Research Article

Evaluation of Heterosis and Combining Ability for Grain Yield and Yield Attributing Traits in Bread Wheat (*Triticum aestivum* L.)

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Abstract

The experiment using half-diallel mating design was conducted at wheat research station, Junagadh Agricultural University, Junagadh. Eight lines along with 28 hybrids and one standard check (GW 547) were evaluated in randomized blocked design in *Rabi*, 2024-25 season to study the extent and magnitude of heterotic effects of hybrids over better parent and standard check. Also it revealed the importance of both additive as well as non-additive genetic variances for control of various traits through combining ability analysis. The analysis of variance revealed highly significant differences among the genotypes for all the characters studied, indicating that experimental materials had sufficient genetic variability for all traits. The cross DBW 187 × HD 3377 (48.58 %) depicted the highest desirable heterosis over better parent followed by CG 1036 × UP 2968 (44.92 %) and CG 1036 × MP 1358 (38.17 %). The cross GW 547 × UP 2968 (35.20 %) recorded the highest significant heterosis towards positive direction over standard check, followed by CG 1036 × UP 2968 (34.92 %) and AKAW 5104 × GW 547 (34.78 %). The ratio of additive gene action to non-additive gene action (σ^2gca/ σ^2 sca) indicated the predominance of non-additive gene effects for these traits. The parent GW 547 considered as best general combiner. The highest sca effects was manifested by the cross DBW 187 × HD 3377 followed by AKAW 5104 × GW 547 and CG 1036 × UP 2968. Hybrid DBW 187 × HD 3377 was also found good specific combiner for number of effective tillers per plant, length of main spike, number of spikelets per main spike, grain filling period, number of grains per main spike, 100-grain weight and biological yield per plant. Overall, recognizing and leveraging non-additive gene action offers a promising avenue for accelerating genetic gains and enhancing productivity in wheat.

Key words: *Triticum aestivum* L., Heterosis, Combining ability, Gene action, Diallel mating design

1. Introduction

Wheat (*Triticum aestivum* L.) is the principal food crop of most areas of world and occupies prominent position in India after rice. India accounted for an area, production and a productivity is 31.32 million hectares, 112.92 million tonnes and 3615 kg/ha, respectively (ICAR-IIWBR, 2024). Yield is a polygenic trait that is controlled by many components. Continuous varietal adoption and their improvement lead the wheat productivity to reach a new level. Non-uniformity of increment in wheat productivity all over the country indicates that there are the opportunities for enhancing its production in future. Yield plateau is the major consequence after the green revolution. Therefore, the plant breeding tools have a great importance in changing the present situation. For the

plant-breeders selection of suitable parents with improved genetic potential for developing better verities is the major task. The most important technique for breaking yield barrier is hybridization. The identification of superior parents is the important pre-requisites for beginning an efficient and effective breeding programme. Heterotic effect is increase or decrease in vigour and productivity of hybrids those compared to their parents which is expressed in F_1s and following generations. The heterosis studies are useful for the evaluation of newly developed lines for their parental usefulness. The commercial exploitation of heterosis in wheat has limited application because of practical difficulties of hybrid seed production in sufficient quantity. High heterotic hybrids may offer better probability for identification of desirable pure lines in advanced generations as compared to hybrids with low heterosis. Heterosis studies may produce desirable segregants by identifying superior cross combination. Yield barriers may be overcome by heterosis breeding. Transgressive segregants for yield and component traits are obtained by exploiting the crosses having high heterosis. In wheat this phenomenon could be commercially exploited which could increase yield per acre. Heterosis study helps in the elimination of less productive crosses in the early generations.

The diallel mating design has been used successfully for over 50 years in plant breeding to estimate the relative combining ability of lines. From the diallel mating design, plant breeders can estimate general combining ability (GCA) and specific combining ability (SCA). Sprague and Tatum (1942) defined GCA as "the average performance of a line in hybrid combinations" and defined SCA as "those cases in which certain combinations do relatively better or worse than would be expected on the basis of the average performance of the lines involved." The diallel analysis method has been frequently used for parent selection as an appropriate scheme to obtain genetic information of yield traits in a short period of time, which can be used for improving efficiency in wheat breeding programs. Among the various diallel techniques, combining ability analysis developed by (Griffing, 1956a) is being considered to be more useful to the wheat breeders and provides valuable information about the ability of parents to transfer desirable traits to their progenies (Seboka and Singh, 2009).

Keeping in view all the above facts, the present investigation was planned to estimate heterobeltiosis, standard heterosis and combining ability analysis for grain yield and its related traits and to identify the superior crosses with their parents.

2. Materials and Methods

Eight genotypes namely, AKAW 5104, CG 1036, DBW 187, GW 547, HD 3377, HI 1625, MP 1358 and UP 2968 were selected along with standard check (GW 547) on the basis of their phenotypic variability. The crossing programme was carried out during *Rabi* 2023-24 using diallel mating design. The experimental material consisting of 37 entries, including 8 parents, 28 crosses and 1 standard check were tested in randomized block design with three replications during *Rabi* 2024-25. A single row plot of 2.5 meters was allotted randomly to each entry. The row-to-row and plant-to-plant distance was kept 22.5 cm and 10 cm, respectively. All the recommended cultural practices and plant protection measures were followed to grow healthy crop. Five competitive plants from each entry excluding border plants were randomly selected for recording the observations on different characters *viz.*, plant height, number of effective tillers per plant, length of main spike, number of spikelets per main spike, number of grains per main spike, 100-grain weight, grain yield per plant, biological yield per plant and harvest index except days to anthesis, days to maturity and grain filling period for which observations were recorded on plot basis and their averages were used for statistical analysis. The estimation of heterosis over better parent and over standard check is more realistic. Hence, in the present investigation Heterobeltiosis was calculated as the deviation of F_1 from the better parent (Fonseca and Patterson, 1968) and was expressed in percentage by following formula:

$$\text{Heterobeltiosis} = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

Standard heterosis is per cent increase or decrease over standard check (GW 547) and was calculated by the following formula:

$$\text{Standard heterosis} = \frac{\overline{F_1} - \overline{SC}}{\overline{SC}} \times 100$$

where, F_1 = Mean performance of F_1, $\bar{F}_1$ = Mean value of batter parent of respective cross combination and Mean performance of standard check, BP = Better parent, SC = Standard check.

