Original Research Article

Heterosis and Combining Ability Analysis for yield and its Component traits in Bread Wheat (*Triticum aestivum* L.)

ABSTRACT

The study was done on 36 treatments of wheat 25 F_1, 10 parental lines and 1 check (GW-451) in Randomized Block Design (RBD) with three replications during *Rabi* season 2021-2022,. The observations were recorded on twelve characters, namely, Days to 50% heading, Days to maturity, Number of effective tillers per plant, Plant height (cm), Length of main spike (cm), Grain filling period, Number of spikelets per main spike, Number of grains per main spike, 100-grain weight (g), Grain yield per plant (g), Biological yield per plant (g), Harvest index (%). The analysis of variance (ANOVA) conducted for both the experimental design and line x tester mating design revealed the presence of sufficient genetic variability among genotypes. Combining ability analysis elucidated higher magnitude of σ^2s (estimated variance due to sca) than σ^2g (estimated variance due to gca) indicating presence of non-additive gene action for all the characters. A significant GCA effects for grain yield per plant and other crucial traits was exhibited by two lines and two tester which were PBW677, HD3226 for line and C-306, CHIRYA 3 in F_1 generation. These specific lines possess valuable qualities as promising parental candidates for hybridization programs. Positive sca effects for grain yield per plant and some other yield components was exhibited by Eleven crosses showed significance. A wide range of variation in the estimates of heterobeltiosis and standard heterosis in positive and negative direction was observed for grain yield per plant in F1. In case of grain yield per plant ten crosses showed positive and significant heterosis over BP and the best among them were DBW222 X HD2967 (68.59), PBW677 X WH711 (55.63), DBW187 X CHIRYA3 (54.03) and HD3226 X CHIRYA3 (44.90). Ten crosses exhibited positive and significant heterosis over standard variety were HD3226 X C-306 (61.68), PBW677 X WH1105 (55.36), DBW187 X CHIRYA3 (31.03), PBW677 X C-306 (30.43) and HD3226 X CHIRYA3 (21.12). However, the number of crosses exhibiting significant estimates and the range of heterosis varied across different traits.

Keywords: Combining ability, Line × Tester, Wheat, Heterosis.

INTRODUCTION

Bread Wheat (*Triticum aestivum* L.) plays an important role in cereal crops in the world and in human and animal nutrition. It covers more ground than other field crops and has an unrivaled range of cultivation. (Deniz istipliler *et al.,* 2015)**.** Wheat was chosen as a trial crop because wheat are ranked first worldwide, measured either by cultivated area or production (Akram *et al.,* 2008)**.** Wheat may be produced by using agronomic methods, creating high yielding cultivars, and other methods. High emphasis has been placed on creating improved varieties with good quality and quality attributes in the breeding programme. (Jain *et al.,* 2012). It is commonly grown because of its exceptional ability to adapt to a variety of environments. Triticum species, a member of the Poaceae family, are native to the Middle East area of Asia. It makes up around 32% of the world's total area planted with grains. While emmer wheat (Tetraploid 2n=28) is only produced in the southern states of India and a small portion of Gujarat, bread wheat (Hexaploid 2n=42) and macaroni wheat (Tetraploid 2n=28) are both primarily grown in the central and southern regions as well as in the north-west. India is the world's second-largest producer of wheat (Kundan *et al.,* 2010). Wheat was chosen as a trial crop because it ranks first worldwide in terms of planted area or production, and it can be produced using agronomic techniques and high-yielding varieties. Excellent emphasis has been placed on the breeding effort on generating improved varieties with high quality and quality attributes. Plant breeders used to combine the ability to choose the parent with height potential for transmitting the desirable genes to the progeny, which is a vital duty in a breeding program (Askander *et al.,* 2021).

Heterosis has been measured in a variety of cultivated crops and is an important topic to research as a means of enhancing crop plant yield. Heterosis occurs because of the combination of different alleles from the two parents. Alleles are alternative forms of genes that control specific traits. Each parent may carry different alleles, and when they are combined in the offspring, certain combinations can result in enhanced traits (Kajla *et al.,* 2020)

The concept of combining ability is important in the plant breeding as a measure which provides the gene action involved in control of yield and other important attributes and thus also provides a basis for adopting a suitable breeding procedure (Sprague and Tatum, 1942). The line x tester analysis is precise approach to estimate the general and specific combining ability effects of parents and at the same time is useful in estimating various types of gene effects (Kempthorne 1957).

MATERIAL AND METHODS

The present study "Heterosis and combining ability for grain yield and its components in bread wheat (*Triticum aestivum* L.)" was carried out during the two successive *rabi* seasons 2022 at the post graduation research farm, School of Agriculture, Lovely professional University. The aim of this work was to study the general (GCA) and specific (SCA) combining ability and heterosis through half diallel mating among ten different wheat varieties.

A line x tester set of 25 hybrids or F_1 derived by crossing five wheat genotypes varieties as lines (females) were (DBW222 (Karan Narendra), HD3226 (Pusa Yashasvi), HD3086 (Pusa Gautami), DBW187 (Karan Vandana), PBW677) with 5 testers (males) were (HD2967, WH711, Chirya 3, C-306, WH1105) and check (GW- 451). The 25 F_1's along with their parents and check varieties, will be evaluated in randomized complete block design with three replications during Rabi 2022-2023. The Area is 192 m^2 and spacing of 22.5 x15 cm. Sowing was done on 15 November 2022.

Five competitive plants per genotype in each replication were randomly selected for the purpose of recording observations on different characters and their averages were used in statistical analysis. The following procedure were adopted for recording observations.The biometric observations were recorded on twelve characters, namely, Days to 50% heading, Days to maturity, Number of effective tillers per plant, Plant height (cm), Length of main spike (cm), Grain filling period, Number of spikelets per main spike, Number of grains per main spike, 100-grain weight (g), Grain yield per plant (g), Biological yield per plant (g), Harvest index (%).

General and specific combining ability estimates were obtained by employing Griffins diallel cross analysis, model 1(fixed model) method 2 (Griffing, 1956). Heterosis effect (Heterobeltiosis) was computed as the percentage increase of F1 over the better parent according to Wynne et al. (1970).Assessing genetic variability is an essential step in initiating any crop improvement program. The analysis of variance (ANOVA) conducted for the experimental design demonstrated the presence of significant and exploitable variability within the examined material, specifically in terms of various morphological traits. This observation indicates the substantial potential for genetic enhancement in wheat through selective breeding and genetic improvement strategies.

