Journal of Pharmacognosy and Phytochemistry
Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2018; SP1: 63-66

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National Conference on Conservation Agriculture
(ITM University, Gwalior on 22-23 February, 2018)

Combing ability analysis for agro-morphological characters in bread wheat (*Triticum aestivum*)

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Abstract
Inheritance analysis was carried out for grain yield and agronomic attributing traits in wheat. A set of 21 F_1s generated by crossing in Line X Tester mating design using 7 lines of bread wheat viz., C 306, DL 803-3, GW190, GW322, PBW 175, MACS 6222 and HI 1544 and 3 testers HD 2932, GW173 and PBW 343. A field experiments was conducted in randomized complete block design with 4 replications. Analysis of variance revealed that both additive as well as non-additive variances were prevalent for the control of grain yield, grain weight, flag-leaf area, biological yield per plant and harvest index. Additive variances controlled days to heading, days to flowering, days to maturity, grain filling period, plant height and spike length, whereas, non-additive variances controlled tillers per plant. 'MACS 6222' and 'HI 1544' were identified as good general combining parents for grain yield per plant and yield component traits. Good specific combiners were cross GW 190 X HD 2932, MACS 6222 X PBW 343, PBW 175 X GW 173, C 306 X PBW 343, DL 803-3 X GW 173, HI 1544 X GW 173 and HI 1544 X HD 2932 for grain yield per plant and various components traits. Five crosses viz., MACS 6222 X PBW 343, HI 1544 X HD 2932, HI 1544 X GW 173, DL 803-3 X PBW 343 and GW 322 X HD 2932 showed significant heterosis over mid parent as well as better parent for grain yield. Cross combination viz., MACS 6222 X PBW 343, HI 1544 X HD 2932 and HI 1544 X GW 173 may be advanced to improve grain yield as these crosses showed high mean performance with good specific combiners involving good general combining parents and also showed significant high positive heterosis over mid-parent and better parent for grain yield per plant.

Keywords: combining ability analysis and heterosis

Introduction
Wheat (*Triticum aestivum* L.) is the most widely cultivated crop among the cereals and is the principal food crop in most areas of the world and also occupies prominent position in Indian agriculture after rice. India has witnessed spectacular progress in wheat production and is the second largest producer next to China. Wheat is a major contributor to the food security system in India recorded remarkable wheat productivity of 3093 kg per ha and achieved a record production of 93.50 m tones (Anonymous, 2016) [1]. This goal can be achieved by enhancing through the development of new cultivars having wider genetic base and better performance. Earlier research review revealed that both general and specific combining abilities were involved for yield and yield component (Chaudhary *et al*., 1992 and Hassan *et al*., 2006). For effective improvement in grain yield of wheat, a plant breeder must have knowledge of inheritance of agronomic traits. Information of the genetic system controlling the quantitative characters is essential to choose most effective and efficient breeding strategy. The present investigation is planned to select parents for efficient hybridization programme as well as to identify superior cross combination for further improvement in wheat.

Materials and methods
A set of 21 F_1s was generated by crossing in Line X Tester mating design using 7 lines of bread wheat viz., C 306, DL 803-3, GW190, GW322, PBW 175, MACS 6222 and HI 1544 and 3 testers viz., HD 2932/ GW173 and PBW 343. A field experiments was conducted in randomized complete block design with 4 replications at College of Agriculture, RVSKVV, Gwalior. The experiment was sown by dibbling seeds in rows with spacing of 20 cm apart and 4-6 cm within row on November 21 (Timely sown environment, 2013-14). Crop was grown

with recommended package of practices. Observations were recorded on five randomly selected plants from each line for yield and its attributes (table 1). Combining ability analysis was worked out in Line X Tester mating design as proposed by Kempthorne (1957).

