

Heterosis and Combining ability analysis in F₁ hybrids of bread wheat

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Summary

Bread wheat (*Triticum aestivum* L.) is the most auspicious cereal food crop with regard to production, consumption, nutritional value, storage space, quality, adaptability and transportation. The all 15 F₁ cross combinations and their parents were planted in a randomized block design (RBD) with three replications. Out of 15 cross combinations, only 10 show significant heterobeltiosis for early maturity over the standard check in desirable direction. Five cross combinations PBW 343 x PBW 65, RAJ 2184 x PBW 65, PBW 343 x RAJ 2184, CPAN 3004 x RAJ 2184, HD 1981 x PBW 154 show significant positive heterobeltiosis whereas two cross combinations HD 1981 x PBW 154 and PBW 343 x PBW 65 show significant positive heterosis over commercial check for seed yield. The GCA (General combining ability) effects of the parent PBW343 showed significant positive effect for most of all the traits followed by CPAN3004, PBW154 and PBW65. Out of fifteen, two cross crosses, namely PBW 343 x PBW 65 and CPAN 3004 x RAJ 2184 showed a significant positive SCA (specific combining ability) effect for grain yield.

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Introduction

Wheat (*Triticum aestivum* L.) is an important food crop and belongs to the family gramineae. The first domesticated food crop was wheat and its primary centre of origin is South west Asia. The wheat flower is bracteates, sessile, incomplete, hermaphrodite and cleistogamous. Each flower consists of two covers i.e. the outer lemma and inner palea. The stiff thread-like outgrowth is called awn bears by lemma. Male and female parts are enclosed by palea. Bread wheat is an allopolyploid developed from two separate hybridization events. Each hybridization was followed by doubling of chromosome in the new F₁; this allowed ordinary bivalent formation at meiosis and, as a result the manufacture of fertile plants (Jatav et al. 2013; Dawlatzay et al. 2022)^{9&26}. Wheat is C3 plant generally grown from irrigated to dry and high-rain-fall areas and from warm-humid to dry, cold environments (Verma et al. 2013)²⁵. Wheat is one of the most essential and broadly cultivated plant the world, used especially for human intake and assist almost 35% of the sector population (Mohammadi-joo et al. 2015)¹³ and imparting 20% of the whole meal calories. The yield plateau is the major consequence after the green revolution. Therefore, plant breeding tools have great importance in changing the present situation. For the plant breeders, choice of appropriate parents with progressed genetic capability for developing high-yielding varieties is the most critical task. The maximum vital approach for breaking yield barrier is hybridization.

Therefore, identifying superior parents is an important pre-requisite for initiating an efficient and effective breeding programme (Jaiswal et al. 2017; Kumari et al. 2022)^{8&27}.

Heterosis is the ascendancy of the F₁ upon both of its parents in terms of plant vegetative growth, adaption and productivity (Shull 1908)²². The heterotic effect is important for the productiveness of hybrids. The heterosis research is beneficial for the assessment of new strains for their parental usefulness. The exploitation of heterosis in wheat has restricted utility due to realistic problems of hybrid seed manufacturing in enough quantity. Heterosis study helps in the elimination of weak crosses in the early generations.

The combining ability was introduced by Sprague and Tatum (1942)²³, according to them, general combining ability and specific combining ability measured the deviation of positive predicted combinations on the premise of the common overall performance of the strains involved. Ability of parents to combine well and produce promising segregants in succeeding generations is a necessary criterion in selecting parents for a successful hybridizing programme. Combining ability often depends upon complex interactions among genes, certain combinations introgress well to provide advanced offspring while others produce inferior progenies. Keeping in view all of the above facts, the prevailing research was done to estimate heterosis and heterobeltiosis for grain yield and its associated traits and to find out the superior crosses with their parents (Kumar et al. 2020)¹².