RESULT AND DISCUSSION

1. Analysis of variance:

Analysis of variance for line x tester mating design revealed that variance due to treatments, parents (lines), crosses, parents vs crosses and line × testers interaction were highly significant for all the traits in F1. Variance due to parents (tester) was highly significant for all the characters except significant variances for the Length of the main spike in F1s. Variance due to line vs tester was highly significant for all the characters except non-significant variances for Length of the main spike (cm), Grain filling period, Grain yield per plant, and Biological yield per plant in F1s. Variances due to Parents vs crosses were highly significant for all the characters except Days to maturity, Number of effective tillers per plant, and Grain filling period in F1s, while lines effect were non-significant for all the characters except Days to 50% heading, Plant height, and Biological yield per plant, show significant in F1s. It further revealed that mean squares due to line × testers interaction were highly significant for all the characters in F1s. The variances due to the tester effect were non-significant for all the twelve characters except highly significant variances for Days to 50% heading and Biological yield per plant while significant for Days to maturity and grain filling period. Analysis of variances due to most of the parents and crosses revealed significant genotypic effect for all the characters under study. This provides evidence of the presence of sufficient genetic variability among lines, testers, and hybrids and allows further assessment of general combining ability analysis.

The highest mean performance for grain yield per plant along with some of the component traits was exhibited by lines, HD3226 (50.10), DBW187 (47.33) testers, C-306 (81.80), WH1105 (70.38) and crosses, HD3086 X C-306 (82.13), HD3226 X WH1105 (81.73), DBW187 X C-306 (80.10), PBW677 X WH711 (77.60), DBW187 X HD2967 (77.30). The lines can serve as potential donor parents and crosses as potential cross combinations in hybridization programs aimed at developing high- yielding varietieswithin their respective groups.

2. Combining ability analysis:

Combining ability analysis elucidated higher magnitude of σ^2s (estimated variance due to sca) than σ^2g (estimated variance due to gca). The values of dominance genetic variance (σ^2D) were higher than additive genetic variance (σ^2A) and degree of dominance were more than unity (>1) for all the characters under study in F1. Whereas the predictability ratio was lesser than unity (<1) for all the characters under study in F1. These data indicate the presence of non-additive gene action for all the characters.

After analyzing the desirable general combining ability (GCA) effects, it was observed that two lines and two tester which were PBW677, HD3226 for line and C-306, CHIRYA3 for tester in F1 generation exhibited significant GCA effects for grain yield per plant and other crucial traits. These lines can be considered as valuable parental candidates for hybridization programs, aimed at obtaining high-yielding wheat varieties or generating transgressive segregants for the development of pure line varieties. Their selection as parents can potentially contribute to the enhancement of key traits and the overall improvement of wheat genotypes.

Parent PBW677 was found good combiner for grain yield per plant along with Days to 50% heading, Length of main spike, 100-grain weight, biological yield per plant, Harvest index. Parent HD3226 for grain yield per plant with days to Days to 50% heading, Days to maturity, Number of effective tillers per plant, Plant height, 100-grain weight, Harvest index.

While, among testers, Parent C-306 was found good general combiner for grain yield per plant in addition to Days to 50% heading, Days to maturity, Plant height, Length of main spike, Number of grains per main spike, Grain yield per plant, Biological yield per plant, Harvest index and Parent CHIRYA3 for grain yield per plant with Number of effective tillers per plant, Grain filling period, Number of spikelet per main spike, Grain yield per plant.

Eleven crosses showed significant and positive sca effects for seed yield per plant as well as some other yield components. Those were PBW677 X WH1105 (6.42), HD3226 X C-306 (5.08), DBW187 X CHIRYA3 (4.69), DBW222 X HD2967 (4.04), DBW187 X HD2967 (3.69), HD3086 X WH711 (1.96), PBW677 X WH711 (1.95), HD3226 X CHIRYA3 (1.57), HD3086 X C-306 (1.36), HD3226 X WH1105 (1.26) and DBW222 X WH711 (1.21). The above-mentioned crosses may be considered for utilization in breeding program for yield enhancement.

The cross PBW677 X WH1105 was the most promising as it had high significant sca effects for grain yield per plant along with plant height, Number of spikelets per main spike, Number of grains per main spike, and 100-grain weight in F1 and HD3226 X C-306 for all trait except Number of effective tillers per plant, Plant height, Number of grains per main spike, 100-grain weight, Biological yield per plant and Harvest index; cross DBW187 X CHIRYA3 for Days to 50% heading, Number of effective tillers per plant, plant height, Grain filling period, Number of grains per main spike, Biological yield per plant and Harvest index in F1.

A critical examination of the results revealed that crosses demonstrating high-order significant and desirable SCA effects for different traits involved parents with various combinations of general combining ability (GCA) effects. These combinations included high × high (H × H), high × average (H × A), high × low (H × L), average × average (A × A), average × low (A × L), and low × low (L× L) GCA effects. In case of grain yield per plant ten crosses showed positive and significant heterosis over BP and the best among them were DBW222 X HD2967 (68.59), PBW677 X WH711 (55.63), DBW187 X CHIRYA3 (54.03) and HD3226 X CHIRYA3 (44.90). Ten crosses exhibited positive and significant heterosis over standard variety were HD3226 X C-306 (61.68), PBW677 X WH1105 (55.36), DBW187 X CHIRYA3 (31.03), PBW677 X C-306 (30.43) and HD3226 X CHIRYA3 (21.12).

