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Research Article

Combining ability analysis for yield and some quality traits in spring wheat (*Triticum aestivum* L.)

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Abstract
Combining ability analysis was studied in a 10 × 10 diallel cross of spring wheat (*Triticum aestivum* L.). The analysis of variance for combining revealed that the variance due to gca and sca were highly significant for all the characters indicated that both the additive and non-additive gene actions were involved in the expression of the traits. The genotypes WH 1094, PBW 590 and PBW 373 were considered as the best general combiners, while hybrids DBW 58 x DBW 17, PBW 550 x PBW 373, MP 1236 x PBW 373, WH 1094 x PBW 590, PBW 590 x PBW 373, RAJ 3765 x HD 2687, PBW 590 x WH 711, MP 1236 x PBW 550, RAJ 3765 x DBW 58, HD 2687 x WH 711 and MP 1236 x WH 1094 as good specific combinations for grain yield and other yield contributing and quality traits. The promising parents namely PBW 373, PBW 590 and WH 1094 which are having high gca effects in desirable direction for yield components and for quality traits may be incorporated in crossing programme to have better genotypes for yield better and quality. The crosses PBW 550 x PBW 373, MP 1236 x PBW 373, WH 1094 x PBW 590, MP 1236 x PBW 550 and RAJ 3765 x DBW 58 which showed good sca effects for major yield and more than six yield components characters were also found superior for gluten content, ash content and showed low reaction of phenol on the grains, may be exploited for better yield and *chapati* quality either by exploiting them through heterosis breeding or involving them in multiple cross breeding programme for obtaining transgressive segregants and broad genetic base population in wheat for improvement in yield.

Key words
Wheat, combining,ability, analysis,qualitytraits, geneaction, diallel analysis.

Introduction:

Spring wheat (*Triticum aestivum* L.) is the major staple food source for a large part of world population and is used to produce a wide diversity of baked food products. For these purpose, the combining ability analysis is a powerful tool to discriminate good as well as poor combiners for choosing appropriate parental materials for particular traits in the wheat improvement programme. Therefore, wheat improvement for quality depends intensive on hybridization using quality and high yielding commercial parental lines. To evolve an effective hybridization programme combining ability analysis is used to test the performance of genotypes in different cross combinations and characterize the nature and magnitude of gene effects in the expression of various yield and quality parameters. However, breeding of yield contributing and quality resistance genotypes requires selection of parents based on their combining ability of the traits. In view of this, objective of present study was to identify the best combining parents on the basis of their general and specific combining ability for various traits for further yield components and quality improvement in spring wheat.

Materials and method

The basic material for the present investigation, comprised of ten wheat genotypes/varieties namely MP 1236, PBW 550, WH 1094, PBW 590, PBW 373, RAJ 3765, DBW 58, HD 2687, DBW 17 and WH 711- was obtained from Department of Genetics and Plant Breeding, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut. The genotypes were used for crossing programme in a diallel half fashion (10 × 10) during crop season 2010-2011. Field plot was well prepared for sowing of the experimental material (55 genotypes- comprising 10 parents and 45 F_1's seeds). The experiment was conducted in a Randomized Complete Block Design with three replications during *rabi* season 2011-2012. Seeds of each of the parental lines and crosses were sown by hand dibbling method in two rows plot. The length of row was 3m long by maintaining 25cm row to row and 10cm plant to plant distance. All the recommended agronomic inputs and practices were applied to the crop during the season. The data were recorded on ten randomly selected competitive plants in each of three replications and fifteen different characters namely days to 50% flowering, days to maturity, number of productive tillers per plant, plant height, flag leaf area (cm^2), spike length (cm), spikelets per spike, grains per spike, 1000-grain weight (g), biological yield per plant (g), grain yield per plant (g), harvest index, ash content (%), gluten content (%) and phenol colour reaction (grading). The mean data on these traits except phenol colour reaction were subjected to statistical and biometrical analysis. Combining ability analysis according to (Griffing 1956) model I and method 2 was conducted using the statistical software package of INDOSTAT.

Result and discussion

The analysis of variance for combining ability (table 1) revealed that the variance due to general combining ability

(GCA) and specific combining ability (SCA) were highly significant for all the characters indicating that both additive and non-additive gene action were involved in expression of these traits. Almost similar trend of involvement of both additive and non-additive gene actions has been earlier reported by Padhar *et al.* (2010), Kumar and Maloo (2012), Adel *et al.* (2013), Desale *et al.* (2014) and Singh *et al.* (2014).

The variance component for σ^2s were less than estimates of σ^2g for all the traits except for days to 50% flowering, days to maturity, plant height, 1000-grain weight and biological yield. Similar findings were also reported by Pather *et al.* (2010) and Gami *et al.* (2011).

The ratio of σ^2g /σ^2s being less than unity indicated the involvement of the non-additive gene action for nine characters viz; number of productive tillers per plant, flag leaf area, spike length, spikelets per spike, grains per spike, grain yield per plant, harvest index, ash content and gluten content, which indicated more involvement of non-additive type of gene action for these traits. The findings are in conformity with Padhar *et al*. (2010), Srivastava *et al*. (2012), Adel *et al.* (2013) and Desale *et al.* (2014). However this ratio was more than unity for five traits namely days to 50% flowering, days to maturity, plant height, 1000-grain weight and biological yield per plant which indicated additive type of gene action for these traits. The results of this study were in agreement with Pancholi *et al.* (2012).