Results and discussion

Analysis of variance revealed that mean sum of square due to both lines and testers were significant for plant height, grain yield per plant, flag leaf area, biological yield per plant and harvest index. However, lines were significant for spike length, grain weight per spike and test weight and testers were significant for days to heading, days to flowering, days to maturity and grain filling period, thereby, indicating presence of significant general combing parents for respective traits (Table-1). Significance of general combing ability variances were also reported earlier for yield and yield components by Meena *et al.* (2003), Pareek and Garg (2004) [7], Grakh and Singh (2005), Chowdhry (2005) [4] and Dagustu *et al.* (2008) [5]. Variances due to Line X tester were significant for tillers per plant, grain weight per spike, test weight, grain yield per plant, flag leaf area, biological yield per plant and harvest index, thereby, indicating presence of specific combing ability for respective traits. Similar results were also reported earlier for yield and yield components by Patil *et al.* (1997) [8], Pareek and Garg (2004) [7], Grakh and Singh (2005), Vanpariya *et al.* (2006) [10] Kashif and Khan (2008) [6], Burungale *et al.* (2011) [2]. The present results also revealed that both genetic components of variances viz.; additive as well as non-additive variances were prevalent for control of grain yield, grain weight, flag leaf area, biological yield per plant and harvest index with some exceptions. Additive variances governed inheritance for days to heading, days to flowering, days to maturity, grain filling period and plant height and spike length., whereas, tillers per plant was under the control of non-additive variances.

The estimates of GCA effects of parents presented table 2 revealed that 'MACS 6222' showed positive significant GCA effects for grain yield per plant, spike length, and harvest index, thereby suggested good general combiner for these traits. 'HI 1544' showed positive and significant GCA effect for grain yield per plant, grain filling period, flag leaf area and harvest index indicating as a good general combiner for these traits but it had negative significant GCA effects for plant height, test weight, and biological yield per plant, thereby, suggesting plenty of choice for better ideotypes except for test weight. ''GW 322" was not good general combiner for grain yield per plant, flag leaf area and harvest index because it possessed significant but negative GCA effects for these traits. "DL 803-3" showed positive significant GCA effect for plant height and test weight, so it was a good combiner for these traits, but it showed significant but negative GCA effect for grain yield and harvest index, thus it was not a good combiner for grain yield and harvest index. PBW 343 was not a good combiner for grain yield per plant, days to maturity, grain filling period, flag leaf area and biological yield per plant because it showed significant but negative GCA effects for these traits, Rests of the parents were poor combiner for grain yield having non-significant negative or positive general combining ability effects. Present results are in agreement with those of Jaiswal *et al.* (2014) for days to heading, tillerss per plant, total number of spikelet per ear, biological yield per plant; Kashif and Khan *et al.* (2008) [6] for tillers per plant, spikelet per spike, grains per spike and grain yield per plant. Chowdhry *et al. (*2005) [4] reported that mean squares for general combining ability for flag leaf area, number of fertile tillers per plant and significant for spike length while non-significant for plant height and peduncle length; Meena and Sastry (2003) for spike length, peduncle length and tillers per plant; Chowdhry *et al. (*2001) [3] for number of tillers per plant, number of grains per spike, flag leaf area and grain yield per plant.