A wide range of variation in the estimates of heterobeltiosis and standard heterosis in positive and negative direction was observed for grain yield per plant in F1. In case of grain yield per plant ten crosses showed positive and significant heterosis over BP and the best among them were DBW222 X HD2967 (68.59), PBW677 X WH711 (55.63), DBW187 X CHIRYA3 (54.03) and HD3226 X CHIRYA3 (44.90). Ten crosses exhibited positive and significant heterosis over standard variety were HD3226 X C-306 (61.68), PBW677 X WH1105 (55.36), DBW187 X CHIRYA3 (31.03), PBW677 X C-306 (30.43) and HD3226 X CHIRYA3 (21.12). However, the number of crosses exhibiting significant estimates and the range of heterosis varied across different traits. Overall, several crosses displayed notable and substantial heterosis for the majority of the traits examined in this study. The wide range of heterosis observed, in both positive and negative directions, along with the expression of significant desirable heterosis by certain crosses for all the traits investigated.

CONCLUSION

The present investigation titled "Heterosis and combining ability for grain yield and its components in bread wheat (*Triticum aestivum* L.)" aimed to study the combining ability variances and their effects, understand the nature of gene actions involved in the inheritance of various traits, and estimate the nature and magnitude of heterosis for grain yield and its component traits in wheat. The study was conducted during the Rabi season of 2021-2022 and 2022-2023 at Lovely Professional University, Punjab. The experimental materials consisted of 36 treatments, including 25 F1 hybrids, 10 parental lines, and 1 check variety. The materials were evaluated using a randomized block design with three replications. Twelve traits related to growth, development, and yield were recorded. The data were analyzed using various statistical methods to assess genetic variability, combining ability, heritability, gene actions, and heterosis. The analysis revealed significant variability among the materials, indicating the potential for genetic enhancement in wheat through selective breeding. The combining ability analysis showed the importance of both general and specific combining abilities, with non-additive gene actions playing a significant role in trait inheritance. Certain parental lines and testers exhibited significant general combining ability effects for grain yield and other important traits, making them valuable candidates for hybridization programs. Specific crosses also showed significant and positive effects for seed yield and other yield components. These crosses can be considered for further breeding programs aimed at yield enhancement. Moreover, the study observed a wide range of heterosis, both positive and negative, for grain yield and other traits, suggesting the possibility of developing high-yielding varieties through hybridization. Overall, the results of this study provide valuable insights into the genetic variability, combining ability, and heterosis in wheat, which can contribute to the improvement of wheat genotypes and the development of high-yielding varieties.

Table 1: Analysis of variance for 12 characters in line x tester mating design in wheat including parents in F1 generation:

	Source of variation											
Characters	**Replications**	**Treatments**	**Parents**	**Lines**	**Testers**	**Lines vs testers**	**Parents vs crosses**	**Crosses**	**Line Effect**	**Tester Effect**	**Line vs Testers Effect**	**Error**
d.f	**2**	**34**	**9**	**4**	**4**	**1**	**1**	**24**	**4**	**4**	**16**	**68**
Days to 50% heading	5.29	107.01**	98.5**	51.23**	144.26**	104.53**	44.43**	112.81**	144.48*	350.48**	45.47**	1.98
Days to maturity	1.62	87.63**	99.63**	52.83**	144.26**	108.30**	15.84	86.12**	54.18	228.15*	58.60**	4.69
Number of effective tillers per plant	0.40	0.40**	5.98**	7.66**	4.80**	3.96**	0.04	5.57**	3.36	5.40	6.16**	0.23
Plant height (cm)	0.37	133.9**	89.48**	118.7**	81.76**	3.20*	16.79**	155.5**	368.1*	200.07	91.21**	0.70
Length of main spike (cm)	0.08	2.18**	0.97**	1.69**	0.41*	0.32	0.79*	2.69**	4.95	2.15	2.26**	0.12
Grain filling period	2.78	66.37**	82.59**	58.73**	126.9**	0.83	1.76	62.99**	60.88	140.34*	44.180**	1.23
Number of spikelets per main spike	0.17	10.46**	13.83**	17.67**	4.38**	36.30**	4.88**	9.42**	8.86	11.10	9.15**	0.33
Number of grains per main spike	44.38**	165.18**	196.78**	143.66**	267.78**	125.25**	359.86**	145.22**	201.18	194.02	119.03**	8.52
100-grain	0.007	1.39**	1.04**	1.003**	1.29**	0.22**	0.80**	1.54**	1.34	2.02	1.47**	0.02

weight (g)												
Grain yield per plant (g)	1.66	95.79**	156.24**	271.13**	80.40**	0.04	129.14**	71.74**	127.78	112.85	47.45**	1.15
Biological yield per plant (g)	7.72	394.73**	651.29**	1136.26**	318.93**	40.83	1104.69**	268.94**	488.74*	682.74**	110.54**	11.18
Harvest index (%)	2.50	707.24**	899.80**	998.59**	1021.43**	18.15**	2601.79**	556.09**	592.82	889.94	463.44**	1.47

Table 2: Summary of general combining ability effects for other characters of good general combiner parents for seed yield per plant in wheat in F1

Characters / Parents	Days to 50% heading	Days to maturity	No. of effective tillers/plant	Plant height (cm)	Length of spike	Grain filling period	No. of spikelet/ spike	No. of grains/ spike	100-grain Wt. (g)	Grain yield/ plant (g)	Biological yield/ plant(g)	Harvest index (%)
PBW677	®	±	O	+	+	®	O	±	+	+	+	+
HD3226	®	®	®	®	®	®	±	±	+	+	±	+
C-306	®	®	+	®	+	®	®	+	O	+	+	+
CHIRYA3	+	+	®	+	®	+	+	®	±	+	O	®

+ = Good combiner (Significant and Positive) O = Average combiner (Positive but not significant)

® = Good combiner (Significant and negative) ± = Poor combiner (negative but not significant)

Table 3: Components of variance, degree of dominance, additive and dominance components, and heritability in narrow sense for twelve characters in wheat (F_1):