Materials and Methods

A set of six genetically diverse wheat parents were used in the current study: HD 1981, PBW 343, RAJ 2184, CPAN

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3004, PBW 154, PBW 65. These parents were crossed in a 6x6 Half diallel mating design by Griffing (1956)⁷ with three replications at Experimental Farm, Mata Gujri College, Fatehgarh Sahib during Rabi 2018-20. This place is situated between 30-27' and 30-46' latitudes and 76-04' and 76-38'E longitude and a mean height of 247 meters above sea level. Row-to-row and plant-to-plant spacing were 22.5cm, respectively, which was maintained by thinning. The HD3226 was used as a commercial check. All the recommended package required for a healthy crop was used for raising the wheat crop.

The combining ability analysis was done as per the procedure given by Griffing (1956)⁷ by using. Method-2 and Model-1. Method-2 includes P inbreds (parents) and P (P-1)/2 F₁s, in all P (P+1)/2 different genotypes, which form a pair of treatments. Model-1 is also called a fixed effect model in which inferences drawn are applicable only to the lines (treatments) included in the experiment and not beyond these errors. The differences in the magnitudes of relative heterosis, heterosis over male and female parents were examined as per Panse & Sukhatme (1967)¹⁵ and Fonesca & Patterson (1968)⁴.

Table 1. Mean performance of F₁ hybrids and extent of heterosis in bread wheat for days to maturity, plant height, number of productive tiller/ plants, Number of grains/ spikes, number of grains/ plants, Grain yield/ plant, Harvest index, Test weight

Cross Combination	Days of maturity			Plant Height			No. of productive tiller		
	Mean	Heterobeltiosis	Standard check	Mean	Heterobeltiosis	Standard check	Mean	Heterobeltiosis	Standard check
HD 1981 x PBW 343	117.52	-5.99 *	-3.75	85.81	-0.59	-9.09 **	7.83	8.65	18.81 *
HD 1981 x CPAN 3004	117.99	-4.18	-3.37	84.93	-3.89	-10.02 **	8.27	12.22	25.38 **
HD 1981 x RAJ 2184	118.67	-4.58	-2.81	93.74	-6.28	-0.69	8.68	16.09 *	31.70 **
HD 1981 x PBW 154	116.59	-5.32 *	-4.52	88.11	2.23	-6.65	9.04	12.96	37.06 **
HD 1981 x PBW 65	115.84	-6.45 **	-5.13 *	97.88	-7.28 *	3.70	8.38	14.23	27.05 **
PBW 343 x CPAN 3004	117.79	-5.78 *	-3.53	85.84	-2.86	-9.05 **	8.56	16.15 *	29.78 **
PBW 343 x RAJ 2184	118.69	-5.06 *	-2.80	93.11	-6.91 *	-1.36	8.36	11.81	26.85 **
PBW 343 x PBW 154	119.16	-4.68	-2.41	81.13	-6.01	-14.04 **	8.89	11.08	34.78 **
PBW 343 x PBW 65	119.11	-4.72	-2.45	101.34	-4.00	7.36 *	8.83	20.45 **	33.97 **
CPAN 3004 x RAJ 2184	119.67	-3.77	-1.99	92.55	-7.47 *	-1.95	8.99	20.23 **	36.40 **
CPAN 3004x PBW 154	118.19	-0.95	-3.20	81.23	-8.08 *	-13.94 **	9.24	15.46 *	40.09 **
CPAN 3004 x PBW 65	115.68	-6.58 **	-5.26 *	95.02	-9.98 **	0.67	9.1	23.57 **	38.07 **
RAJ 2184 x PBW 154	119.66	-3.78	-2.00	91.86	-8.16 **	-2.68	7.81	-2.42	18.40 *
RAJ 2184 x PBW 65	118.19	-4.96 *	-3.21	98.61	-6.59 *	4.47	9.25	23.66 **	40.29 **
PBW 154 x PBW 65	122.03	-1.45	-0.06	93.58	-11.35 **	-0.85	8.98	12.21	36.15 **
SE±		2.80	2.80		2.98	2.98		0.50	0.5091
CD at 1%		6.0	6.01		6.39	6.39		1.09	1.09
CD at 5%		7.58	7.58		8.06	8.06		1.37	1.37
Cross Combination	Number of grain/ spikes			No. of grain/plant			Grain yield/ plant		
	Mean	Heterobeltiosi	Standar	Mean	Heterobeltiosi	Standar	Mea	Heterobeltiosi	Standar