The combining ability analysis was carried out according to Model-I (Fixed effect), Method-2 (Parents and one set of F_1's without reciprocals) of Griffing (1956).

3. Results and Discussion

Analysis of variance revealed significant differences among the genotypes for all the characters studied, indicating that experimental materials had sufficient genetic variability for all these traits. The variance due to genotypes was further partitioned into variance due to parents, hybrids and parents *vs.* hybrids. The differences among parents were found significant for all the characters studied except number of effective tillers per plant. The mean squares due to parents *vs.* hybrids were also found significant for the characters *viz.,* days to maturity, grain filling period, no. of effective tillers per plant, length of main spike, number of spikelets per main spike, number of grains per main spike, 100-grain weight, grain yield per plant, biological yield per plant and harvest index indicating that the performance of hybrids as a group was different from that of the parents for these characters.

Earliness is desirable character in wheat and days to anthesis is component which effects on earliness. The earliest hybrid was DBW 187 × UP 2968 (-22.52 %) followed by HD 3337 × UP 2968 (-21.97 %), CG 1036 × UP 2968 (-20.42 %) and HI 1625 × MP 1358 (-19.15 %). Out of 28 hybrids, 18 hybrids showed significant and desirable (negative) estimate of heterobeltiosis (Table 2). Heterosis over standard check ranged from -9.57 per cent (DBW 187 × UP 2968) to 8.94 per cent (MP 1358 × UP 2968). The earliest hybrid was DBW 187 × UP 2968 (-9.57 %) followed by DBW 187 × GW 547 (-9.15 %), HD 3377 × UP 2968 (-8.94 %) and HI 1625 × MP 1358 (-8.83 %). Out of 28 hybrids, 19 hybrids showed significant and desirable (negative) heterosis over standard check variety GW 547 (Table 2). Significant desirable heterosis for this character has also been reported by Saren *et al.* (2018), Sharma *et al.* (2018) and Singh *et al.* (2022).

Early maturing parent is considered as better parent in wheat crop. The range of heterosis over better parent recorded from -20.07 per cent (HD 3377 × UP 2968) to 15.38 per cent (CG 1036 × HI 1625). The earliest hybrid

was HD 3377 × UP 2968 (-20.07 %) followed by DBW 187 × UP 2968 (-17.87 %), CG 1036 × UP 2968 (-14.32 %) and DBW 187 × GW 547 (-12.98 %). Out of 28 hybrids, 18 hybrids showed significant and desirable (negative) estimate of heterobeltiosis (Table 2). Heterosis over standard check ranged from -9.81 per cent (HD 3377 × UP 2968) to 10.91 per cent (MP 1358 × UP 2968). The highest desirable standard heterosis was recorded by the cross HD 3377 × UP 2968 (-9.81 %) followed by DBW 187 × UP 2968 (-7.32 %), DBW 187 × GW 547 (-6.98 %) and DBW 187 × HD 3377 (-6.49 %). Out of 28 hybrids, 14 hybrids showed significant and desirable (negative) heterosis over standard check variety GW 547 (Table 2). Significant negative heterosis for days to maturity have also been reported by Dedaniya *et al.* (2018), Saren *et al.* (2018), Joshi and Kumar (2020), Singh *et al.* (2022), Dahiya *et al.* (2023), Reddy *et al.* (2023) and Puri *et al.* (2025).

The duration of the grain filling period in wheat is a critical determinant of grain weight and overall yield. The magnitude of heterosis over better parent ranged from -22.00 per cent (DBW 187 × GW 547) to 21.88 per cent (HI 1625 × MP 1358). The highest desirable heterobeltiosis was exhibited by the cross DBW 187 × GW 547 (-22.00 %) followed by CG 1036 × GW 547 (-16.42 %) and DBW 187 × HD 3377 (-9.41 %). Out of 28 hybrids, 9 hybrids showed significant and desirable (negative) estimate of heterobeltiosis (Table 2). Heterosis over standard check ranged from -21.42 per cent (DBW 187 × HD 3377) to 12.70 per cent (GW 547 × UP 2968). The highest desirable standard heterosis was recorded by the cross DBW 187 × HD 3377 (-21.42 %) followed by HD 3377 × UP 2968 (-14.52 %) and DBW 187 × GW 547 (-13.79 %). Out of 28 hybrids, 13 hybrids showed significant and desirable (negative) heterosis over standard check variety GW 547 (Table 2). Significant desirable heterosis for this character has been reported by Thomas *et al.* (2017), Dedaniya *et al.* (2018) and Dahiya *et al.* (2023).

Positive significant heterosis is desirable for number of effective tillers per plant because each effective tiller adds directly to the number of spikes per plant, which increases the number of grains per plant and ultimately the grain yield. Heterosis over better parent ranged from -4.95 per cent (HI 1625 × UP 2968) to 51.35 per cent (GW 547 × UP 2968 and CG 1036 × UP 2968). The highest significant positive heterosis over better parent was depicted by the

Table 1: Analysis of variance (mean squares) for experimental design for grain yield and its contributing characters in bread wheat

