166	-1.288	-4.956	1.254
5	GW 173 × GW 366	-0.479	-2.115**	-1.011	-0.139	0.000	0.235	-1.583*	0.594	-0.263	-1.891	-4.267	-0.447
6	GW 173 × GW 451	3.563**	1.969**	0.283	0.136	0.208	0.313	-2.083**	0.840	0.386	3.149**	4.902	2.318
7	GW 173 × GW 496	-2.271**	0.135	0.381	0.011	-0.387	-0.582	2.667**	-1.527	-0.109	-1.842	-2.821	-1.727
8	GW 173 × HI 1544	-0.813	0.010	0.347	0.009	0.179	0.033	1.000	0.094	-0.014	0.585	2.185	-0.144
9	GJW 463 × GW 366	1.021	0.385	2.789	-0.197	0.098	0.689	-0.917	2.260	-0.247	-1.155	-2.627	-0.364
10	GJW 463 × GW 451	-2.271**	-0.531	-0.517	1.278**	-0.405	-0.316	1.917**	-1.560	0.100	2.435*	3.525	2.258
11	GJW 463 × GW 496	-0.438	-1.365*	-1.553	-0.114	0.359	-0.161	-0.667	0.140	-0.022	1.200	4.156	-0.897
12	GJW 463 × HI 1544	1.688**	1.510**	-0.719	-0.968	-0.052	-0.213	-0.333	-0.840	0.168	-2.480*	-5.055	-0.997
13	HD 2932 × GW 366	-2.146**	-2.365**	-1.061	0.411	-0.183	0.093	0.083	-0.031	-0.254	-0.311	-2.671	2.190
14	HD 2932 × GW 451	3.229**	1.385*	9.967**	0.253	0.353	1.038	-2.417**	2.048	-0.202	2.115*	4.208	0.075
15	HD 2932 × GW 496	0.729	2.552**	-5.003*	0.061	0.224	-0.457	1.667*	-0.219	0.437*	1.411	6.102	-2.756
16	HD 2932 × HI 1544	-1.813**	-1.573**	-3.903	-0.726	-0.394	-0.675	0.667	-1.798	0.019	-3.215**	-7.639*	0.490
17	J 11-04 × GW 366	-0.979	1.635**	0.156	0.345	-0.376	-0.011	2.833**	0.194	0.168	0.372	0.692	0.346
18	J 11-04 × GW 451	-2.938**	-3.281**	-2.150	-1.314**	-0.334	-1.332*	0.333	-3.560*	0.174	-2.671**	-10.426**	3.281*
19	J 11-04 × GW 496	0.229	-0.115	-0.453	1.395**	0.384	0.573	-0.583	1.173	-0.144	2.888**	9.139**	-0.910
20	J 11-04 × HI 1544	3.688**	1.760**	2.447	-0.426	0.326	0.771	-2.583**	2.194	-0.197	-0.589	0.594	-2.717
21	Lok 1 × GW 366	-1.813**	-2.865**	2.064	0.928	-0.035	-0.869	-0.583	-2.273	0.191	0.699	3.077	-0.863
22	Lok 1 × GW 451	1.563**	2.885**	-1.408	-1.197*	-0.471	-0.691	1.250	-1.327	0.307	-1.948	-5.977	0.082
23	Lok 1 × GW 496	0.729	0.719	-0.678	0.011	0.098	0.914	-0.667	1.473	-0.039	-0.085	0.987	-0.929
24	Lok 1 × HI 1544	-0.479	-0.740	0.022	0.257	0.408	0.646	1.375*	2.127	-0.459*	1.335	1.913	1.710
25	MP 3288 × GW 366	4.271**	3.052**	-0.755	1.170*	0.059	-0.592	-1.750*	-1.048	-0.107	3.314**	6.906*	1.198
26	MP 3288 × GW 451	-5.354**	-0.531	-5.951**	-0.739	-0.238	-0.457	5.750**	-1.202	-0.129	-4.133**	0.431	-8.094**
27	MP 3288 × GW 496	-1.188*	-4.365**	3.003	-1.689**	0.135	1.125*	-3.167**	2.931*	-0.197	-2.454*	-13.495**	6.102**
28	MP 3288 × HI 1544	2.271**	1.844**	3.703	1.257**	0.044	-0.077	-0.833	-0.681	0.433*	3.273**	6.158	0.795
29	Raj 4238 × GW 366	-1.646**	-0.448	-0.844	-0.855	0.407	0.364	1.417*	0.744	0.224	-0.163	0.480	-0.955
30	Raj 4238 × GW 451	1.063*	-1.031	-1.650	-0.780	0.397	0.809	-2.417**	2.523	-0.523*	-1.640	-5.755	1.077
31	Raj 4238 × GW 496	3.229**	1.802**	3.081	0.828	-0.702*	-0.819	-1.667*	-2.377	0.085	-0.577	-1.524	0.269
32	Raj 4238 × HI 1544	-2.646**	-0.323	-0.586	0.807	-0.102	-0.354	2.667**	-0.890	0.214	2.380*	6.799*	-0.391
	SE±	**0.516**	**0.566**	**2.013**	**0.491**	**0.285**	**0.555**	**0.667**	**1.385**	**0.210**	**1.030**	**3.204**	**1.446**
	CD at 5%	**1.031**	**1.131**	**4.024**	**0.982**	**0.570**	**1.110**	**1.334**	**2.768**	**0.419**	**2.059**	**6.405**	**2.891**

*,** Significant at 5% and 1% against error, respectively