Result and Discussion

Exploiting hybrid vigour provides an opportunity to improve and develop hybrids for yield traits and adaptability for specific production environments. According to the modern concept, heterosis is an expression of the joint effect of favourable genes, the interplay among alleles, non-alleles and mitochondrial genes introduce collectively from the parents. In self-pollinated crop like wheat, where commercial hybrid seed manufacturing is not possible because of loss of appropriate mechanism to supply hybrid seed, exploitation of hybrid vigour is limited. The heterotic impact in F₁ over better parent and commercial check are provided in Table 1. The mean performance for days to maturity varied in cross combinations from 115.68 (CPAN 3004x PBW 65) to 122.02 days (PBW 154 x PBW 65). Heterobeltiosis for productive tillers/ plant ranged from - 4.96% (RAJ 2184 x PBW 65) to -6.58% (CPAN 3004x PBW 65), while standard economics ranged from - 5.13% (HD 1981 x PBW 65) and -5.26% (CPAN 3004 x PBW 65). The emphasis of negative heterosis for this trait has been highlighted by Saren *et al.* (2018)¹⁹.

s		s	d check		s	d check	n	s	d check
HD 1981 x PBW 343	43.75	5.73	-24.72 **	341.8 3	14.22	-1.23	11.6 2	6.05	09.55
HD 1981 x CPAN 3004	42.61	-0.60	-26.68 **	352.6 1	11.89	1.88	11.7 8	7.51	11.06
HD 1981 x RAJ 2184	41.19	-3.15	-29.12 **	357.3 4	12.7	3.25	11.2 8	2.89	06.28
HD 1981 x PBW 154	42.52	1.39	-26.84 **	382.9 5	13.99	10.65	13.4 6	22.78 *	26.83**
HD 1981 x PBW 65	43.30	4.64	-25.49 **	363.8 1	21.56 *	5.12	12.0 6	10.01	13.63
PBW 343 x CPAN 3004	40.25	-6.11	-30.74 **	344.7 1	9.38	-0.40	10.9 8	10.39	03.49
PBW 343 x RAJ 2184	45.32	6.56	-22.01 **	379.3 9	19.65 *	9.62	12.4 6	28.31 **	17.47
PBW 343 x PBW 154	42.73	1.91	-26.47 **	378.9 4	12.80	9.49	11.8 9	12.17	12.03
PBW 343 x PBW 65	46.18	14.86 **	-20.53 **	408.0 3	37.97 **	17.90 *	12.8 6	37.93 **	21.21*
CPAN 3004 x RAJ 2184	42.74	-0.29	-26.45 **	384.8 2	21.37 *	11.19	12.5 0	25.70 *	17.84
CPAN 3004 x PBW 154	41.42	-3.37	-28.73 **	382.9 2	13.99	10.64	12.2 0	15.13	14.99
CPAN 3004 x PBW 65	40.24	-6.13	-30.76 **	366.0 9	16.16	5.78	11.6 2	16.86	09.55
RAJ 2184 x PBW 154	42.26	-0.63	-27.27 **	330.3 9	-1.65	-4.54	10.6 1	0.13	0.00
RAJ 2184 x PBW 65	41.84	-1.63	-28.00 **	386.8 6	22.01 **	11.78	12.6 5	30.23 **	19.23
PBW 154 x PBW 65	43.03	2.62	-25.96 **	386.5 6	15.07	11.69	12.0 7	13.87	13.73
SE±		1.96	1.96		25.46	25.46		0.98	0.98
CD at 1%		4.22	4.22		54.61	54.61		2.11	2.11
CD at 5%		5.32	5.32		68.86	68.86		2.66	2.66
Cross Combination s	Harvest Index			Test Weight					
	Mean	Heterobeltiosis	Standard check	Mean	Heterobeltiosis	Standard check			
HD 1981 x PBW 343	44.30	-24.83 **	22.32 *	34.01	-7.35	10.78 *			
HD 1981 x CPAN 3004	44.47	-9.57	22.80 *	33.3	-9.31 *	8.45			
HD 1981 x RAJ 2184	41.16	-16.29 *	13.67	31.61	-13.89 **	2.96			
HD 1981 x PBW 154	46.10	-6.25	27.31 **	35.14	-4.29	14.45 **			
HD 1981 x PBW 65	44.40	-9.71	27.31 **	33.02	-10.07 **	7.53			
PBW 343 x CPAN 3004	43.91	-25.48 **	21.26	31.95	-5.32	4.05			
PBW 343 x RAJ 2184	42.80	-27.37 **	18.19	32.86	-2.62	7.01			
PBW 343 x PBW 154	40.04	-32.06 **	10.56	31.34	-7.12	2.06			
PBW 343 x PBW 65	40.61	-31.08 **	12.15	31.47	-6.73	2.5			
CPAN 3004 x RAJ 2184	41.58	9.63	14.83	32.36	2.56	5.38			
CPAN 3004 x PBW 154	41.38	8.21	14.28	31.87	1.02	3.81			
CPAN 3004 x PBW 65	41.24	8.73	13.88	31.73	0.18	3.34			
RAJ 2184 x PBW 154	46.80	22.37 *	29.23 **	32.08	1.69	4.48			
RAJ 2184 x PBW 65	42.41	20.33	17.10	32.66	3.10	6.36			
PBW 154 x PBW 65	39.40	3.02	8.80	31.15	-1.65	1.45			