Source of variation	d.f.	Days to anthesis	Days to maturity	Grain filling period	No. of effective tillers per plant	Plant height	Length of main spike	No. of spikelets per main spike	No. of grains per main spike	100-grain weight	Grain yield per plant	Biological yield per plant	Harvest index
Replications	2	1.93	8.85	5.21	0.55	22.12	0.12	3.18	11.91	0.07	1.71	5.21	27.89
Genotypes	36	59.94**	121.22**	33.72**	7.20**	93.15**	2.08**	19.82**	141.82**	1.32**	17.70**	57.80**	45.26**
Parents (P)	7	196.09**	387.83**	34.68**	0.81	56.19**	1.63**	6.94**	77.52**	0.86**	4.49**	50.14**	63.00**
Hybrids (H)	27	28.43**	51.17**	29.97**	6.36**	102.74**	1.68**	18.29**	119.80**	1.12**	17.13**	58.08**	31.99*
P *vs.* H	1	1.83	257.85**	154.80**	76.03**	7.82	18.23**	170.67**	1323.66**	11.53**	142.90**	161.86**	322.83**
Error	72	6.67	15.45	1.74	0.78	10.19	0.36	1.48	6.56	0.08	1.18	4.62	17.26

hybrid GW 547 × UP 2968 (51.35 %) and CG 1036 × UP 2968 (51.35 %). Out of 28 hybrids, only 2 hybrids showed significant and desirable (positive) estimate of heterobeltiosis (Table 2). Heterosis over standard check ranged from -2.83 per cent (AKAW 5104 × MP 1358) to 58.49 per cent (GW 547 × MP 1358 and CG 1036 × UP 2968). The highest desirable standard heterosis was recorded by the crosses GW 547 × MP 1358 (58.49 %) and CG 1036 × UP 2968 (58.49 %) followed by AKAW 5104 × GW 547 (53.78 %). Out of 28 hybrids, 3 hybrids showed significant and desirable (positive) heterosis over standard check variety GW 547 (Table 2). Similar findings were also reported by earlier workers *viz.,* Saren *et al.* (2018), Khokhar *et al.* (2019), Joshi and Kumar (2020), Singh *et al.* (2022), Khan *et al.* (2023), Singh *et al.* (2024), Fareed *et al.* (2024) and Tiwari *et al.* (2024).

In wheat, dwarf varieties are desirable as they provide resistance against lodging. Heterosis for plant height over better parent ranged from -16.60 per cent (HD 3377 × MP 1358) to 13.94 per cent (AKAW 5104 × DBW 187). The maximum desirable value was observed in hybrid HD 3377 × MP 1358 (-16.60 %) followed by AKAW 5104 × UP 2968 (-13.76 %) and AKAW 5104 × HI 1625 (-13.66 %). Out of 28 hybrids, 11 hybrids showed significant and negative heterosis over better parent (Table 2). Heterosis over standard check ranged from -22.51 per cent (HD 3377 × MP 1358) to 4.67 per cent (AKAW 5104 × DBW 187). The most desirable negative heterosis was recorded by the cross HD 3377 × MP 1358 (-22.51 %) followed by AKAW 5104 × UP 2968 (-20.77%) and AKAW 5104 × HI 1625 (-20.68 %). Out of 28 hybrids, 22 hybrids showed significant and negative heterosis over standard check GW 547 (Table 2). These results are in confirmity with those obtained by Saren *et al.* (2018), Khokhar *et al.* (2019), Kumar *et al.* (2019), Joshi and Kumar (2020), Dudhat *et al.* (2022), Singh *et al.* (2022), Dahiya *et al.* (2023), Elwasef *et al.* (2023), Fareed *et al.* (2024) and Puri *et al.* (2025).

Spike length is generally associated with the number of spikelets per spike and consequently, the number of grains per spike. Therefore, the longer spike may accommodate more spikelets, increasing the grain number and ultimately yield potential. The range of heterosis over better parent was recorded from -2.01 per cent (HD 3377 × MP 1358) to 40.54 per cent (AKAW 5104 × GW 547). The highest significant positive heterosis over better parent was

expressed by the hybrid AKAW 5104 × GW 547 (40.54 %) followed by AKAW 5104 × DBW 187 (32.61 %) and AKAW 5104 × HD 3377 (30.23 %). Out of 28 hybrids, 20 hybrids showed significant and desirable (positive) estimate of heterobeltiosis (Table 2). Heterosis over standard check ranged from -13.95 per cent (AKAW 5104 ×MP 1358) to 25.10 per cent (GW 547 × UP 2968). The highest desirable standard heterosis was recorded by the cross GW 547 × UP 2968 (25.10 %). Out of 28 hybrids, only one hybrid showed significant and desirable (positive) heterosis over standard check variety GW 547 (Table 2). The results are in corroboration with those reported earlier by Saren *et al.* (2018), Khokhar *et al.* (2019), Kumar *et al.* (2019), Joshi and Kumar (2020), Singh *et al.* (2022), Elwasef *et al.* (2023), Khan *et al.* (2023) and Tiwari *et al.* (2024).

Number of spikelets per main spike is an important yield attribute as it influencing the number of grains per spike. The magnitude of heterosis over better parent ranged from -12.69 per cent (AKAW 5104 × MP 1358) to 37.15 per cent (AKAW 5104 × DBW 187). The highest heterobeltiosis was exhibited by the cross AKAW 5104 × DBW 187 (37.15 %) followed by DBW 187 × HD 3377 (35.18 %), CG 1036 × HI 1625 (31.90 %) and CG 1036 × UP 2968 (31.90 %). Out of 28 hybrids, 20 hybrid registered significant and positive heterosis over better parent for number of spikelets per main spike (Table 2). The lowest and the highest values of heterosis over standard check were -18.37 per cent (AKAW 5104 × MP 1358) and 30.96 per cent (GW 547 × UP 2968), respectively. The cross GW 547 × UP 2968 (30.96 %) exhibited the highest significant positive heterosis over standard check which was followed by CG 1036 × UP 2968 (27.29 %) and AKAW 5104 × GW 547 (25.52 %). Out of 28 hybrids, 16 hybrids showed significant and positive heterosis over standard check (Table 2). Saren *et al.* (2018), Khokhar *et al.* (2019), Kumar *et al.* (2019), Joshi and Kumar (2020), Singh *et al.* (2022) and Dahiya *et al.* (2023) also reported significant positive heterosis for number of spikelets per main spike.