Characters	gca variance ($\sigma^2 g$)	sca variance ($\sigma^2 s$)	Average degree of	Predictability ratio	$\sigma^2 A$	$\sigma^2 D$	Heritability (ns)

			dominance	$(2\sigma^2\ g/2\sigma^2\ g\ \sigma^2\ s)$			
Days to 50% heading	16.34**	14.38**	0.93	0.53	65.37	57.54	68.31
Days to maturity	8.98**	17.42**	1.39	0.34	35.95	69.69	47.92
Number of effective tillers per plant	0.27	1.97**	2.67	0.12	1.10	7.91	21.22
Plant height (cm)	18.89**	30.17**	1.26	0.38	75.57	120.69	55.4
Length of main spike (cm)	0.22*	0.71**	1.76	0.23	0.91	2.86	37.8
Grain filling period	6.62**	12.31**	1.47	0.34	26.50	57.27	47.36
Number of spikelets per main spike	0.63	2.92**	2.13	0.17	2.55	11.68	29.55
Number of grains per main spike	12.5*	36.34**	1.70	0.25	50.02	145.37	38.66
100-grain weight (g)	0.11	0.48**	2.09	0.18	0.44	1.93	30.97
Grain yield per plant (g)	7.96**	15.5**	1.39	0.33	31.87	62.22	50.18
Biological yield per plant (g)	38.09**	32.05**	0.91	0.54	152.3	128.2	67.39
Harvest index (%)	49.2*	153.8**	1.76	0.24	197.1	615.3	38.95

Table 4: Summary of specific combining ability effects for other characters of good specific combiner crosses for seed yield per plant wheat in F_1

Characters / Parents	Days to 50% heading	Days to maturity	No. of effective tillers/plant	Plant height (cm)	Length of spike	Grain filling period	No. of spikelet/ spike	No. of grains/ spike	100-grain Wt. (g)	Biological yield/ plant(g)	Harvest index (%)	Grain yield/ plant (g)
PBW677 X WH1105	O	O	+	®	O	O	+	+	+	O	O	6.42
HD3226 X C-306	®	®	O	±	+	+	+	®	®	O	®	5.08
DBW187 X CHIRYA3	±	®	+	+	+	®	+	±	+	O	O	4.69
DBW222 X HD2967	O	®	®	+	+	®	®	O	+	+	+	4.04
DBW187 X HD2967	®	O	®	®	±	±	O	±	®	+	+	3.69
HD3086 X WH711	®	®	+	®	O	+	®	+	O	+	+	1.96
PBW677 X WH711	±	+	O	+	O	®	®	®	®	O	+	1.95
HD3226 X CHIRYA3	O	±	®	®	±	+	O	±	+	±	®	1.57
HD3086 X C-306	±	O	O	±	®	±	O	®	+	+	+	1.36
HD3226 X WH1105	±	±	O	+	+	®	O	O	®	+	+	1.26
DBW222 X WH711	+	+	®	+	+	+	+	®	±	®		1.21

+ = Good combiner (Significant and Positive) O = Average combiner (Positive but not significant)

® = Good combiner (Significant and negative) ± = Poor combiner (negative but not significant)

Table 5: Estimates of GCA effects of parents (females and males) for twelve characters in wheat:

Sr. No.	Lines	Days to 50% heading		Days to maturity		Number of effective tillers per plant		Plant height (cm)		Length of main spike (cm)	
		Mean	**GCA**	**Mean**	**GCA**	**Mean**	**GCA**	**Mean**	**GCA**	**Mean**	**GCA**
1.	DBW222	109.00	4.77**	159.67	2.89 **	7.93	0.41	72.93	-4.39**	9.43	0.58**
2.	HD3226	109.67	-3.56**	160.00	-2.173 **	7.87	-0.83**	76.73	-4.02**	9.60	-0.33**
3.	HD3086	105.00	0.90**	155.33	-1.040*	10.27	0.34**	71.00	-2.16**	7.80	-0.75**
4.	DBW187	99.33	-1.09**	149.67	0.49	10.80	0.23*	60.40	4.27**	9.07	-0.04
5.	PBW677	104.00	-1.02**	154.00	-0.17	7.67	0.11	71.80	6.30**	8.67	0.54**
	Mean	105.4		155.734		8.908		70.572		8.91	
	C.D at 5%		0.79		1.30		0.25		0.43		0.17
	SE (gi) lines		0.39		0.64		0.12		0.21		0.08
	SE (gi – gj)		0.55		0.91		0.17		0.30		0.24
TESTER											
1.	HD2967	102.67	-2.22**	152.67	-0.37	9.00	0.19	69.67	-1.94**	8.47	-0.23*
2.	WH711	108.00	-1.02**	158.00	-0.97	7.53	-0.31*	74.80	-0.37	9.07	0.15
3.	CHIRYA3	106.00	4.77**	156.00	4.29**	10.27	-0.48**	66.93	1.31**	8.13	-0.39**
4.	C-306	90.33	-6.36**	140.33	-5.77**	9.97	0.96**	61.07	-4.35**	8.93	0.57**
5.	WH1105	107.33	4.9**	157.33	2.82**	8.20	-0.36**	76.80	5.35**	9.07	-0.11
	Mean	102.86		152.86		8.99		69.85		8.73	
	C.D at 5%		0.81		1.36		0.25		0.48		0.20
	SE (gi) Tester		0.48		0.64		0.12		0.30		0.08
	SE (gi – gj)		0.58		0.91		0.17		0.27		0.29

**, ** significant at 5 and 1 per cent probability levels, respectively.*

Table 5 Cont…

Sr. No.	Lines	Grain filling period		Number of spikelets per main spike		Number of grains per main spike		100-grain weight (g)		Grain yield per plant (g)	
		Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA
1.	DBW222	30.00	3.32**	13.27	1.22**	45.87	6.07**	4.30	-0.29**	7.90	-1.54**
2.	HD3226	40.00	-1.21**	14.00	-0.004	44.40	-1.20	4.11	0.33**	10.73	1.15**
3.	HD3086	35.33	0.52*	11.80	-0.75**	36.80	-0.05	4.13	-0.33**	12.66	-3.58**
4.	DBW187	29.33	-1.41**	18.27	-0.53**	55.47	-3.77**	3.52	0.07*	15.17	-0.19
5.	PBW677	33.33	-1.21**	16.80	0.07	44.53	-1.03	4.56	0.21**	13.87	4.17**
	Mean	33.59		14.82		45.41		4.12		12.06	
	C.D at 5%		0.57		0.32		1.64		0.08		0.46
	SE(gi) lines		0.28		0.16		0.81		0.04		0.22
	SE(gi – gj)		0.40		0.22		1.15		0.06		0.32
TESTER											
1.	HD2967	31.00	-1.61**	15.67	1.28**	48.93	-1.46	4.52	0.02	11.52	-1.25**
2.	WH711	43.00	1.05**	17.67	-0.44**	46.80	4.33**	3.71	-0.56**	13.80	-2.74**
3.	CHIRYA3	36.00	1.52**	14.67	0.47**	45.47	-2.63**	3.06	0.00	14.91	0.67**
4.	C-306	25.33	-4.41**	17.13	-0.53**	67.23	3.33**	4.46	0.07	24.77	4.4**
5.	WH1105	36.33	3.45**	16.93	-0.77**	56.13	-3.56**	3.91	0.464**	23.10	-1.08**
	Mean	34.33		16.41		52.91		3.93		17.62	
	C.D at 5%		0.57		0.36		1.60		0.08		0.50
	SE(gi) Tester		0.28		0.20		0.78		0.04		0.20
	SE(gi – gj)		0.40		0.24		1.09		0.06		0.32