SE±		3.64	3.64		1.30	1.30			
CD at 1%		7.82	7.82		2.80	2.80			
CD at 5%		9.86	9.86		3.53	3.53			

*, **Significant at 5% and 1% level respective

Short statured cultivars of bread wheat have been exploited after the commencement of green revolution in 1960s which drew the attention and attempts of plant breeders to breed for shorten the height of plant. In this contest mean performance for the height of plant varied in the combinations from 81.13 (PBW 343 x PBW 154) to 101.33 (PBW 343 x PBW 65). Heterobeltiosis for height of plant ranged from -6.59% (RAJ 2184x PBW 65) and -11.35% (PBW 154 x PBW 65), whereas commercial heterosis observed was from 9.05% (PBW 343 x CPAN 3004) to -14.04% (PBW 343 x PBW 154) over the check variety HD 3226. Significant inferiority of heterosis for plant height was earlier reported by Ahmad et al. (2016)¹.

The number of productive tillers according to plant is one of the most crucial yield traits, which contributes in the direction of productiveness and is considered during selection. The mean performance for productive tillers/plant varied in cross combination from 7.80 (RAJ 2184 x PBW 154) to 9.25 (RAJ 2184 x PBW 65). Heterobeltiosis for productive tillers / plant ranged from 16.09% (HD1981 x RAJ 2184) to 23.66% (RAJ 2184 x PBW65), whereas commercial heterosis varied from 40.29% (RAJ 2184 x PBW 65) to 18.81% (HD 1981xPBW 343). These effects are in accordance with the Noorka et al. (2013)¹⁴ and Gite et al. (2014)⁶.

A number of grains spike is a crucial yield component, which contributes closer to productiveness therefore, effective heterosis for grains/spike is desirable. The mean overall performance for a number of grains per spike varied in combination from 40.24 (CPAN 3004 x PBW 65) to 46.18 (PBW 343 x PBW 65). In the current research, the combination 14.86 (PBW 343 x PBW 65) was shown significant heterosis over the higher parent. The present findings are similar with Patel (2018)¹⁶.

Mean performance for a number of grains/ plants varied in cross combinations from 330.39 (RAJ 184 x PBW 154) to 408.03 (PBW 343 x PBW 65). A significant and high degree of heterosis for grain per plant was obtained compared to the better parent and the commercial genotype. F_1 crosses range from 19.65% (PBW 343 x RAJ 2184) to 37.97% (PBW 343 x PBW 65) and showed significant positive heterosis over better parents in a desirable direction. Cross combination, namely PBW 343 x PBW 65 (43.65) revealed significant positive, useful heterosis over the commercial check HD3226. The importance of positive heterosis for this character has been shown by Sharma et al. (2018)²¹.