Number of grains per main spike is one of the most important components of grain yield and hence, their positive values are beneficial in wheat. The range of heterosis over better parent recorded from -13.37 per cent (AKAW 5104 × MP 1358) to 40.24 per cent (AKAW 5104 × DBW 187) for number of grains per main spike. The highest heterosis over better parent in desirable

direction was recorded by the cross AKAW 5104 × DBW 187 (40.24 %) followed by DBW 187 × HD 3377 (38.46 %), CG 1036 × UP 2968 (32.14 %) and CG 1036 × MP 1358 (30.57 %). Twenty two hybrids expressed significant positive heterosis over better parent (Table 2). The range of standard heterosis varied from -24.33 per cent (AKAW 5104 × MP 1358) to 29.29 per cent (GW 547 × UP 2968). The cross GW 547 × UP 2968 (29.29 %) exhibited the highest heterosis over standard check in desired direction followed by CG 1036 × UP 2968 (22.50 %) and AKAW 5104 × GW 547 (21.64 %). Out of 28 hybrids, 14 exerted significant positive heterosis over standard check variety GW 547 (Table 2). Significant and posistive heterosis for this character has been reported by Khokhar *et al.* (2019), Kumar *et al.* (2019), Singh *et al.* (2022), Khan *et al.* (2023), El-Karamity *et al.* (2025) and Puri *et al.* (2025).

The range of heterobeltiosis recorded from -23.62 per cent (AKAW 5104 × MP 1358) to 37.23 per cent (GW 547 × UP 2968) for 100-grain weight. Out of 28 hybrids, none of the crosses showed significant and positive heterosis over better parent. The standard heterosis for this trait laid between -24.45 per cent (AKAW 5104 × MP 1358) and 38.15 per cent (GW 547 × UP 2968). Out of 28 hybrids, none of the crosses showed significant and positive heterosis over standard check (Table 2).

Grain yield is the most important economic characters and the final product of the multiplicative interaction of contributing traits. Therefore, it is imperative to know the extent of heterosis for grain yield. The estimates of heterosis over better parent varied from -9.32 per cent (AKAW 5104 × MP 1358) to 48.58 per cent (DBW 187 × HD 3377) for grain yield per plant. The cross DBW 187 × HD 3377 (48.58 %) depicted the highest desirable heterosis over better parent followed by CG 1036 × UP 2968 (44.92 %) and CG 1036 × MP 1358 (38.17 %). Out of 28 hybrids, 6 hybrids expressed significant positive heterosis over better parent (Table 2). The economic heterosis ranged from -17.25 per cent (AKAW 5104 × MP 1358) to 35.20 per cent (GW 547 × UP 2968). The cross GW 547 × UP 2968 (35.20 %) recorded the highest significant heterosis towards positive direction over standard check, followed by CG 1036 × UP 2968 (34.92 %), AKAW 5104 × GW 547 (34.78 %) and DBW 187 × HD 3377 (34.62 %). Out of 28 hybrids, 4 hybrids showed significant positive desirable heterosis over standard check GW 547 (Table

Table 2: Per cent heterosis observed over better parent (H) and standard check GW 547 (SH) for different characters