The mean degree of dominance $(\sigma^2s/ \sigma^2g)^{.5}$ was found greater than unity for nine characters namely number of productive tillers/ plant, flag leaf area, spike length, spikelets per spike, grains per spike, grain yield per plant, harvest index, ash content and gluten content indicating the involvement of over dominance. Such types of findings were also reported by Gami, *et al.* (2011). However, it was less than one for five characters namely days to 50% flowering, days to maturity, plant height, 1000-grain weight and biological yield per plant, indicated the involvement of partial dominance. In earlier studies role of non-additive genetic variance were reported by Padhar *et al.* (2010), Srivastava *et al*. (2012) and Adel *et al.* (2013).

The estimate of gca effects, along with range and mean performance of 10 parents for all the 14 attributes have been presented in Table 2. Based on the combining ability effects, the parents values were categorized in three groups as good (G), average (A) and poor (P) general combiners. The parents with significant gca effects towards desirable direction were considered as good general combiners (G), with positive gca effects were considered as average general combiners (A) basis of good general combiner was taken as significance gca and desirable *per se* performance and the parents with negative *gca* effects were designated as poor general combiners (P).

Parent MP 1236 was found to be significant and good general combiner for days to 50% flowering, days to maturity, number of productive tillers per plant, spikelets per spike, grains per spike and harvest index, Similarly, parent PBW 550 was found to be good general combiner for days to 50% flowering, days to maturity, flag leaf area, spikelets per spike and grains per spike.

Parent, WH 1094 was found to be good general combiner for days to 50% flowering, days to maturity, plant height, spike length, spikelets per spike, grains per spike, ash content and gluten content. Parent, PBW 590 was found to be good general combiner for number of productive tillers per plant and spike length. Parent, PBW 373 was found to be good general combiner for days to 50% flowering, flag leaf area, spike length, grain per spike, 1000-grain weight, biological yield per plant and grain yield per plant. Genotype, RAJ 3765 was found to be good general combiner for flag leaf area and grain yield per plant. Parent DBW 58 was found to be good general combiner for 1000-grain weight, Variety, HD 2687 was found to be good general combiner for days to maturity, flag leaf area, spikelets per spike and gluten content. Parent, DBW 17 was found to be good general combiner for plant height and gluten content. Genotype, WH 711 was found to be good general combiner for plant height, flag leaf area, spike length, 1000-grain weight, harvest index and gluten content.

A close examination of the result revealed that the parent WH 1094 combined well for the highest number of eight characters followed by PBW 373 for seven characters, MP 1236 for six characters, PBW 550 for five characters, HD 2687 and WH 711 for four characters each and the parent, RAJ 3765, PBW590 and DBW 17 for two characters and DBW 58 was good general combiner for one character.

The good combiners on the basis of *per se* performance and significant gca effects in desirable direction were observed in PBW 550, MP 1236, PBW 373 and WH 1094 for days to 50% flowering; PBW 550, MP 1236, WH 1094 and HD 2687 for days to maturity; PBW 590 and MP 1236 for number of tillers per plant; WH 711, WH 1094 and DBW 17 plant height; RAJ 3765, PBW 373, WH 711, PBW 550 and HD 2687 for flag leaf area; PBW 373, PBW 590 and WH 1094 for spike length; MP 1236, HD 2687, WH 1094 and PBW 550 for spikelets per spike; MP 1236, WH 1094, PBW 550 and PBW 373 for grain number per spike; PBW 373, DBW 58, and WH 711 for 1000 grain weight; PBW 373 for biological yield per plant ; PBW 373 and RAJ 3765 for grain yield per plant; MP 1236 for harvest index; WH 1094 for ash content and WH 711, HD 2687, DBW 17 and WH 1094 for gluten content.

The estimates of gca effects of the parental lines for different characters revealed that none of the parental lines excelled in gca effects for all the characters studied. However parent WH 1094, PBW 373 and MP 1236 showed significant gca effect with good *per se* for 6-8 characters related to productivity. These may be used for exploiting additive type genetic variability which is fixable type and selection may be effective in segregating population for development of better genotype with regards to yield. However parents PBW 550, RAJ 3765, DBW 17, PBW 373 and WH 1094 which showed significant gca effect and good *per se* performance may be used for multiple parent participation through multiple crossing to effect substantial improvement having for broad genetic base population. Similar results were reported by Karnwal, *et al.* (2011) for spikelets per spike, 1000-grain weight and harvest index and Adel *et al.* (2013) for number of spikes/plant, spikes weight/plant and grain yield/plant.