Mean performance for the harvest index varied in cross combinations from 39.40% (PBW 154 x PBW 65) to 46.80% (RAJ 2184 x PBW 154). In the case of harvest index one cross combination, RAJ 2184 x PBW 154 (22.37) found extensively high-quality heterosis over the better parent. Five cross combination ranges from 22.32% (HD 1981 x PBW 343) to 29.23% (RAJ 2184 x PBW 154) with significant positive, useful heterosis.

These results are in accordance with the Thomas et al. (2017)²⁴.

Test weight is an important parameter for grain yield improvement, which varied in cross combinations from 31.15 (PBW 154 x PBW 65) to 35.14 (HD 1981 x PBW 154). High seed yield consistent with the plant is the ultimate goal of any breeding program, so requires higher consideration. Two crosses, particularly HD 1981 x PBW 343 (10.78%) and HD 1981 x PBW 154 (14.45%) confirmed high beneficial heterosis. These outcomes are in line with Ahmad et al. (2016)¹.

Making use of heterosis for increased yield is largely attributed to cross-pollinated crops. Freeman (1919)⁵ reported the presence of heterotic outcomes in self-pollinated plants like wheat. The grain yield in different cross combinations ranged 22.78% (HD 1981x PBW 154) and 37.93% (PBW 343 x PBW 65) exhibited significant effective heterosis. While some cross combinations showed positive standard heterosis, namely, PBW 343x PBW 65 (21.21) and HD 1981 x PBW 154 (26.84). The present findings are similar with the earlier findings of Khokhar et al. (2019)¹⁰.

Combining ability

Table 2 revealed that the parents CPAN3004 showed various magnitude for days of booting, days of maturity, plant top and quantity of spikelets/ spike; PBW 343 for peduncle length, plant top and harvest index; HD1981 for plant top, harvest index and test weight, PBW 154 for plant top. Similar observations on GCA were reported by Seboka et al. (2009)²⁰ and Rajput & Kandalkar (2018)¹⁸.

For grain yield per plant, certain crosses such as HD 1981 x PBW 154, PBW 343 x RAJ 2184, PBW 343 x PBW 65, CPAN 3004 x RAJ 2184, CPAN 3004 x PBW 154 and RAJ 2184 x PBW 65 confirmed the better value of SCA effect (Table 3). All these crosses had a significant and higher magnitude of SCA consequences for other important yield characters (such as grains/spike, grains/plant, test weight, biological yield per plant and grain yield/plant). Similar results had been suggested through studies of Kumar et al. (2015)¹¹ and Barot et al. (2014)².

Table 4 revealed that HD 1981x PBW 154, PBW 343x RAJ 2184, PBW 343 x PBW 65, CPAN 3004 x RAJ 2184 and RAJ 2184 x PBW 65 resulted from good x poor, poor x poor, poor x good, poor x poor and poor x good combining parents, also these crosses have higher per se performance. This might be due to additive x dominance type of interaction with epistasis gene action and non-fixable genetic component for total yield per plant. PBW 343 x RAJ 2184 and CPAN 3004 x RAJ2184 combination gives poor x poor GCA effect due to non-additive gene interaction and non-fixable genetic component for total yield per plant. Therefore, there are possibilities to obtain desirable transgressive segregants and hybrid vigour from such crosses by adopting a selection cycle or biparental breeding programme. Similar findings had

been obtained by Qayyum et al. (2014)¹⁷ and Fasahat et al. (2016)³.

Table 2. Analysis of general combining ability for yield and yield producing component in bread wheat (*Triticum aestivum* L.)