Crosses	Days to anthesis		Days to maturity		Grain filling period		No. of effective tillers		Plant height		Length of main spike	
	H (%)	SH (%)	H (%)	SH (%)	H (%)	SH (%)	H (%)	SH (%)	H (%)	SH (%)	H (%)	SH (%)
AKAW 5104×CG 1036	3.63	-5.85**	7.42**	-3.04**	6.51**	-7.99**	1.92	0.01	-7.74**	-15.25**	20.23**	-6.68
AKAW 5104×DBW 187	6.40**	-7.98**	10.48**	-0.28	14.85**	-0.36	43.14	37.74	13.94**	4.67**	32.61**	2.94
AKAW 5104×GW 547	-9.07**	-6.17**	-4.78**	1.80**	-3.28**	6.90**	46.85	53.78*	0.28	0.87	40.54**	9.09
AKAW 5104×HD 3377	-1.34	-5.96**	3.92**	-2.90**	16.81**	0.91	26.17	27.36	7.78**	-0.99	30.23**	1.08
AKAW 5104×HI 1625	9.59**	-5.21**	10.64**	-0.14	18.00**	4.72**	8.33	-1.89	-13.66**	-20.68**	12.70	-12.52*
AKAW 5104×MP 1358	-9.15**	2.45	-2.38**	1.93**	12.84**	-1.09	-4.63	-2.83	-4.84**	-11.58**	10.86	-13.95*
AKAW 5104×UP 2968	-16.40**	-2.45	-8.14**	3.66**	12.84**	5.26**	18.92	24.53	-13.76**	-20.77**	29.64**	0.63
CG 1036 × DBW 187	10.66**	0.53	13.87**	0.35	9.83**	-4.72**	9.62	7.55	0.97	-12.53**	14.43*	-1.82
CG 1036 × GW 547	-6.49**	-3.51*	-9.69**	-3.45**	-16.42**	-7.62**	36.04	42.45	-7.64**	-7.09**	17.69**	6.54
CG 1036 × HD 3377	-3.46	-7.98**	4.51**	-2.35**	19.13**	-0.54	33.64	34.91	-1.16	-15.54**	12.40*	1.75
CG 1036 × HI 1625	7.26**	-2.55	15.38**	0.01	11.45**	-1.09	41.35	38.68	-2.37	-12.94**	21.78**	3.22
CG 1036 × MP 1358	-16.32**	-5.64**	-7.14**	-3.04**	6.63**	-6.53**	42.59	45.28	4.40**	-3.00*	18.27**	7.06
CG 1036 × UP 2968	-20.42**	-7.13**	-14.32**	-3.31**	0.58	-6.17**	51.35*	58.49*	2.71	-9.19**	21.21**	9.72
DBW 187 × GW 547	-11.96**	-9.15**	-12.98**	-6.98**	-22.00**	-13.79**	28.83	34.91	-9.17**	-8.63**	18.99**	2.10
DBW 187 × HD 3377	6.25**	1.28	0.07	-6.49**	-9.41**	-21.42**	44.86	46.23	-0.83	-14.08**	27.06**	9.02
DBW 187 × HI 1625	17.19**	-0.64	11.76**	-1.52**	-2.25	-13.25**	3.92	0.01	3.19**	-7.98**	9.82	-6.92
DBW 187 × MP 1358	-14.34**	-3.40*	-9.26**	-5.25**	7.45**	-5.81**	11.11	13.21	2.24	-5.01**	15.57*	-0.84
DBW 187 × UP 2968	-22.52**	-9.57**	-17.87**	-7.32**	-6.23**	-12.52**	-1.80	2.83	5.03**	-7.14**	13.04**	-3.01
GW 547 × HD 3377	-10.62**	-7.77**	-3.17**	3.52**	1.64	12.34**	28.83	34.91	-11.82**	-11.30**	8.86	2.24
GW 547 × HI 1625	-10.31**	-7.45**	-6.72**	-0.28	-6.40**	3.45**	35.14	41.51	-0.10	0.50	23.02**	4.27
GW 547 × MP 1358	-17.26**	-6.70**	-5.81**	0.69	-7.06**	2.72*	33.33	39.62	-1.58	-1.00	8.92	4.13
GW 547 × UP 2968	-17.59**	-3.83*	-6.12**	5.94**	1.97*	12.70**	51.35*	58.49*	1.24	1.84	27.51**	25.10**
HD 3377 × HI 1625	0.78	-3.94*	5.40**	-1.52**	19.84**	6.35**	36.45	37.74	-4.47**	-14.81**	21.04**	2.59
HD 3377 × MP 1358	-9.72**	1.81	-3.11**	1.17**	13.66**	-0.36	-2.31	-0.47	-16.60**	-22.51**	-2.01	-7.97
HD 3377 × UP 2968	-21.97**	-8.94**	-20.07**	-9.81**	-8.37**	-14.52**	9.01	14.15	-1.07	-12.53**	6.89	0.38
HI 1625 × MP 1358	-19.15**	-8.83**	-6.55**	-2.42**	21.88**	8.17**	0.93	2.83	-3.36*	-10.21**	14.44*	-3.01
HI 1625 × UP 2968	-7.29**	8.19**	-10.40**	1.10*	-7.00**	-13.25**	-4.95	-0.47	-4.20**	-14.57**	8.58	-7.97
MP 1358 × UP 2968	-6.65**	8.94**	-1.71**	10.91**	3.70**	-3.27**	39.64	46.23	-2.30	-9.22**	12.80*	7.83
SE ±	1.05	1.05	0.42	0.42	0.39	0.39	1.90	1.90	1.05	1.05	0.53	0.53
Range of heterosis	-22.52 to 17.19	-9.57 to 8.94	-20.07 to 15.38	-9.81 to 10.91	-22.00 to 21.88	-21.42 to 12.70	-4.95 to 51.35	-2.83 to 58.49	-16.59 to 13.94	-22.51 to 4.67	-2.01 to 40.54	-13.95 to 25.10
No. of positive & significant crosses	6	2	9	8	16	9	2	3	5	1	20	1
No. of negative & significant crosses	18	19	18	14	9	13	0	0	11	22	0	2

*, ** Significant at 5% and 1% levels, respectively.