The sca effects represent the non-additive gene action which is non-fixable (Table 3). The estimation of specific combining ability (sca) effects for 45 hybrids along with mean performance for all the fourteen characters are presented in Table 3, significant positive or negative sca effects were observed in F_1 generation for yield and various yields attributing traits. In the present investigation, none of the crosses expressed good specific combining ability effect for all the traits under study. Out of 45 crosses, ten for days to 50 per cent flowering; six for days to maturity; nine for number of tillers per plant; sixteen for plant height; seven for flag leaf area; fourteen for Spike length; fourteen for Spikelets per spike; twelve for Grains per spike; thirteen for biological yield per plant; four for harvest index; nine for ash content, seven for gluten content and 11 crosses showed significant and positive sca effect for grain yield per plant. The cross combinations *viz;* DBW 58 x DBW 17, PBW 550 x PBW 373, MP 1236 x PBW 373, WH 1094 x PBW 590, PBW 590 x PBW 373, RAJ 3765 x HD 2687, PBW 590 x WH 711, MP 1236 x PBW 550, RAJ 3765 x DBW 58, HD 2687 x WH 711 and MP 1236 x WH 1094 which showed significant and positive sca effects with good *per se* performance for grain yield per plant, also showed significant sca effects for other important yield component traits. However, the best cross negative and positive desirable direction highest significant sca effects yield and yield contributing traits (Table 4). These individual crosses or their multiple cross combinations may be exploited developing broad genetic base population. Out of these 11 crosses, the cross PBW 550 x PBW 373 and MP 1236 x PBW 373 which showed significant sca effect with good *per se* performance for grain yield may be used in cross breeding programme and might be expected to give transgressive segregants in F_2 as these two crosses are having the parents with low x high and high x high gca effect. On the other hand, the crosses *viz.,* PBW 550 x PBW 373, MP 1236 x PBW 373, WH 1094 x PBW 590, MP 1236 x PBW 550 and RAJ 3765 x DBW 58 with good *per se* performance and significant gca effect were common for gluten content, ash content and grain yield per plant. These crosses also showed light colouration on grains when tested with phenol solution (1%). Hence these crosses may be exploited for developing hybrid/genotypes with better yield and quality including *chapati* quality. These cross combinations may be exploited in heterosis breeding programme for developing genotype having broad genetic base by multiple crossing programme.

The good specific combiners involved all the three possible combinations of the parents with high and low gca effects viz; high x high, high x low and low x low, indicated additive and non additive type of gene action. Similar results were reported by Padhar *et al*. (2010) for number of tillers per plant, number of grains per plant, flag leaf area and biological yield per plant Awasthi, *et al.* (2011), Kumar and Maloo (2012) and Adel *et al.* (2013) for grain yield/ plant.

Both additive and non-additive components of genetic variation appeared important in the expression of almost all the traits in present set of material. For exploitation of both the additive and non-additive component of variation, material may be handled though pedigree method, reciprocal recurrent selection or biparental mating for obtaining superior segregants and genotypes. The promising parents namely PBW 373, PBW 590 and WH 1094 which are having high gca effects in desirable direction for yield and yield components and for quality traits may be incorporated in crossing programme to have better genotypes for better and quality.

The crosses PBW 550 x PBW 373, MP 1236 x PBW 373, WH 1094 x PBW 590, MP 1236 x PBW 550 and RAJ 3765 x DBW 58 which showed good sca effects for major yield and 6-8 yield components were also found superior for gluten content, ash content and showed low reaction of phenol on the grains, may be exploited for better yield and *chapati* quality either by exploiting them through heterosis breeding or involving them in multiple cross breeding programme for obtaining transgressive segregants and broad genetic base population in wheat for improvement in yield.

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Table 1. Analysis of variance for combing ability for 14 characters in wheat

Parents & hybrids variation	DF	Days to 50% Flowering	Days to maturity	Number of productive tillers/ plant	Plant height (cm)	Flag leaf area (cm)	Spike length (cm)	Spikelets / spike	Grains / spike	1000 grain weight (g)	Biological yield/ plant (g)	Grain yield/ plant(g)	Harvest index	Ash content	Gluten content
GCA	9	51.46**	10.50**	1.80**	196.92**	139.11**	1.18**	0.74**	85.86**	25.41**	121.87**	32.52**	8.72**	0.018**	0.34**
SCA	45	2.10**	0.97**	0.60**	8.53**	14.67**	0.18**	0.33**	10.42**	2.78**	9.14**	3.23**	9.30***	0.017**	0.06**
Error	108	0.29	0.25	0.13	0.55	1.11	0.03	0.03	1.31	1.52	0.87	0.50	2.89	0.004	0.01
Estimated variances due to:															
$\delta^2 \dot{g}$		4.26	0.85	0.14	16.36	11.50	0.10	0.06	7.05	1.99	10.08	2.67	0.49	0.001	0.03
$\delta^2 s$		1.82	0.71	0.47	7.98	13.57	0.15	0.29	9.11	1.26	8.26	2.74	6.41	0.014	0.05
$\delta^2 \dot{g} / \delta^2 s$		2.35	1.19	0.29	2.05	0.85	0.65	0.20	0.77	1.58	1.22	0.98	0.08	0.081	0.59
$(\delta^2 s / \delta\dot{g})^{½}$		0.65	0.91	1.82	0.70	1.09	1.22	2.19	1.14	0.79	0.90	1.01	3.62	3.449	1.29

Table 2. Estimates of gca effects along with mean performance of parents for grain yield and its components traits in wheat.