**, ** significant at 5 and 1 per cent probability levels, respectively.*

Table 5 Cont…

Sr. No.	Lines	Biological yield per plant (g)		Harvest index (%)	
		Mean	**GCA**	**Mean**	**GCA**
1.	DBW222	39.00	-7.54**	39.08	-8.05**
2.	HD3226	38.00	-0.61	50.10	5.44**
3.	HD3086	40.67	-3.01**	40.72	-5.41**
4.	DBW187	47.33	4.72**	47.44	5.01**
5.	PBW677	42.00	6.45**	42.00	3.00**
	Mean	41.4		43.86	
	C.D at 5%		1.96		0.71
	SE(gi) lines		0.97		0.35
	SE(gi – gj)		1.38		0.50
TESTER					
1.	HD2967	36.67	-9.14**	34.16	-1.45**
2.	WH711	44.00	-3.81**	44.00	-5.90**
3.	CHIRYA3	51.33	1.65	51.44	-5.43**
4.	C-306	63.33	8.58**	81.80	13.06**
5.	WH1105	72.00	2.72**	70.38	-0.27
	Mean	53.46		56.35	
	C.D at 5%		1.90		0.71
	SE(gi) Tester		0.92		0.35
	SE(gi – gj)		1.29		0.50

**, ** significant at 5 and 1 per cent probability levels, respectively*

Table 6: Estimates of SCA effects of parents (females and males) for twelve characters in wheat.

Sr. No.	Crosses	Days to 50% heading		Days to maturity		Number of effective tillers per plant		Plant height (cm)		Length of main spike (cm)	
		Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA
1.	DBW222 X HD2967	106.00	0.827	150.00	-5.760 **	8.33	-1.208 **	65.60	3.648 **	9.40	0.477 *
2.	DBW222 X WH711	109.67	3.360 **	159.67	4.507 **	8.00	-1.035 **	65.00	1.475 **	9.80	0.491 *
3	DBW222 X CHIRYA3	110.67	-1.507	160.67	0.240	10.67	1.805 **	62.07	-3.152 **	8.47	-0.296
4.	DBW222 X C-306	98.67	-2.373 **	155.67	5.307 **	11.67	1.352 **	58.10	-1.445 **	10.17	0.437 *
5.	DBW222 X WH1105	112.00	-0.307	154.67	-4.293 **	8.07	-0.915 **	68.73	-0.525	7.93	-1.109 **
6.	HD3226 X HD2967	103.67	6.827 **	153.67	2.973 *	8.47	-0.101	67.80	5.475 **	8.00	0.004
7.	HD3226 X WH711	93.33	-4.640 **	154.00	3.907 **	8.73	0.672 *	60.40	-3.499 **	7.60	-0.783 **
8.	HD3226 X CHIRYA3	105.33	1.493	155.33	-0.027	6.93	-0.955 **	62.20	-3.392 **	7.47	-0.369
9.	HD3226 X C-306	90.67	-2.040 *	140.00	-5.293 **	9.60	0.259	59.37	-0.552	9.53	0.731 **
10.	HD3226 X WH1105	102.33	-1.640	152.33	-1.560	8.13	0.125	71.60	1.968 **	8.53	0.417 *
11.	HD3086 X HD2967	105.00	3.693 **	155.00	3.173 *	10.40	0.659 *	62.07	-2.119 **	6.93	-0.649 **
12.	HD3086 X WH711	98.33	-4.107 **	141.67	-9.560 **	9.87	0.632 *	59.53	-6.225 **	8.13	0.164
13.	HD3086 X CHIRYA3	109.00	0.693	159.33	2.840	7.00	-2.061 **	72.40	4.948 **	6.47	-0.956 **
14.	HD3086 X C-306	97.00	-0.173	146.67	0.240	10.93	0.419	61.73	-0.045	9.53	1.144 **
15.	HD3086 X WH1105	108.33	-0.107	158.33	3.307 *	9.53	0.352	74.93	3.441 **	8.00	0.297
16.	DBW187 X HD2967	93.33	-5.973 **	154.33	0.973	8.80	-0.835 **	69.07	-1.552 **	7.93	-0.356
17.	DBW187 X WH711	106.00	5.560 **	156.00	3.240 *	8.60	-0.528	81.60	9.408 **	8.80	0.124
18.	DBW187 X CHIRYA3	104.67	-1.640	154.67	-3.360 *	11.00	2.045 **	79.27	5.381 **	9.67	1.537 **
19.	DBW187 X C-306	96.33	1.160	146.33	-1.627	10.80	0.392	62.57	-5.645 **	7.53	-1.563 **
20.	DBW187 X WH1105	107.33	0.893	157.33	0.773	8.00	-1.075 **	70.33	-7.592 **	8.67	0.257
21.	PBW677 X HD2967	94.00	-5.373 **	151.33	0.973	11.00	1.485 **	67.20	-1.552 **	9.40	0.524 **
22.	PBW677 X WH711	100.33	-0.173	150.00	3.240 *	9.27	0.259	73.07	9.408 **	9.27	0.004
23.	PBW677 X CHIRYA3	107.33	0.960	157.67	-3.360 *	8.00	-0.835 **	72.13	5.381 **	8.80	0.084
24.	PBW677 X C-306	98.67	3.427 **	148.67	-1.627	7.87	-2.421 **	77.93	-5.645 **	8.93	-0.749 **
25.	PBW677 X WH1105	107.67	1.160	157.67	0.773	10.47	1.512 **	82.67	-7.592 **	9.13	0.137
	Mean	102.17		153.10		9.29		68.55		8.47	
	C.D at 5%		1.76		2.92		0.55		0.96		0.39
	SE (Sij)		0.87		1.45		0.27		0.48		0.19
	SE (Sij – Skl)		1.24		2.05		0.39		0.68		0.27