Table 2: continue…

Crosses	No. of spikelets / main spike		No. of grains / main spike		100-grain weight		Grain yield / plant		Biological yield / plant		Harvest Index	
	H (%)	SH (%)	H (%)	SH (%)	H (%)	SH (%)	H (%)	SH (%)	H (%)	SH (%)	H (%)	SH (%)
AKAW 5104×CG 1036	5.24*	-10.08**	3.75**	-14.70**	28.65	-2.27	4.62	-10.10	-10.87*	-12.65**	8.60*	2.98
AKAW 5104×DBW 187	37.15**	11.91**	40.24**	4.03**	36.82	2.10	33.30	6.94	16.11**	13.79**	3.89	-5.57
AKAW 5104×GW 547	22.06**	25.52**	20.13**	21.64**	26.21	27.06	33.66*	34.78*	-4.25	14.44**	37.66**	18.12**
AKAW 5104×HD 3377	15.67**	5.76*	18.62**	1.37	2.72	1.43	12.02	1.50	-0.73	-2.71	-4.70	4.24
AKAW 5104×HI 1625	1.38	-18.04**	8.97**	-23.23**	2.27	-24.12	5.91	-16.20	-15.38**	-17.07**	15.54**	2.11
AKAW 5104×MP 1358	-12.70**	-18.37**	-13.37**	-24.33**	-23.62	-24.45	-9.32	-17.25	-13.89**	-15.61**	2.69	-1.77
AKAW 5104×UP 2968	4.32	0.68	8.96**	1.01	1.27	0.59	7.98	0.54	-2.12	-4.07	-4.64	4.73
CG 1036 × DBW 187	14.31**	-2.32	14.57**	-5.81**	30.86	-0.59	11.32	-4.35	5.13	-4.74	6.89	1.36
CG 1036 × GW 547	12.44**	15.63**	9.90**	11.28**	22.12	22.94	19.68	20.69	-7.54*	10.50*	15.47**	9.49*
CG 1036 × HD 3377	19.30**	9.08**	19.06**	1.74	2.98	1.68	12.23	1.68	4.87	-4.98	-1.74	7.48
CG 1036 × HI 1625	31.90**	12.70**	28.27**	5.45**	35.51	2.94	30.98	12.55	11.94*	1.56	18.15**	12.04**
CG 1036 × MP 1358	24.18**	16.12**	30.57**	14.04**	24.55	23.19	38.17*	26.09	12.23*	7.38	22.98**	17.63**
CG 1036 × UP 2968	31.90**	27.29**	32.14**	22.50**	28.00	27.14	44.92*	34.92*	27.04**	15.11**	6.61	17.09**
DBW 187 × GW 547	6.74**	9.76**	1.36	2.64**	1.00	1.68	2.64	3.51	-18.41**	-2.48	17.00**	6.35
DBW 187 × HD 3377	35.18**	23.59**	38.46**	18.32**	28.60	26.97	48.58**	34.62**	40.49**	24.10**	-0.96	8.33**
DBW 187 × HI 1625	9.51**	-10.65**	13.94**	-15.47**	29.95	-3.03	9.88	-11.85	4.09	-5.56	2.81	-6.55
DBW 187 × MP 1358	5.73*	-1.13	8.01**	-5.66**	0.51	-0.59	8.27	-1.19	-4.75	-8.86	13.86**	8.90*
DBW 187 × UP 2968	-0.33	-3.81	-0.31	-7.58**	-0.17	-0.84	-0.20	-7.08	12.67*	-0.47	-14.69**	-6.31
GW 547 × HD 3377	7.87**	10.93**	1.52	2.79**	1.09	1.76	3.94	4.82	-2.65	16.35**	-17.88**	-10.18*
GW 547 × HI 1625	11.29**	14.44**	7.93**	9.29**	20.78	21.60	13.49	14.45	-5.68	12.72**	14.97**	1.60
GW 547 × MP 1358	10.24**	13.36**	6.81**	8.16**	20.62	21.43	13.03	13.98	-10.29**	7.22	10.79*	5.97
GW 547 × UP 2968	27.35**	30.96**	27.69**	29.29**	37.23	38.15	34.08*	35.20*	4.58	24.99**	-1.43	8.25*
HD 3377 × HI 1625	22.36**	11.87**	21.08**	3.47**	3.23	1.93	17.88	6.80	25.16**	13.55**	-13.76**	-5.67
HD 3377 × MP 1358	-7.06**	-13.10**	-3.55**	-15.76**	-2.21	-3.28	-5.02	-13.32	-2.60	-6.81	-15.09**	-7.13
HD 3377 × UP 2968	4.05	0.42	8.82**	0.88	1.18	0.50	7.43	0.02	6.52	-9.67*	1.09	11.03**
HI 1625 × MP 1358	2.87	-3.81	5.81**	-7.58**	0.25	-0.84	1.82	-7.08	-12.83**	-16.59**	16.59**	11.52**
HI 1625 × UP 2968	-9.96**	-13.10**	-9.13**	-15.76**	-2.62	-3.28	-6.90	-13.32	2.86	-6.68	-15.52**	-7.22
MP 1358 × UP 2968	25.19**	20.82**	26.68**	17.43**	26.99	26.13	37.33*	27.86	22.20**	16.92**	-0.28	9.52*
SE ±	0.39	0.39	0.42	0.42	1.90	1.90	2.42	2.42	1.59	1.59	1.59	1.59
Range of heterosis	-12.69 to 37.15	-18.37 to 30.96	-13.37 to 40.24	-24.33 to 29.29	-23.62 to 37.23	-24.45 to 38.15	-9.32 to 48.58	-17.25 to 35.20	-18.41 to 40.49	-17.07 to 24.99	-17.88 to 37.66	-10.18 to 18.12
No. of positive & significant crosses	20	16	22	14	0	0	6	4	8	10	11	11
No. of negative & significant crosses	3	6	3	10	0	0	0	0	7	5	5	1

*, ** Significant at 5% and 1% levels, respectively.

2). Comparable results were reported by Thomas *et al.* (2017), Saren *et al.* (2018), Khokhar *et al.* (2019), Kumar *et al.* (2021), Burdak *et al.* (2023), Elwasef *et al.* (2023), Khan *et al.* (2023), Singh *et al.* (2024) and El-Karamity *et al.* (2025).

Biological yield per plant is a comprehensive measure of productivity. It plays a central role in assessing plant growth, yield potential and breeding efficiency, especially when combined with traits like harvest index and grain yield. The range of heterosis over better parent was obtained from -18.41 per cent (DBW 187 × GW 547) to 40.49 per cent (DBW 187 × HD 3377) for biological yield per plant. The highest heterobeltiosis was recorded by the cross DBW 187 × HD 3377 (40.49 %). Out of 28 hybrids, 8 hybrids expressed significant and positive heterosis over better parent (Table 2). The range of heterosis over standard check observed from -17.07 per cent (AKAW 5104 × HI 1625) to 24.99 per cent (GW 547 × UP 2968). The cross GW 547 × UP 2968 (24.99 %) exhibited the highest significant heterosis over standard check, followed by DBW 187 × HD 3377 (24.10 %), MP 1358 × UP 2968 (16.92 %) and GW 547 × HD 3377 (16.35 %). Ten hybrids expressed significant positive desirable heterosis over standard check for biological yield per plant (Table 2). The present findings are in accordance with those of Kumar *et al.* (2019), Joshi and Kumar (2020), Dudhat *et al.* (2022), Singh *et al.* (2022), Elwasef *et al.* (2023) and El-Karamity *et al.* (2025).

Harvest index is a crucial physiological parameter that represents the proportion of the total biological yield that is converted into economic yield, specifically grain in the case of wheat. A high harvest index means a greater proportion of the plant's total biomass is converted into grain. The estimates of heterobeltiosis for this important trait varied from -17.88 per cent (GW 547 × HD 3377) to 37.66 per cent (AKAW 5104 × GW 547). The highest significant and desirable heterosis over better parent was recorded by the cross AKAW 5104 × GW 547 (37.66 %), followed by CG 1036 × MP 1358 (22.98 %), CG 1036 × HI 1625 (18.15 %) and DBW 187 × GW 547 (17.00 %). Out of 28 hybrids, 11 hybrids demonstrated significant and positive heterosis over better parent (Table 2). The standard heterosis ranged from -10.18 per cent (GW 547 × HD 3377) to 18.12 per cent (AKAW 5104 × GW 547). The cross AKAW 5104 × GW 547 (18.12 %) exhibited

the highest significant standard heterosis, followed by CG 1036 × MP 1358 (17.63%), CG 1036 × UP 2968 (17.09%) and CG 1036 × HI 1625 (12.04 %). Out of 28 hybrids, 11 manifested significant and positive heterosis over standard check for harvest index (Table 2). Similar findings have also been observed by Sharma *et al.* (2018), Dudhat *et al.* (2022), Khan *et al.* (2023), Tiwari *et al.* (2024) and El-Karamity *et al.* (2025).