Genotyps (Parents)	Days to 50% Flowering		Days to maturity		No. of productive tillers/plant		Plant height (cm)		Flag leaf area (cm^2)		Spike length (cm)		Spikelets/ spike	
	gca	Mean	gca	Mean	gca	Mean	gca	Mean	gca	Mean	gca	Mean	gca	Mean
MP1236	-2.62**	82.66	-0.89**	136.66	0.22*	8.53	4.01**	103.66	-4.28**	28.78	-0.08	8.27	0.38**	20.56
PBW550	-3.46**	83.66	-1.89**	135.33	0.18	8.50	1.11**	95.76	0.84**	35.96	-0.03	8.59	0.17**	20.30
WH1094	-0.62**	92.00	-0.44**	139.33	-0.02	7.50	-5.82**	78.53	-3.25**	32.58	0.18**	9.30	0.19**	19.86
PBW590	-0.26	91.66	0.25	140.00	0.88**	9.37	-0.25	93.00	-2.30**	35.64	0.25**	9.68	-0.43**	17.30
PBW373	-1.26**	90.00	0.47**	141.33	0.03	8.03	4.17**	101.43	4.74**	47.86	0.68**	10.28	-0.15**	17.70
RAJ3765	-0.04	91.66	0.67**	141.33	-0.15	7.73	4.16**	100.50	5.99**	49.30	-0.31**	8.45	-0.27**	18.33
DBW58	1.54**	94.00	0.36**	140.66	-0.47**	5.77	1.99**	97.26	-0.47	42.19	-0.06	8.91	-0.13*	18.70
HD2687	2.10**	96.00	-0.28*	139.66	-0.20*	6.97	1.19**	93.03	0.66*	41.32	0.00	9.45	0.22**	20.00
DBW17	1.93**	95.66	0.22	141.00	-0.45**	6.43	-4.65**	79.10	-3.03**	31.21	-0.19**	8.75	-0.02	19.53
WH711	2.68**	96.66	1.53**	142.00	-0.03	7.77	-5.90**	76.93	1.11**	36.08	-0.43**	8.14	0.03	19.50
Mean		91.40		139.73		7.66		91.92		38.09		8.98		19.18
Range		82.66-96.66		135.33-142.00		5.77-9.37		76.93-103.66		28.78-49.30		8.14-10.28		17.30-20.56
S.E.		0.42		0.44		0.22		0.36		0.74		0.11		0.21
SE (Gi)	0.33		0.31		0.22		0.46		0.65		0.10		0.12	
SE (Gi-Gj)	0.50		0.46		0.33		0.68		0.97		0.15		0.17	

Contd...

Table 2. Contd…

Genotypes	Grains / spike		1000 grain weight(g)		Biological yield/ plant(g)		Grain yield per plant(g)		Harvest index (%)		Ash content		Gluten content	
	gca	Mean	gca	Mean	gca	Mean	gca	Mean	gca	Mean	gca	Mean	gca	Mean
MP1236	4.35**	62.70	0.41	42.24	-0.66*	38.43	0.34	17.90	1.71**	46.57	0.028	1.655	-0.26**	8.41
PBW550	2.40**	63.30	-0.76*	39.23	-0.33	35.76	-0.11	16.20	-0.01	45.29	0.032	1.177	-0.26**	8.18
WH1094	2.93**	61.30	0.53	42.62	-0.11	38.90	0.10	18.60	0.33	47.86	0.064**	1.577	0.07*	8.76
PBW590	-2.18**	48.10	-0.05	39.64	-0.46	38.76	-0.31	17.06	-0.24	44.06	-0.036*	1.288	0.01	8.68
PBW373	1.94**	52.43	2.28**	46.82	8.56**	50.23	4.22**	28.30	-0.20	56.32	0.030	1.532	-0.05	8.73
RAJ3765	-2.46**	47.90	0.42	40.82	0.50	39.66	0.52**	21.80	0.85	55.38	-0.025	1.444	-0.00	8.80
DBW58	-1.82**	50.53	0.81*	43.46	-0.92**	34.66	-0.84**	16.70	-0.87	48.13	-0.058**	1.377	-0.02	8.50
HD2687	-0.06	52.76	-3.18**	35.58	-1.68**	35.03	-1.36**	14.76	-1.31**	42.15	-0.003	1.566	0.15**	9.00
DBW17	-2.89**	49.56	-1.18**	37.86	-1.56**	36.66	-0.97**	16.86	-0.43	46.01	-0.034*	1.488	0.08*	8.75
WH711	-2.20**	49.13	0.71*	40.14	-3.32**	35.96	-1.60**	16.70	0.17	46.42	0.002	1.533	0.29**	9.35
Mean		53.77		40.84		38.41		18.49		47.81		1.464		8.72
Range		47.90-		35.58-		34.66		14.76-		42.14-		1.180-		8.18-
		63.30		46.82		50.23-		28.30		56.32		1.653		9.35
S.E.		1.08		1.024		0.60		0.90		2.64		0.077		0.09
SE (Gi)	0.71		0.76		0.58		0.44		1.05		0.038		0.07	
SE (Gi-Gj)	1.06		1.14		0.86		0.65		1.57		0.056		0.10	

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Table 3. Estimates of sca effects along with mean performance of crosses for grain yield and its components traits in wheat