Genotype	Days of booting	Days of Heading	Day of anthesis	Days of maturity	Number of tiller/plant	Plant height	Spike length	Peduncle length
HD 1981	-0.62	-0.97	-0.81	-0.31	-0.19	-2.03**	0.20	-0.22
PBW 343	0.81	0.99	1.16	0.86	-0.24*	-2.40**	-0.18	-2.11**
CPAN 3004	-1.82*	-1.47	-1.39	-1.80**	0.09	-2.85**	0.05	0.07
RAJ 2184	0.32	0.09	0.31	1.02	-0.01	3.84**	0.07	1.41**
PBW 154	1.55	1.49	1.28	-0.14	0.22	-3.85**	-0.23	0.31
PBW 65	-0.24	-0.14	-0.55	0.38	0.13	7.30**	0.08	0.54
G _i <> at 95%	1.99**	2.03**	2.20**	1.64**	0.29**	1.75**	0.31**	1.04**
G _i <> at 99%	3.12**	3.19**	3.45**	2.58**	0.46**	2.74**	0.48**	1.63**
Genotype	Number of spikelets/Spike	Number of grains/Spike	Number of grain/Plant	Biological Yield	Grain Yield/plant	Harvest index	Test weight	Genotype
HD 1981	-0.21	0.04	-7.76	-0.94	0.28	2.55**	1.62**	HD 1981
PBW 343	-0.20	0.05	-9.01	-2.24**	-0.25	3.89**	0.20	PBW 343
CPAN 3004	0.60**	-0.34	0.28	0.43	-0.11	-1.24	-0.39	CPAN 3004
RAJ 2184	-0.24	0.33	1.72	0.56	-0.11	-1.64	-0.56	RAJ 2184
PBW 154	-0.22	0.00	9.31	0.85	0.19	-1.02	-0.35	PBW 154
PBW 65	0.28	-0.09	5.45	1.33	0.00	-2.53**	-0.51	PBW 65
G _i <> at 95%	0.43**	1.15**	14.93**	1.72**	0.57**	2.14**	0.76**	G _i <> at 95%
G _i <> at 99%	0.68**	1.81**	23.43**	2.71**	0.90**	3.35**	1.20**	G _i <> at 99%

*, **Significant at 5% and 1% level respectively

Table 3. Analysis of specific combining ability for yield and its contributing traits in bread wheat (*Triticum aestivum* L.)

Cross Combinations	Days of booting	Days of Heading	Day of anthesis	Days of maturity	Number of tiller/plant	Plant height	Spike length	Peduncle length	Number of spikelets/spike	Number of grain/spike	Number of grain/plant	Biological Yield	Grain Yield/Plant	Harvest index	Test weight
HD 1981 x PBW 343	2.12	2.12	0.39	-2.36	-0.03	-1.05	-0.48	2.93*	0.30	1.39	7.29	2.20	0.18	-4.77	-0.31
HD 1981 x CPAN 3004	1.82	1.91	2.20	0.77	0.05	-1.48	-0.21	1.34	-0.20	0.65	8.77	-0.22	0.20	0.53	-0.43
HD 1981 x RAJ 2184	-0.64	-1.37	-1.56	-1.38	0.58	0.62	-0.14	0.21	0.01	-1.43	12.06	0.66	-0.29	-2.37	-1.94*
HD 1981 x PBW 154	-0.73	-0.01	-0.80	-2.29	0.69*	2.69	0.26	-5.26**	-0.20	0.21	30.09	2.07	1.57*	1.94	1.36
HD 1981 x PBW 65	0.30	0.10	0.07	-3.57	0.12	1.30	-0.28	0.75	-0.02	1.09	14.80	-0.30	0.36	1.76	-0.59
PBW 343 x CPAN 3004	-1.87	-1.68	-0.37	-0.60	0.40	-0.20	0.05	-4.26**	-0.27	-1.71	2.12	-0.06	-0.06	-1.36	-0.35
PBW 343 x RAJ 2184	1.40	1.75	1.58	-2.54	0.31	0.36	0.06	2.06	0.11	2.68*	35.36*	3.65	1.42*	-2.07	0.72
PBW 343 x PBW 154	0.88	0.50	-0.08	-0.90	0.60	-3.90	-0.09	4.94**	0.79	0.41	27.33	3.82	0.53	-5.46*	-1.01
PBW 343 x PBW 65	-0.41	-0.46	-0.86	-1.47	0.63	5.13*	-0.06	2.53*	0.77	3.96**	60.27**	5.28*	1.70*	-3.36	-0.71
CPAN 3004 x RAJ 2184	2.07	2.74	1.78	1.11	0.60	0.24	-0.61	1.77	0.16	0.50	31.50	1.74	1.32*	1.84	0.82
CPAN 3004 x	0.71	0.39	0.14	0.79	0.61	-3.36	-0.48	2.03	0.54	-0.49	22.01	1.04	0.70	1.02	0.12