The estimates of heterosis over better parent varied from -9.32 % to 48.58 % for grain yield per plant. The cross DBW 187 × HD 3377 (48.58 %) depicted the highest desirable heterosis over better parent followed by CG 1036 × UP 2968 (44.92 %) and CG 1036 × MP 1358 (38.17 %). The cross combination DBW 187 × HD 3377 (for number of spikelets per main spike, grain filling period, number of grains per main spike and biological yield per plant) and CG 1036 × UP 2968 (for days to maturity, number of effective tillers per plant, number of spikelets per main spike, number of grains per main spike and biological yield per plant) exhibited good heterobeltiosis.

The hybrids exhibited marked standard heterosis for various characters. Significant estimates of standard heterosis were observed in four cross combinations for grain yield per plant. The economic heterosis ranged from -17.25 % to 35.20 %. The cross GW 547 × UP 2968 (35.20 %) recorded the highest significant heterosis towards positive direction over standard check, followed by CG 1036 × UP 2968 (34.92 %) and AKAW 5104 × GW 547 (34.78 %). Hybrid GW 547 × UP 2968 exhibited significant standard heterosis (for length of main spike, number of grains per main spike and biological yield per plant), CG 1036 × UP 2968 (for the number of effective tillers per plant, number of spikelets per main spike, number of grains per main spike, harvest index and grain yield per plant) exhibited good standard heterosis. The results thus, showed that the grain yield per plant was associated with heterosis for its component characters and such crosses could be exploited for practical plant breeding programme in wheat.

3.1. Analysis of variance for combining ability

The analysis of variance for combining ability for twelve characters is revealed that the mean squares due to GCA and SCA were significant for all the characters *viz.,* days to anthesis (days), days to maturity (days), plant height (cm), number of effective tillers per plant, length of main

spike (cm), number of spikelets per main spike, grain filling period (days), number of grains per main spike, 100-grain weight (g), grain yield per plant (g), biological yield per plant (g) and harvest index (%). This indicated that both additive and non-additive type of gene effects played a vital role in the inheritance of all these traits under studied. the results, in general, are in accordance with the findings of Chaudhary *et al.* (2022), Mahmud *et al.* (2023), Saini *et al.* (2023), Abdo *et al.* (2024) and Ocaktan *et al.* (2024).

The magnitude of GCA and SCA variances revealed that the SCA variances were higher than their respective GCA variances for all the characters *viz.,* days to anthesis (days), days to maturity (days), plant height (cm), number of effective tillers per plant, length of main spike (cm), number of spikelets per main spike, grain filling period (days), number of grains per main spike, 100-grain weight (g), grain yield per plant (g), biological yield per plant (g) and harvest index (%). The potence ratio less than unity confirmed the preponderance of non-additive gene action for all the studied traits. Similar results were found by Singh *et al.* (2022), Jalaj *et al.* (2021) for days to anthesis, Patel *et al.* (2020), Jalaj *et al.* (2021) and Tiwari *et al.* (2024) for days to maturity, Patel *et al.* (2020) and Tiwari *et al.* (2024) for plant height, Patel *et al.* (2020), Jalaj *et al.* (2021) and Tiwari *et al.* (2024) for number of effective tillers per plant, Patel *et al.* (2020) for length of main spike, Patel *et al.* (2020) and Jalaj *et al.* (2021) for number of spikelets per main spike, Tiwari *et al.* (2024) for grain filling period, Patel *et al.* (2020), Jalaj *et al.* (2021) and Tiwari *et al.* (2024) for number of grains per main spike, Patel *et al.* (2020) for 100-grain weight, Jalaj *et al.* (2021) and Tiwari *et al.* (2024) for grain yield per plant, Patel *et al.* (2020) and Tiwari *et al.* (2024) for biological yield per plant and Patel *et al.* (2020), Hossain *et al.* (2022) and Tiwari *et al.* (2024) for harvest index.

This was further supported by the ratio of $(\sigma^2_{gca}/\sigma^2_{sca})$ was less than unity for all the characters studied, confirmed the preponderance of non-additive gene action which suggest the equal chances of hybrid breeding approach in bread wheat. These findings are in accordance with Patel *et al.* (2020) and Tiwari *et al.* (2024).

3.2. General combining ability effects

The character-wise estimates of general combining ability effects for each parent have been present in Table 4.

Nature and magnitude of combining ability effect helps in identifying superior parents for their utilization in further breeding programme. Estimates of gca effect in the present study showed that it was difficult to pick one good general combiner simultaneously for all the traits together as the combining ability effect of parents were not consistent for all the traits. Selection of the parents for hybridization is an important aspect in the crop improvement programme and the performance of varieties in a trial may give an idea of their relative superiority. Therefore, in any sound breeding programme, the proper choice of parents based on their combining ability is a pre-requisite.

As such studies intended to determine the combining ability provide not only necessary information regarding the choice of parents but also illustrate the nature and magnitude of gene action involved. Accordingly, the present investigation was undertaken on combining ability for grain yield and yield components in wheat with a view to identify good combiners which may be used to create a population with favorable genes for yield and component characters in wheat. However, on an overall basis, the results of gca effect of the parents were categorized as good, average and poor combiners on the basis of their gene effect for different traits. The parents showing desirable and significant gca effects were considered as good general combiners, while those with non-significant gca effects as average general combiners and parents with significant but undesirable gca effects were considered as poor general combiners. The gca effect of the parents presented in Table 4 have also been discussed here.