Crosses	Days to 50% Flowering		Days to maturity		Number of productive tillers/plant		Plant height (cm)		Flag leaf area (cm^2)		Spike length (cm)		Spikelets/ spike	
	sca	Mean	sca	Mean	sca	Mean	sca	Mean	sca	Mean	sca	Mean	sca	Mean
MP 1236xPBW 550	-1.90**	84.00	-0.19	136.66	1.03**	10.20	1.97**	98.10	2.57*	40.39	0.47**	9.61	0.43*	20.80
MP 1236xWH 1094	1.26*	90.00	-0.30	138.00	0.94**	9.90	-1.54*	87.66	-0.85	32.87	0.54**	9.88	0.31	20.70
MP 1236xPBW 590	0.57	89.66	-2.33**	136.66	-0.47	9.40	-1.77*	93.00	-4.50**	30.17	0.44**	9.86	0.40*	20.16
MP 1236xPBW 373	1.23*	89.33	0.45	139.66	0.45	9.47	-1.26	97.93	3.29**	45.00	0.35*	10.20	0.12	20.16
MP 1236xRAJ 3765	0.01	89.33	0.92	140.33	0.33	9.17	-1.21	97.96	2.10*	45.07	-0.08	8.78	-0.53**	19.40
MP 1236xDBW 58	3.10**	94.00	1.89**	141.00	-0.35	8.17	-3.28**	93.73	-0.14	36.37	0.34*	9.45	-0.24	19.83
MP 1236xHD 2687	2.87**	94.33	0.20	138.66	-0.32	8.47	-2.28**	93.93	3.76**	41.39	-0.10	9.06	-0.22	20.20
MP 1236xDBW 17	1.71**	93.00	2.03**	141.00	-0.50	8.03	-0.54	89.83	-1.23	32.72	-0.01	8.96	-0.32	19.86
MP 1236xWH 711	-0.71	91.33	-0.28	140.00	0.24	9.20	0.64	89.76	2.83**	40.91	-0.34*	8.40	0.07	20.30
PBW 550xWH 1094	-1.90**	86.00	-0.97*	136.33	0.17	9.10	2.96**	89.26	-4.49**	34.35	0.33*	9.73	0.20	20.36
PBW 550xPBW 590	-1.27*	87.00	0.67	138.66	0.70*	10.53	-0.11	91.76	-4.24**	35.56	0.17	9.65	0.68**	20.23
PBW 550xPBW 373	-1.27*	86.00	1.11*	139.33	-0.08	8.90	-3.96**	92.33	6.18**	53.02	-0.47**	9.43	0.17	20.00
PBW 550xRAJ 3765	1.85**	90.33	-0.41	138.00	-0.30	8.50	-1.42*	94.86	1.89	49.98	0.25	9.16	-0.22	19.50
PBW 550xDBW 58	1.93**	92.00	0.22	138.33	-0.08	8.40	-0.92	93.20	1.55	43.18	0.47**	9.63	-0.05	19.80
PBW 550xHD 2687	2.37**	93.00	-1.47**	136.00	-0.25	8.50	-1.55*	91.76	4.28**	47.05	0.45**	9.66	-0.44*	19.76
PBW 550xDBW 17	1.21*	91.66	-0.30	137.66	0.20	8.70	1.22	88.70	4.92**	44.00	-0.15	8.88	-0.77**	19.20
PBW 550xWH 711	1.79**	93.00	2.39**	141.66	-0.15	8.77	-3.26**	82.96	1.29	44.50	-0.31*	8.48	-0.31	19.70
WH 1094xPBW 590	-0.10	91.00	-0.44	139.00	0.84*	10.47	-8.41**	76.53	-1.63	34.07	0.33*	10.01	0.66**	20.23
WH 1094xPBW 373	0.23	90.33	0.00	139.66	0.02	8.80	3.07**	92.43	2.07*	44.81	0.13	10.23	-0.12	19.73
WH 1094xRAJ 3765	-0.99	90.33	0.81	140.66	0.07	8.67	0.91	90.26	6.12**	50.12	-0.14	8.98	-0.10	19.63
WH 1094xDBW 58	-0.90	92.00	-0.22	139.33	0.19	8.47	5.18**	92.36	-1.25	36.29	0.28	9.65	-0.04	19.83
WH 1094xHD 2687	0.21	93.66	0.09	139.00	0.09	8.63	2.99**	89.36	2.46*	41.12	0.24	9.66	-0.32	19.90
WH 1094xDBW 17	0.71	94.00	-0.08	139.33	0.27	8.57	-1.65*	78.90	-0.16	34.81	-0.33*	8.90	0.18	20.16

Contd….