Specific combining ability effects (SCA) effects presented table 3 revealed that cross "MACS 6222 X PBW 343" showed significant positive SCA effect for grain yield along with higher grain yield performance, thereby, indicating good specific combiner only for grain yield per plant. This cross also involved both the parents showing significant GCA effect for grain yield. Cross "HI 1544 X HD 2932" revealed good specific combiner for grain yield per plant, flag leaf area and harvest index, whereas, it was not a good specific combiner for biological yield per plant. Only one parent of this cross showed good GCA effect for grain yield per plant. Cross "HI 1544 X GW 173" showed significant and positive SCA values for grain yield per plant, test weight and biological yield per plant indicating good specific combiner, "GW 190 X HD 2932"revealed good specific combiner for grain yield per plant, tillers per plant, biological yield and harvest index as reflected by significant and positive SCA values, Cross "DL 803-3 X GW 173" revealed good specific combiner for grain yield per plant, plant height and grain weight per spike as reflected by significant and positive SCA values. Cross "PBW 175 X GW 173" revealed good specific combiner for grain yield per plant and harvest index because it showed positive SCA effect for these traits, whereas, it also showed uncomplimentary SCA effects for days to maturity, plant height, spike length, grain weight per spike, grain per spike, test weight and biological yield per plant. Cross "C 306 X PBW 343" revealed good specific combiner for grain yield per plant, flag leaf area and harvest index as reflected by significant and positive SCA values. It also showed positive significant SCA effect for days to maturity but negative SCA effects for test weight indicating poor general combiner for both component traits. It was noticed that the crosses with high SCA had either one or both parents with average or good GCA effects. The good specific combining crosses involved good X poor, poor X poor or bad X poor combining parents this may be attributed to the presence of genetic diversity among the parent and there could be made some complementation thereby indicating importance of both additive and non-additive effects. The similar results were also reported earlier by Feng *et al.* (2011) for grain yield per plant, Burungale *et al.* (2011) [2] for higher grain yield and also for various yield contributing traits, Kumar and Gupta (2010) for number of tillers/plant, grain yield/plant 100-grain weight, and harvest index, Vanpariya *et al*. (2006) [10] for length of main spike, spikelet per spike, days to maturity, effective tillers per plant and number of grains per spike. Chowdhry *et al.* (2005) [4] for plant height, number of fertile tillers per plant and peduncle length, and non-significant for flag leaf area and spike length, Sharma and Singh (1992) [9] grain yield.

Heterosis over mid parent and better parent revealed that HI 1544 X GW 173, MACS 6222 X PBW 343, DL 803-3 X PBW 343, HI 1544 X HD 293 and GW 322 X HD 2932 recorded significant heterosis over both mid parent and better parent for grain yield. However, PBW 175 X GW 173, DL 803-3 X GW 173, C 306 X PBW 343,GW 190 X HD 2932, DL 803-3 X HD 2932 and C 306 X HD 2932 recorded significant heterosis over mid parent for grain yield. These crosses also showed significant heterosis for yield contributing traits viz., days to maturity, grain filling period, plant height, tillers per plant, spike length, grain weight per spike, grain per spike, test weight, grain yield per plant, flag leaf area, biological yield per plant and harvest index. Cross combination 'DL 803-3 X GW 173' (57.82 %), C 306 X HD 2932 (57.40%), 'C 306 X GW 173' (40.06%) and 'HI 1544 X GW 173' (31.18%) showed significantly high heterosis over mid parent for biological yield per plant. The highest heterosis over mid parent were recorded for different traits in HI 1544 X HD 2932 (36.14%) for grain weight per spike, 'C 306 X HD 2932 (35.44%), for flag leaf area, MACS 6222 X PBW 343 (35.48%) for harvest index, PBW 175 X PBW 343 (15.76%) for test weight, GW 322 X HD 2932 (20.08%) for grain per spike, GW 190 X HD 2932 (41.98%) for grain weight per spike, GW 190 X GW 173(17.77%) for spike length, GW 322 X GW 173(50.12%) for tillers per plant, C 306 X HD 2932(14.19%) for plant height, C 306 X HD 2932 (7.29%) for grain filling period. It was noticed that crosses showing significant heterosis in positive direction also showed significant SCA effects in respective cross as well as significant GCA effect either one or both of their parents, thus, attributing the heterosis for grain yield through both additive as well as non-additive components. Further they also showed significant heterosis either one or more component traits, may boost up heterosis for grain yield.