**, ** significant at 5 and 1 per cent probability levels, respectively.*

Sr. No.	Crosses	Grain filling period		Number of spikelets per main spike		Number of grains per main spike		100-grain weight (g)		Grain yield per plant (g)	
		Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA
1.	DBW222 X HD2967	30.00	-5.320 **	17.20	-1.069 **	60.67	3.415	4.11	0.424 **	19.43	4.041 **
2.	DBW222 X WH711	41.67	3.680 **	17.53	0.991 **	55.47	-7.585 **	3.19	0.095	15.11	1.210 *
3	DBW222 X CHIRYA3	40.00	1.547 *	17.60	0.137	59.40	3.315	2.76	-0.902 **	16.04	-1.276 *
4.	DBW222 X C-306	28.33	-4.187 **	17.27	0.817 *	68.80	6.741 **	4.60	0.857 **	21.00	-0.046
5.	DBW222 X WH1105	44.67	4.280 **	15.33	-0.876 *	49.27	-5.885 **	3.65	-0.474 **	11.62	-3.929 **
6.	HD3226 X HD2967	35.67	4.880 **	15.47	-1.576 **	47.40	-2.572	4.33	0.013	11.60	-6.495 **
7.	HD3226 X WH711	28.00	-5.453 **	15.67	0.351	64.13	8.361 **	4.54	0.815 **	15.18	-1.429 **
8.	HD3226 X CHIRYA3	35.67	1.747 **	16.27	0.031	48.40	-0.405	4.78	0.491 **	21.60	1.578 **
9.	HD3226 X C-306	30.00	2.013 **	16.40	1.177 **	49.20	-5.579 **	3.63	-0.737 **	28.83	5.085 ***
10.	HD3226 X WH1105	32.67	-3.187 **	15.00	0.017	48.07	0.195	4.17	-0.581 **	19.52	1.262 *
11.	HD3086 X HD2967	35.00	2.480 **	18.63	2.344 **	49.20	-1.925	3.36	-0.282 **	13.56	0.209
12.	HD3086 X WH711	37.00	1.813 **	12.07	-2.496 **	68.30	11.375 **	3.21	0.149	13.83	1.968 **
13.	HD3086 X CHIRYA3	34.00	-1.653 *	15.00	-0.483	49.07	-0.892	3.49	-0.135	13.77	-1.505 **
14.	HD3086 X C-306	29.33	-0.387	15.07	0.597	47.00	-8.932 **	4.19	0.494 **	20.37	1.362 *
15.	HD3086 X WH1105	35.33	-2.253 **	14.27	0.037	49.40	0.375	3.86	-0.227 *	11.48	-2.034 **
16.	DBW187 X HD2967	30.00	-0.587	17.13	0.624	47.27	-0.139	3.52	-0.533 **	20.37	3.626 **
17.	DBW187 X WH711	36.67	3.413 **	16.87	2.084 **	46.93	-6.272 **	2.92	-0.545 **	11.55	-3.704 **
18.	DBW187 X CHIRYA3	28.67	-5.053 **	17.47	1.764 **	47.87	1.628	5.01	0.974 **	23.37	4.699 **
19.	DBW187 X C-306	29.33	1.547 *	12.20	-2.489 **	57.10	4.888 *	4.06	-0.054	19.50	-2.894 **
20.	DBW187 X WH1105	36.33	0.680	12.47	-1.983 **	45.20	-0.105	4.66	0.159	15.18	-1.727 **
21.	PBW677 X HD2967	29.33	-1.453 *	16.80	-0.323	51.37	1.221	4.57	0.378 **	19.73	-1.381 **
22.	PBW677 X WH711	30.00	-3.453 **	14.47	-0.929 *	50.07	-5.879 **	3.09	-0.514 **	21.58	1.955 **
23.	PBW677 X CHIRYA3	37.33	3.413 **	14.87	-1.449 **	45.33	-3.645	3.74	-0.428 **	19.55	-3.495 **
24.	PBW677 X C-306	29.00	1.013	15.20	-0.103	57.83	2.881	3.68	-0.559 **	23.26	-3.508 **
25.	PBW677 X WH1105	36.33	0.480	17.87	2.804 **	53.47	5.421 **	5.75	1.123 **	27.70	6.429 **
	Mean	33.42		15.62		52.17		3.98		18.26	
	C.D at 5%		1.28		0.72		3.67		0.19		1.03
	SE (Sij)		0.63		0.35		1.82		0.09		0.51
	SE (Sij – Skl)		0.90		0.50		2.58		0.13		0.72

Sr. No.	Crosses	Biological yield per plant (g)		Harvest index (%)	
		Mean	SCA	Mean	SCA
1.	DBW222 X HD2967	44.00	4.880 *	62.47	9.499 **
2.	DBW222 X WH711	44.00	-0.453	44.00	-4.518 **
3	DBW222 X CHIRYA3	52.00	2.080	52.17	3.178 **
4.	DBW222 X C-306	60.00	3.147	72.73	5.244 **
5.	DBW222 X WH1105	41.33	-9.653 **	40.75	-13.404 **
6.	HD3226 X HD2967	38.67	-7.387 **	74.23	7.768 **
7.	HD3226 X WH711	52.00	0.613	52.00	-10.016 **
8.	HD3226 X CHIRYA3	56.67	-0.187	56.56	-5.930 **
9.	HD3226 X C-306	66.00	2.213	75.08	-5.904 **
10.	HD3226 X WH1105	62.67	4.747 *	81.73	14.082 **
11.	HD3086 X HD2967	39.33	-4.320	39.11	-16.495 **
12.	HD3086 X WH711	56.67	7.680 **	64.79	13.638 **
13.	HD3086 X CHIRYA3	51.33	-3.120	48.88	-2.749 **
14.	HD3086 X C-306	66.00	4.613 *	82.13	12.007 **
15.	HD3086 X WH1105	50.67	-4.853 *	50.39	-6.401 **
16.	DBW187 X HD2967	56.67	5.280 *	77.30	11.260 **
17.	DBW187 X WH711	48.67	-8.053 **	44.47	-17.124 **
18.	DBW187 X CHIRYA3	62.67	0.480	62.72	0.662
19.	DBW187 X C-306	62.00	-7.120 **	80.10	-0.462
20.	DBW187 X WH1105	72.67	9.413 **	72.89	5.664 **
21.	PBW677 X HD2967	54.67	1.547	52.00	-12.031 **
22.	PBW677 X WH711	58.67	0.213	77.60	18.019 **
23.	PBW677 X CHIRYA3	64.67	0.747	64.89	4.838 **
24.	PBW677 X C-306	68.00	-2.853	67.67	-10.886 **
25.	PBW677 X WH1105	65.33	0.347	65.28	0.060
	Mean	55.81		62.47	
	C.D at 5%	4.40		1.60	
	SE (Sij)	2.18		0.80	
	SE (Sij – Skl)	3.09		1.13	