Table 3 Contd…

Crosses	Days to 50% Flowering		Days to maturity		Number of productive tillers/plant		Plant height (cm)		Flag leaf area (cm^2)		Spike length (cm)		Spikelets/ spike	
	sca	Mean	sca	Mean	sca	Mean	sca	Mean	sca	Mean	sca	Mean	sca	Mean
WH 1094xWH 711	-1.04*	93.00	-0.05	140.66	-0.15	8.57	-1.83*	77.46	2.08*	41.19	-0.76**	8.23	-0.13	19.90
PBW 590xPBW 373	0.54	91.00	0.64	141.00	0.95**	10.63	0.34	95.26	4.16**	47.87	-0.02	10.16	0.33	19.56
PBW 590xRAJ 3765	0.65	92.33	0.78	141.33	-0.57	8.93	1.25	96.16	-1.27	43.67	-0.02	9.18	0.51**	19.63
PBW 590xDBW 58	-0.60	92.66	0.09	140.33	0.32	9.50	0.18	92.93	1.52	40.01	-0.30	9.15	0.68**	19.93
PBW 590xHD 2687	-0.82	93.00	0.72	140.33	-0.01	9.43	0.85	92.80	6.47**	46.09	-0.37*	9.13	0.09	19.70
PBW 590xDBW 17	0.01	93.66	0.22	140.33	0.50	9.70	5.05**	91.16	3.17**	39.10	-0.06	9.25	0.06	19.43
PBW 590xWH 711	0.60	95.00	-0.08	141.33	0.05	9.67	-2.36**	82.50	-1.67	38.40	-0.02	9.05	-0.12	19.30
PBW 373xRAJ 3765	-1.02*	89.66	-1.44**	139.33	-0.05	8.60	-0.38	98.96	1.17	53.16	0.11	9.73	0.77**	20.16
PBW 373xDBW 58	-0.27	92.00	0.20	140.66	0.30	8.63	-4.28**	92.90	-6.94**	38.59	0.13	10.00	0.53**	20.06
PBW 373xHD 2687	-0.82	92.00	-0.16	139.66	-0.23	8.37	-2.80**	93.56	-5.87**	40.78	-0.73**	9.20	0.68**	20.56
PBW 373xDBW 17	-1.32*	91.33	-1.66**	138.66	0.42	8.77	-0.37	90.16	-1.64	41.33	0.71**	10.45	0.69***	20.33
PBW 373xWH 711	1.60**	95.00	-0.64	141.00	-0.17	8.60	5.48**	94.76	3.35**	50.46	0.43**	9.93	0.44*	20.13
RAJ 3765xDBW 58	-0.15	93.33	-0.33	140.33	0.79*	8.93	-3.96**	93.20	0.16	46.94	-0.64**	8.25	0.41*	19.83
RAJ 3765xHD 2687	0.62	94.66	-0.36	139.66	0.22	8.63	-0.33	96.03	-3.02**	44.88	0.48**	9.41	0.20	19.96
RAJ 3765xDBW 17	-0.88	93.00	0.14	140.66	0.30	8.47	0.31	90.83	1.20	45.42	0.15	8.90	0.53**	20.06
RAJ 3765xWH 711	0.37	95.00	-0.83	141.00	0.71*	9.30	2.49**	91.76	-0.48	47.88	0.25	8.76	0.32	19.90
DBW 58xHD 2687	-1.96**	93.67	-0.39	139.33	1.87**	9.97	-0.66	93.53	-2.46*	38.99	-0.66**	8.53	0.06	19.96
DBW 58xDBW 17	0.54	96.00	-1.55**	138.66	0.55	8.40	0.54	88.90	-1.30	36.46	0.15	9.15	0.20	19.86
DBW 58xWH 711	0.46	96.67	-0.53	141.00	0.50	8.77	2.66**	89.76	5.15**	47.05	0.66**	9.41	0.18	19.90
HD 2687xDBW 17	-1.02*	95.00	-0.91	138.66	0.85*	8.97	2.21**	89.76	-1.17	37.72	-0.27	8.78	0.05	20.06
HD 2687xWH 711	-1.10*	95.67	1.11*	142.00	0.57	9.10	2.27**	88.56	-1.93	41.11	0.55**	9.36	0.43*	20.50
DBW 17xWH 711	-0.60	96.00	0.28	141.66	0.28	8.57	-1.53*	78.93	4.19**	43.53	0.04	8.66	-0.13	19.70
Mean		92.11		139.61		9.01		90.81		41.96		9.31		19.95
		84.00-96.67		136.00-142.00		8.03-10.63		76.53-98.96		30.17-53.15		8.23-10.45		19.20-20.80
S.E.		0.56		0.52		0.34		0.78		1.10		0.17		0.18
SE (Sij)	1.00		0.93		0.66		1.37		1.95		0.31		0.35	
SE (Sij-Sik)	1.47		1.37		0.98		2.02		2.87		0.45		0.51	

Table 3. Contd..