In self–pollinated crops like wheat, SCA effects are not much important as they are mostly related to non-additive gene effects excluding those of arising from complementary gene action or linkage effects they cannot be fixed in pure lines. Further superiority of the hybrids might not indicate their ability to yield transgressive segregates; rather SCA would provide satisfactory criteria and expected to throw desirable transgressive segregates in later generations. The presence of both significant additive and non-additive genetic variances for grain yield and major yield attributing traits suggested that high performance of yield and contributing traits can be fixed in subsequent segregating generation, GW 190 X HD 2932, MACS 6222 X PBW 343, PBW 175 X GW 173, C 306 X PBW 343, DL 803-3 X GW 173, HI 1544 X GW 173 and HI 1544 X HD 2932. The good general combiners may be used for varietal improvement through the recurrent selection, inter-mating and bi-parental mating in F_2 generation of promising crosses consisting parents 'MACS 6222' and 'HI 1544' and cross MACS 6222 X PBW 343, HI 1544 X HD 2932 and HI 1544 X GW 173 would be used for improvement for high yielding varieties through the simple/recurrent selection from segregating generations in wheat. This may lead in the fixation of both additive and non-additive components while making improvement in grain yield and its attributes.

Table 1: Analysis of variance for combining ability for grain yield and yield contributing characters in wheat

Sources	DF	Days to heading	Days to flowering	Days to maturity	Grain filling period	Plant height	Tillerss per plant	Spike length	Grain weight per spike	Grain per spike	Test weight	Grain yield per plant	Flag leaf area	Biological yield	harvest index
Lines	6	13.10	10.87	2.44	13.75	153.34**	4.92	3.12*	0.36*	23.49	38.01*	47.56**	126.71**	110.25**	408.81**
Tester	2	64.00**	73.37**	12.58*	133.11**	252.62**	0.85	0.22	0.01	65.1	27.62	30.02*	422.59**	375.98**	172.52**
L X T	12	4.56	4.90	2.76	7.16	41.29	7.55*	1.55	0.41**	47.42	41.59*	22.91**	116.40**	122.89**	131.22**
Error	90	9.72	12.75	3.17	12.09	46.29	3.14	1.22	0.12	48.10	16.94	5.91	31.87	22.47	51.99
Genetic components															
σ2gca (Lines)		0.71	0.50	0.00	0.55	9.34	-0.22	0.13	0.00	-1.99	-0.30	2.05	0.86	-1.05	23.13
σ2gca(Testers)		2.85	1.99	-0.03	2.19	37.35	-0.88	0.52	-0.02	-7.98	-1.19	8.22	3.43	-4.22	92.53
σ2gca(Parents)		201.74	228.51	-1.68	415.90	798.85	-24.40	-2.73	-1.38	33.53	-48.98	47.76	1005.42	809.87	411.80
σ2sca		-1.49	-1.96	-0.11	-2.17	-10.10	1.01	0.05	0.07	-0.84	5.61	3.82	19.62	24.82	16.64
σ2gca / σ2sca		-134.97	-116.42	15.41	-191.25	-79.11	-24.17	-50.84	-18.72	-39.89	-8.73	12.52	51.25	32.62	24.74
σ2 A		403.48	457.02	31.59	831.81	1597.70	-48.80	-5.45	-2.76	67.06	-97.96	95.53	2010.84	1619.75	823.61
σ2 D		26.73	30.31	63.17	58.62	85.47	-1.33	-0.55	-0.06	7.16	4.23	11.19	192.33	176.19	53.93

*, ** significant at 5 and 1 percent levels, respectively

Table 2: Estimate of GCA effect for grain yield and yield contributing characters in lines and tester parents in wheat