Table 7: Lists of crosses showed desirable heterosis over standard variety and better parent for twelve characters in wheat:

Sr. No.	Crosses	Days to 50% heading		Days to maturity		Number of effective tillers per plant		Plant height (cm)	
		BP%	SH%	BP%	SH%	BP%	SH%	BP%	SH%
1.	DBW222 X HD2967	3.25**	-0.63	-1.75	-3.43**	-7.41	-25.60**	-5.84**	-1.30
2.	DBW222 X WH711	1.54	2.81*	1.05	2.79*	0.84	-28.57**	-10.88**	-2.21*
3	DBW222 X CHIRYA3	4.40**	3.75**	2.99**	3.43**	3.90	-4.76	-7.27**	-6.62**
4.	DBW222 X C-306	9.23**	-7.50**	10.93**	0.21	17.06**	4.17	-4.86**	-12.59**
5.	DBW222 X WH1105	4.35**	5.00**	-1.69	-0.43	-1.63	-27.98**	-5.76**	3.41**
6.	HD3226 X HD2967	0.97	-2.81*	0.66	-1.07	-5.93	-24.40**	-2.68**	2.01
7.	HD3226 X WH711	-13.58**	-12.50**	-2.53*	-0.86	11.02*	-22.02**	-19.25**	-9.13**
8.	HD3226 X CHIRYA3	-0.63	-1.25	-0.43	0.00	-32.47**	-38.10**	-7.07**	-6.42**
9.	HD3226 X C-306	0.37	-15.00**	-0.24	-9.87**	-3.68	-14.29**	-2.78*	-10.68**
10.	HD3226 X WH1105	-4.66**	-4.06**	-3.18**	-1.93	-0.81	-27.38**	-6.69**	7.72**
11.	HD3086 X HD2967	2.27*	-1.56	1.53	-0.21	1.30	-7.14*	-10.91**	-6.62**
12.	HD3086 X WH711	-6.35**	-7.81**	-8.80**	-8.80**	-3.90	-11.90**	-16.15**	-10.43**
13.	HD3086 X CHIRYA3	3.81**	2.19*	2.58*	2.58*	-31.82**	-37.50**	8.17**	8.93**
14.	HD3086 X C-306	7.38**	-9.06**	4.51**	-5.58**	6.49	-2.38	1.09	-7.12**
15.	HD3086 X WH1105	3.17**	1.56	1.93	1.93	-7.14	-14.88**	5.54**	12.74**
16.	DBW187 X HD2967	-6.04**	-12.50**	3.12**	-0.64	-18.52**	-21.43**	14.35**	3.91**
17.	DBW187 X WH711	6.71**	-0.63	4.23**	0.43	-20.37**	-23.21**	35.10**	22.77**
18.	DBW187 X CHIRYA3	5.37**	-1.88	3.34**	-0.43	1.85	-1.79	31.24**	19.26**
19.	DBW187 X C-306	6.64**	-9.69**	4.28**	-5.79**	0.00	-3.57	3.59**	-5.87**
20.	DBW187 X WH1105	8.05**	0.62	5.12	1.29	-25.93**	-28.57**	16.45**	5.82**
21.	PBW677 X HD2967	-8.44**	-11.88**	-0.87	-2.58*	22.22**	-1.79	-3.54**	1.10
22.	PBW677 X WH711	-3.53**	-5.94**	-2.60*	-3.43**	20.87**	-17.26**	1.76	9.93**
23.	PBW677 X CHIRYA3	3.21**	0.62	2.38*	1.50	-22.08**	-28.57**	7.77**	8.53**
24.	PBW677 X C-306	9.23**	-7.50**	5.94**	-4.29**	-21.07**	-29.76**	27.62**	17.25**
25.	PBW677 X WH1105	3.53**	0.94	2.38*	1.50	27.64**	-6.55	15.13**	24.37**