Crosses	Grains / spike		1000 grain weight (g)		Biological yield per plant (g)		Grain yield per plant (g)		Harvest index		Ash content		Gluten content	
	sca	Mean	sca	Mean	sca	Mean	sca	Mean	sca	Mean	sca	Mean	sca	Mean
MP 1236xPBW 550	4.19**	64.90	0.23	39.05	3.92**	43.83	1.79**	22.53	-0.51	51.39	0.066	1.666	0.29**	8.71
MP 1236xWH 1094	1.62	62.86	1.12	41.22	3.54**	43.66	1.48*	22.43	-0.89	51.35	0.097	1.733	0.20	8.94
MP 1236xPBW 590	2.43*	58.56	-0.28	39.25	-1.28	38.50	-0.95	19.60	-0.79	50.88	0.153**	1.688	0.04	8.73
MP 1236xPBW 373	-1.33	58.93	2.06	43.91	3.80**	52.60	2.22**	27.30	0.19	51.90	-0.256**	1.344	-0.07	8.56
MP 1236xRAJ 3765	-3.79**	52.06	-1.22	38.77	-1.17	39.56	0.36	21.73	2.22	54.98	-0.254**	1.288	0.01	8.68
MP 1236xDBW 58	0.07	56.56	-1.01	39.38	-1.38	37.93	-0.05	19.96	1.61	52.65	-0.044	1.466	0.07	8.73
MP 1236xHD 2687	-0.75	57.50	-1.84	34.55	-3.29**	35.26	0.20	19.70	5.27**	55.86	0.088	1.655	-0.04	8.78
MP 1236xDBW 17	-5.12**	50.30	-3.55**	34.85	-2.08*	36.60	0.25	20.13	3.78*	55.26	-0.002	1.533	-0.05	8.71
MP 1236xWH 711	2.62*	58.73	-0.00	40.29	0.25	37.16	1.28	20.53	3.22*	55.29	0.039	1.610	-0.44**	8.54
PBW 550xWH 1094	1.55	60.83	-1.80	37.14	0.11	40.56	0.39	20.90	0.99	51.51	0.001	1.632	-0.38**	8.36
PBW 550xPBW 590	3.69**	57.86	0.81	39.17	0.88	41.00	1.07	21.16	1.62	51.57	0.173**	1.710	0.48**	9.16
PBW 550xPBW 373	-0.24	58.06	-1.10	39.58	5.20**	54.33	3.23**	27.86	1.29	51.28	0.151**	1.755	-0.22*	8.40
PBW 550xRAJ 3765	-1.10	52.80	-0.95	37.88	1.13	42.20	0.37	21.30	-0.57	50.47	0.110	1.655	-0.19	8.48
PBW 550xDBW 58	-4.14**	50.40	-0.05	39.16	-1.55	38.10	-0.10	19.46	1.80	51.13	0.129*	1.644	0.06	8.71
PBW 550xHD 2687	-5.30**	51.00	-2.11	33.12	-0.32	38.56	0.58	19.63	2.04	50.91	0.231***	1.799	-0.33**	8.49
PBW 550xDBW 17	-4.57**	48.90	1.24	38.47	-1.81*	37.20	-0.17	19.26	2.03	51.79	-0.039	1.499	0.64**	9.39
PBW 550xWH 711	-3.16**	51.00	0.57	39.69	1.38	38.63	1.05	19.86	1.08	51.43	0.025	1.599	0.11	9.08
WH 1094xPBW 590	3.56**	58.26	-0.69	38.95	3.27**	43.60	2.19**	22.50	1.33	51.61	0.021	1.588	-0.05	8.97
WH 1094xPBW 373	2.67*	61.50	0.10	42.07	-1.15	48.20	-0.28	24.56	0.65	50.97	0.002	1.632	0.16	9.10
WH 1094xRAJ 3765	-4.53**	49.90	-2.33*	37.78	-0.78	40.50	-0.03	21.10	0.67	52.04	-0.146*	1.433	0.22*	9.22
WH 1094xDBW 58	-3.83**	51.23	0.91	41.40	1.73*	41.60	1.02	20.80	0.38	50.04	0.007	1.555	0.04	9.02
WH 1094xHD 2687	-1.66	55.16	-1.74	34.77	-1.14	37.96	0.34	19.60	2.41	51.62	-0.011	1.588	0.03	9.18
WH 1094xDBW 17	0.57	54.56	-0.44	38.07	-0.09	39.13	0.25	19.90	0.75	50.85	0.096	1.666	0.33**	9.41
WH 1094xWH 711	-2.92**	51.76	0.07	40.48	-1.93*	35.53	-1.12	17.90	-0.32	50.37	0.116*	1.722	0.06	9.36
PBW 590xPBW 373	-4.72**	49.00	-1.08	40.32	3.53**	52.53	2.10**	26.53	0.76	50.52	0.055	1.588	0.02	8.91