Lines	Days to heading	Days to flowering	Days to maturity	Grain filling period	Plant height	Tillers per plant	Spike length	Grain weight per spike	Grain per spike	Test weight	Grain yield per plant	Flag leaf area	Biological yield	harvest index
HI 1544	-1.8571	-1.5714	0.5595	2.1310**	-4.7287**	-0.8688	0.1807	-0.0742	1.2964	-3.3564**	2.1169**	4.8386**	-3.5856**	7.3308**
GW 190	-0.6071	-0.7381	-0.3571	0.3810	1.3563	-0.6513	0.5257	0.3003**	-0.7009	-0.1556	-0.4339	2.6894	-3.0173**	1.0825
MACS 6222	0.2262	0.0952	0.1429	0.0476	-2.1629	-0.1996	0.6607**	0.1178	0.2414	0.8794	2.5061**	-1.3689	-1.1531	8.0423**
PBW 175	0.8929	0.7619	-0.0238	-0.7857	-2.8387	0.4654	-0.4143	-0.0839	-0.9244	0.3119	-0.4048	-0.1906	4.3652**	-4.7785**
GW 322	-0.2738	-0.2381	-0.2738	-0.0357	1.5230	-0.1021	0.1565	-0.1822	1.3539	-0.0623	-3.1123**	-4.6973**	-1.2839	-5.5508**
C 306	0.3095	0.4286	-0.6071	-1.0357	0.7846	0.8945	-0.5202	-0.1514	1.1022	-0.2231	0.8377	-2.6264	2.6561	-0.5729
DL 803-3	1.3095	1.2619	0.5595	-0.7024	6.0663**	0.4620	-0.5890	0.0736	-2.3686	2.6061**	-1.5098**	1.3552	2.0186	-5.5535**
SE (gca line)	0.900	1.031	0.514	1.004	1.964	0.511	0.319	0.099	2.002	1.188	0.702	1.630	1.368	2.082
Testers														
GW 173	-1.7143**	-1.8690**	0.5952	2.4643**	-1.6332	0.1056	-0.0692	-0.0141	-0.354	0.2817	0.4289	-0.7156	4.2030**	-2.6857*
PBW 343	1.1429	0.9524	-0.7262**	-1.6786**	-1.8332	-0.2008	0.1006	0.0160	-1.317	-1.1037	-1.1811**	-3.4774**	-2.5245**	0.4760
HD 2932	0.5714	0.9167	0.1310	-0.7857	3.4664**	0.0952	-0.0314	-0.0019	1.671	0.8220	0.7521	4.1930**	-1.6785	2.2097
SE (gca tester)	0.589	0.675	0.337	0.657	1.286	0.335	0.209	0.065	1.311	0.778	0.460	1.067	0.896	1.363

*, ** significant at 5 and 1 percent levels, respectively

Table 3: Promising crosses with high mean performance, significant SCA and GCA effects for grain yield and yield contributing characters

Crosses	GCA of parents involved in the cross for grain yield		Grain yield per plant		Days to maturity	Plant height	Tillers per plant	Spike length	Grain weight per spike	Grain per spike	Test weight	Flag leaf area	Biological yield	harvest index
	P 1	P2	Mean	SCA	SCA	SCA	SCA	SCA	SCA	SCA	SCA	SCA	SCA	SCA
MACS 6222 X PBW 343	2.51**	-1.18**	20.61	5.9271**	-0.7143	-1.7786	-0.2950	0.0705	-0.0720	-3.1971	1.3740	3.4364	3.7390	11.0427
HI 1544 X HD 2932	2.12**	0.75	20.43	2.4740*	0.2381	0.1338	-0.2188	0.9069	-0.2023	-1.7864	-1.4557	6.6407**	-10.9631**	10.7275**
HI 1544 X GW 173	2.12**	0.43	20.24	2.7355**	-0.6905	-1.7069	-1.7395*	-0.3799	-0.2947	-5.4016	9.8200**	2.4529	13.8590**	-5.2293
GW 190 X HD 2932	-0.44	0.75	20.14	6.9957**	-0.9286	-1.5862	2.6812**	-1.0056	-0.0413	-7.2869**	-0.6374	-5.8410**	5.8552**	10.6031**
DL 803-3 X GW 173	-1.51**	0.43	19.16	3.1338**	-3.6905**	7.3964**	-0.0162	-0.5982	0.8716**	1.9718	3.8783	-1.5271	4.2907	3.3145
PBW 175 X GW 173	-0.41	0.75	18.56	4.4138**	1.9762**	-10.916**	-1.4879	-1.844**	-1.0334**	-9.9599**	-6.6717**	1.4562	-7.9626**	17.8905**
C 306 X PBW 343	0.84	-1.18**	15.52	3.7738**	1.9524**	4.7531	-1.0383	0.6222	0.2013	4.3579	-7.6793**	17.1431**	-4.1443	10.9786**

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