Sr. No.	Crosses	Length of main spike (cm)		Grain filling period		Number of spikelets per main spike		Number of grains per main spike	
		BP%	SH%	BP%	SH%	BP%	SH%	BP%	SH%
1.	DBW222 X HD2967	-0.35	11.90**	0.00	-15.89**	9.79**	26.47**	23.98**	21.33**
2.	DBW222 X WH711	3.89	16.67**	38.89**	16.82**	-0.75	28.92**	18.52**	10.93**
3	DBW222 X CHIRYA3	-10.25**	0.79	33.33**	12.15**	20.00**	29.41**	29.51**	18.80**
4.	DBW222 X C-306	7.77*	21.03**	11.84**	-20.56**	0.78	26.96**	2.33	37.60**
5.	DBW222 X WH1105	-15.90**	-5.56	48.89**	25.23**	-9.45**	12.75**	-12.23**	-1.47
6.	HD3226 X HD2967	-16.67**	-4.76	15.05**	0.00	-1.28	13.73**	-3.13	-5.20
7.	HD3226 X WH711	-20.83**	-9.52**	-30.00**	-21.50**	-11.32**	15.20**	37.04**	28.27**
8.	HD3226 X CHIRYA3	-22.22**	-11.11**	-0.93	0.00	10.91**	19.61**	6.45	-3.20
9.	HD3226 X C-306	-0.69	13.49**	18.42**	-15.89**	-4.28	20.59**	-26.82**	-1.60
10.	HD3226 X WH1105	-11.11**	1.59	-10.09**	-8.41**	-11.42**	10.29**	-14.37**	-3.87
11.	HD3086 X HD2967	-18.11**	-17.46**	12.90**	-1.87	18.94**	37.01**	0.54	-1.60
12.	HD3086 X WH711	-10.29**	-3.17	4.72	3.74	-31.70**	-11.27**	45.94**	36.60**
13.	HD3086 X CHIRYA3	-20.49**	-23.02**	-3.77	-4.67	2.27	10.29**	7.92	-1.87
14.	HD3086 X C-306	6.72*	13.49**	15.79**	-17.76**	-12.06**	10.78**	-30.09**	-6.00
15.	HD3086 X WH1105	-11.76**	-4.76	0.00	-0.93	-15.75**	4.90	-12.00**	-1.20
16.	DBW187 X HD2967	-12.50**	-5.56	2.27	-15.89**	-6.20*	25.98**	-14.78**	-5.47
17.	DBW187 X WH711	-2.94	4.76	25.00**	2.80	-7.66**	24.02**	-15.38**	-6.13
18.	DBW187 X CHIRYA3	6.62*	15.08**	-2.27	-19.63**	-4.38	28.43**	-13.70**	-4.27
19.	DBW187 X C-306	-16.91**	-10.32**	15.79**	-17.76**	-33.21**	-10.29**	-15.07**	14.20**
20.	DBW187 X WH1105	-4.41	3.17	23.86**	1.87	-31.75**	-8.33*	-19.48**	-9.60
21.	PBW677 X HD2967	8.46*	11.90**	-5.38	-17.76**	0.00	23.53**	4.97	2.73
22.	PBW677 X WH711	2.21	10.32**	-10.00**	-15.89**	-18.11**	6.37	6.98	0.13
23.	PBW677 X CHIRYA3	1.54	4.76	12.00**	4.67	-11.51**	9.31**	-0.29	-9.33
24.	PBW677 X C-306	0.00	6.35	14.47**	-18.69**	-11.28**	11.76**	-13.98**	15.67**
25.	PBW677 X WH1105	0.74	8.73*	9.00**	1.87	5.51	31.37**	-4.75	6.93

Table 8: Cont…

Sr. No.	Crosses	100-grain weight (g)		Grain yield per plant (g)		Biological yield per plant (g)		Harvest index (%)	
		BP%	SH%	BP%	SH%	BP%	SH%	BP%	SH%
1.	DBW222 X HD2967	-9.00**	-19.78**	68.59**	8.97	20.00**	-47.62**	59.83**	-6.3**
2.	DBW222 X WH711	-25.79**	-37.67**	9.54	-15.25**	12.82	-47.62**	0.00	-34**
3	DBW222 X CHIRYA3	-35.79**	-46.06**	7.63	-10.04*	33.33**	-38.10**	1.41	-21.7**5
4.	DBW222 X C-306	3.14	-10.28**	-15.21**	17.76**	53.85**	-28.57**	-11.08**	9.1**
5.	DBW222 X WH1105	-15.10**	-28.69**	-49.67**	-34.8**	5.98	-50.79**	-42.10**	-38.88**
6.	HD3226 X HD2967	-4.21	-15.55**	0.64	-34.95**	5.45	-53.97**	48.17**	11.35**
7.	HD3226 X WH711	10.55**	-11.39**	10.00**	-14.9**	36.84**	-38.10**	3.79	-22**
8.	HD3226 X CHIRYA3	16.48**	-6.64*	44.90**	21.12**	49.12**	32.54**	9.94**	-15.17**
9.	HD3226 X C-306	-18.55**	-29.15**	16.42**	61.68**	73.68**	-21.43**	-8.21**	12.63**
10.	HD3226 X WH1105	1.62	-18.54**	-15.50**	9.46	64.91**	-25.40**	16.14**	22.6**
11.	HD3086 X HD2967	-25.54**	-34.35**	7.11	-23.96**	7.27	-53.17**	-3.96	-41.34**
12.	HD3086 X WH711	-22.29**	-37.41**	0.24	-22.45**	39.34**	-32.54**	47.26**	-2.81
13.	HD3086 X CHIRYA3	-15.43**	-31.88**	-7.60	-22.77**	26.23**	-38.89**	-4.99*	-26.69**
14.	HD3086 X C-306	-5.91	-18.15**	-17.77**	14.21**	62.30**	21.43**	0.41	23.2**
15.	HD3086 X WH1105	-6.46	-24.66**	-50.30**	-35.63**	24.59**	-39.68**	-28.40**	-24.42**
16.	DBW187 X HD2967	-21.99**	-31.23**	34.26**	14.21**	54.55**	32.54**	62.93**	15.95**
17.	DBW187 X WH711	-21.27**	-42.94**	-23.88**	-35.25**	10.61	-42.06**	-6.27**	-33.3**
18.	DBW187 X CHIRYA3	42.46**	-2.21	54.03**	31.03**	32.39**	-25.40**	21.93**	-5.92**
19.	DBW187 X C-306	-8.98**	-20.82**	-21.27**	9.35	30.99**	-26.19**	-2.08	20.15**
20.	DBW187 X WH1105	18.99**	-9.11**	-34.30**	-14.9**	53.52**	-13.49**	3.57*	9.33**
21.	PBW677 X HD2967	0.15	-10.87**	42.31**	10.65*	49.09**	-34.92**	23.81**	-22**
22.	PBW677 X WH711	-32.31**	-39.75**	55.63**	21.01**	39.68**	30.16**	76.36**	16.4**
23.	PBW677 X CHIRYA3	-17.98**	-27.00**	31.13**	9.61	53.97**	-23.02**	26.14**	-2.67
24.	PBW677 X C-306	-19.23**	-28.11**	-6.08	30.43**	61.90**	-19.05**	-17.28**	1.5
25.	PBW677 X WH1105	26.17**	12.30**	19.94**	55.36**	55.56**	22.22**	-7.25**	-2.09

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