Contd…

Table 3. Contd…

Crosses	Grains / spike		1000 grain weight (g)		Biological yield per plant (g)		Grain yield per plant (g)		Harvest index		Ash content		Gluten content	
	sca	Mean	sca	Mean	sca	Mean	SCA	Mean	sca	Mean	sca	Mean	sca	Mean
PBW 590xRAJ 3765	1.35	50.66	1.62	38.90	-1.31	39.63	-0.79	19.93	-0.50	50.31	0.153**	1.633	-0.13	8.82
PBW 590xDBW 58	3.18**	53.13	-1.03	36.68	-1.02	38.50	0.07	19.43	1.44	50.53	0.110	1.555	0.35**	9.28
PBW 590xHD 2687	-2.25*	49.46	0.74	38.56	-0.16	38.60	0.49	19.33	1.44	50.09	-0.168**	1.333	0.13	9.23
PBW 590xDBW 17	-1.12	47.76	0.62	37.98	-2.08*	36.80	-0.50	18.73	1.39	50.91	-0.038	1.433	-0.36**	8.66
PBW 590xWH 711	-3.11**	46.46	-1.85	40.76	0.61	37.73	1.99**	20.60	4.63**	54.75	-0.094	1.410	0.08	9.32
PBW 373xRAJ 3765	4.95**	58.40	-1.10	39.67	0.08	50.03	-2.52**	22.73	-5.35**	45.50	0.068	1.610	0.14	9.02
PBW 373xDBW 58	1.35	55.43	-2.58*	36.99	1.47	50.00	-1.50*	22.40	-4.33**	44.80	0.044	1.555	0.01	8.87
PBW 373xHD 2687	1.29	57.13	-1.27	39.12	2.39**	50.16	-0.78	22.60	-3.58*	45.11	0.113	1.677	0.14	9.17
PBW 373xDBW 17	4.72***	57.73	-1.15	42.08	-1.23	46.66	-1.44*	22.33	-1.72	47.85	-0.071	1.466	0.00	8.96
PBW 373xWH 711	2.13*	55.83	-0.07	42.39	1.47	47.60	0.29	23.43	-0.95	49.22	0.023	1.599	0.02	9.19
RAJ 3765xDBW 58	0.19	49.86	2.00	36.09	4.29**	44.76	1.71*	21.90	-1.28	48.90	0.122*	1.577	-0.01	8.90
RAJ 3765xHD 2687	3.63**	55.06	-0.31	37.47	3.98**	43.70	2.03**	21.70	-0.06	49.67	-0.092	1.422	0.12	9.20
RAJ 3765xDBW 17	2.09	50.70	-0.93	41.89	2.13*	41.96	0.47	20.53	-1.72	48.90	0.151**	1.633	-0.19	8.82
RAJ 3765xWH 711	-0.50	48.80	1.59	34.93	-3.91**	34.16	-2.10**	17.33	-0.42	50.79	-0.018	1.499	0.26*	9.49
DBW 58xHD 2687	1.42	53.50	-1.86	38.77	0.07	38.36	0.48	18.80	0.98	49.00	-0.093	1.388	0.21	9.26
DBW 58xDBW 17	1.85	51.10	-0.02	38.97	8.08**	46.50	3.93**	22.63	-0.24	48.66	-0.116*	1.333	-0.01	8.98
DBW 58xWH 711	-0.54	49.40	-1.72	36.15	-2.92**	33.73	-1.28	16.80	0.28	49.78	-0.062	1.422	0.06	9.26
HD 2687xDBW 17	-0.91	50.10	1.34	38.20	0.58	38.23	1.11	19.30	2.01	50.46	-0.070	1.433	0.15	9.31
HD 2687xWH 711	6.67**	58.36	1.50	39.51	2.90**	38.80	1.61*	19.16	0.34	49.39	-0.063	1.477	0.04	9.41
DBW 17xWH 711	-0.30	48.56	0.81	38.90	-1.28	34.73	-0.48	17.46	0.37	50.31	0.057	1.566	0.15	9.46
Mean		54.00		38.79		41.45		20.96		50.72		1.557		8.98
Range		46.46-64.90		33.12-43.91		33.73-54.33		16.80-27.86		44.80-55.86		1.290-1.800		8.36-9.49
S.E.		1.15		1.28		0.99		0.65		1.40		0.057		0.11
SE (Sij)	2.12		2.29		1.74		1.31		3.15		0.113		0.21	
SE (Sij-Sik)	3.12		3.36		2.55		1.92		4.64		0.166		0.30	

Table 4. Best cross on basis of negative and positive highest significant sca effects in different contributing traits

Characters	**Best cross on basis of negative and positive desirable direction highest significant sca effects**
Days to 50% Flowering	DBW 58 x HD 2687, MP 1236 x PBW550, PBW550 x WH 1094, PBW 373 x DBW 17, PBW550 x PBW 590
Days to maturity	MP 1236 x PBW590, PBW 373 x DBW 17, DBW 58 x DBW 17, PBW550 x HD 2687, PBW 373 x RAJ 3765
Number of tillers per plant	DBW 58 x HD 2967, MP 1236 x PBW550, PBW590 x PBW 373, MP 1236 x WH 1094, HD 2687 x DBW 58
Plant height (cm)	WH1094 x PBW 590, PBW 373 x DBW 58, PBW550 x PBW 373, RAJ 3765 x DBW 58, MP 1236 x DBW58
Flag leaf area (cm^2)	PBW 590 x HD 2687, PBW550 x PBW 373, WH1094 x RAJ 3765, DBW 58 x WH 711, PBW550 x DBW 17
Spike length (cm)	PBW 373 x DBW 17, DBW 58 x WH 711, DBW 17 x WH 711, MP 1236 x WH 1094, RAJ 3765 x HD 2687
Spikelets per spike	PBW 373 x RAJ 3765, PBW 373 x DBW 17, PBW 590 x DBW 58, PBW 373 x HD 2687, PBW550 x PBW 590
Grains per spike	HD 2687 x WH 711, PBW 373 x RAJ 3765, PBW 373 x DBW 17, MP 1236 x PBW 550, PBW550 x PBW 590
1000 grain weight (g)	MP1236 x PBW373, PBW590 x RAJ3765, RAJ3765 x WH711, HD2687 x WH711, HD2687 x DBW17
Biological yield per plant (g)	DBW 58 x DBW 17, PBW550 x PBW 373, RAJ 3765 x DBW 58, RAJ 3765 x HD 2687, MP 1236 x PBW 550
Grain yield per plant (g)	DBW 58 x DBW 17, PBW550 x PBW 373, MP 1236 x PBW 373, WH1094 x PBW 590, PBW 590 x PBW 373
Harvest index	MP 1236 x HD 2687, PBW590 x WH 711, MP 1236 x DBW 17, MP 1236 x WH 711
Ash content	PBW550 x HD 2687, PBW550 x PBW 590, MP 1236 x PBW590, PBW 590 x RAJ 3765, PBW550 x PBW 373
Gluten content	PBW550 x DBW 17, PBW550 x PBW 590, PBW 590 x DBW 58, WH 1094 x DBW 17, MP 1236 x PBW550