PBW 154															
CPAN 3004 x PBW 65	-3.29	-2.04	-2.37	-2.24	0.57	-0.73	0.02	0.01	-0.35	-1.57	9.04	-0.84	0.31	2.39	0.14
RAJ 2184 x PBW 154	0.58	0.97	2.40	-0.56	-0.71*	0.56	-0.52	0.27	-0.20	-0.32	-31.95	-5.53**	-0.87	6.83*	0.50
RAJ 2184 x PBW 65	1.19	1.08	0.65	-2.56	0.82*	-3.84	0.01	-0.48	-0.51	-0.65	28.37	0.67	1.35*	3.96	1.23
PBW 154 x PBW 65	4.34	4.69*	4.86	2.43	0.31	-1.16	-0.51	0.57	-0.45	0.86	20.48	1.12	0.45	0.33	-0.48
$S_{ij}>$ at 95%	4.56	4.66	5.04	3.77	0.68	4.01	0.71	2.38	1.00	2.64	34.22	3.96	1.32	4.90	1.75
$S_{ij}>$ at 99%	6.33	6.47	6.99	5.23	0.95	5.56	0.99	3.30	1.38	3.67	47.50	5.49	1.83	6.80	2.43

*, **Significant at 5% and 1% level respectively

Table 4. Top five specific combinations for total yield per plant on the basis of per se, GCA effect of parents and showing desirable significant SCA effects for other traits

Crosses	Per se	GCA effects of parent involve in cross combination	SCA	Desirable SCA effect for other traits
HD 1981 x PBW 154	13.46	(G) 0.28 x 0.19 (P)	1.57*	Peduncle length, Number of tiller/plants
PBW 343 x RAJ 2184	12.46	(P)-0.25 x -0.11 (P)	1.42*	Number of grain/ spikes, Number of grain/ plant
PBW 343 x PBW 65	12.86	(P)-0.25 x 0.00 (G)	1.70*	Plant height Peduncle length, Number of grain/ spikes, Number of grain/ plant, Biological yield
CPAN 3004 x RAJ2184	12.50	(P)-0.11 x -0.11(P)	1.32*	Number of grain/ plant, Number of grain/spike
RAJ 2184 x PBW 65	12.65	(P)-0.11 x 0.00(G)	1.35*	Peduncle length, Number of tiller/ plant

GCA= General combining ability

SCA= Specific combining ability

Conclusion

Out of 15 cross combinations, 10 cross combinations displayed considerably high heterosis for grain yield/ plant, number of grain/ plant, number of productive tillers, test weight and harvest index. Similarly, eight combinations showed significant negative heterosis for days of maturity and height of the plant. The experimental study of combining ability for GCA and SCA revealed that out of six parents, three parents- CPAN 3004, PBW 343 and HD 1981 are good combiners than others for the different contributing character. Similarly, for SCA, some of the cross combinations PBW 343 x PBW 154, PBW 343 x PBW 65, HD 1981 x PBW 154, CPAN 3004 x RAJ 2184, HD 1981 x PBW 154 and PBW 343 x CPAN 3004 showed better results for yield and its contributing characters. These crosses can be evaluated for their inclusion in different breeding programme for the improvement of wheat for the development high yield wheat varieties.

Declarations of interests

All authors of this manuscript declare that they have no conflict of interest.

Data sharing

All relevant data are within the manuscript.

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