The general combining ability effects of the parents revealed that none of the parents was found to be good general combiner for all the characters. An overall appraisal of gca effect revealed that parent, GW 547 was good general combiners for grain yield per plant and some of its components except days to anthesis, days to maturity, plant height and harvest index. Whereas, HI 1625 and AKAW 5104 were poor combiners for Grain yield per plant. Four parents *viz.,* AKAW 5104, CG 1036, DBW 187 and HI 1625 exhibited significant and negative gca effects and hence, they were registered as good general combiner for days to anthesis. For days to maturity, parents CG 1036, DBW 187, HD 3377 and HI 1625 were registered as good general combiners.

Table 3: Analysis of variance (mean squares) for combining ability and variance components for different characters

Source of variation	d.f.	Days to anthesis	Days to maturity	Plant height	No. of effective tillers / plant	Length of main spike	No. of spikelets / main spike
GCA	7	39.55**	90.60**	59.10**	2.63**	1.40**	10.19**
SCA	28	15.61**	29.19**	23.03**	2.36**	0.54**	5.94**
Error	72	2.22	5.15	3.40	0.26	0.12	0.50
σ^2 gca	-	2.39	6.14	3.61	0.03	0.09	0.42
σ^2 sca	-	13.39	24.04	19.63	2.10	0.42	5.44
σ^2 gca/ σ^2 sca	-	0.18	0.25	0.18	0.01	0.20	0.08

Source of variation	d.f.	Grain filling period	No. of grains / main spike	100-grain weight	Grain yield / plant	Biological yield / plant	Harvest Index
GCA	7	22.02**	86.19**	0.79**	7.93**	32.12**	16.56**
SCA	28	8.86**	39.18**	0.37**	5.60**	16.74**	15.24**
Error	72	0.58	2.19	0.03	0.39	1.54	5.75
σ^2 gca	-	1.32	4.70	0.04	0.23	1.54	0.13
σ^2 sca	-	8.28	36.99	0.34	5.21	15.20	9.49
σ^2 gca/ σ^2 sca	-	0.16	0.13	0.13	0.05	0.10	0.02

Where, * and ** Significant at 5% and 1% levels, respectively.

The good general combining ability effects were expressed by the parents CG 1036, HD 3377 and HI 1625 for plant height. The gca effects were significant and positive for the parents GW 547 and CG 1036 thus it indicated good general combining ability effects of this lines for number of effective tillers per plant. The estimate of gca effect revealed that lines GW 547 and UP 2968 were good general combiner for length of main spike. For number of spikelets per main spike parents GW 547 and UP 2968 registered as good general combiners. As the parents CG 1036 and DBW 187 exhibited significant and desirable gca effects, they were good general combiner for grain filling period. Estimates of gca effects revealed that parental lines GW 547, UP 2968 and CG 1036 exhibited significant positive gca effects, indicating that they are good general combiners for number of grains per main spike. For 100-grain weight gca effects revealed that parental lines GW 547 and UP 2968 were good general combiner. Significant and positive gca effect depicted by GW 547, CG 1036 and UP 2968 for grain yield per plant. Highly significant and positive gca effect depicted by only GW 187 indicating that it is a good general combiner for biological yield per plant. Two parents CG 1036 and UP 2968 were observed as good general combiners for harvest index.

High gca effects of the parents mostly contribute additive gene effects and additive × additive interaction effect and represents fixable portion of genetic variation. In view of this, GW 547, CG 1036 and UP 2968 offered the best possibilities for exploitation in the development of improved lines with enhanced yielding ability. Further, the varieties or lines showing good general combining ability for particular component ultimately seeking improvement in grain yield itself. The high gca effects for grain yield and its different components traits were also reported by Dhoot *et al.* (2020), Chaudhary *et al.* (2022) and Ocaktan *et al.* (2024).

3.3. Estimation of specific combining ability effects

The estimates of specific combining ability (sca) effects of hybrids for yield and its component traits is presented in table 5 and described as under:

The estimates of sca effects of crosses indicated that ten out of twenty-eight crosses had reported significant and positive sca effects for grain yield per plant. Among them the highest sca effects was manifested by the cross DBW 187 × HD 3377 (5.20) followed by AKAW 5104 × GW

Table 4: General combining ability effects for different characters

Characters	Parents								SE (gi)	SE (gi-gj)
	AKAW 5104	CG 1036	DBW 187	GW 547	HD 3377	HI 1625	MP 1358	UP 2968		
Days to anthesis	-1.55**	-1.06*	-1.62**	-0.29	-0.46	-1.29**	2.99**	3.27**	0.44	0.67
Days to maturity	-0.14	-2.36**	-3.30**	3.10**	-1.40*	-3.02**	2.89**	4.24**	0.67	1.02
Plant height	0.44	-1.80**	0.65	5.09**	-2.92**	-1.40*	0.71	-0.77	0.54	0.82
No. of effective tillers per plant	-0.52**	0.30*	-0.32*	0.97**	0.12	-0.57**	-0.23	0.23	0.15	0.23
Grain filling period	0.72**	-1.32**	-2.20**	2.80**	-0.44	0.41	0.28	-0.28	0.22	0.34
Length of main spike	-0.52**	0.10	-0.17	0.61**	0.06	-0.39**	-0.06	0.37**	0.10	0.16
No. of spikelets / main spike	-1.15**	0.35	-0.51*	1.89**	0.22	-1.13**	-0.32	0.65**	0.21	0.32
No. of grains / main spike	-3.24**	1.06*	-1.67**	5.08**	0.37	-3.56**	-0.66	2.61**	0.44	0.66
100-grain weight	-0.38**	0.03	-0.18**	0.46**	0.03	-0.30**	0.08	0.27**	0.05	0.072
Grain yield / plant	-0.98**	0.49**	-0.54**	1.57**	-0.02	-1.07**	-0.10	0.65**	0.19	0.280
Biological yield / plant	-1.08**	-0.32	-0.36	4.26**	-0.25	-1.39**	-0.98**	0.11	0.37	0.555
Harvest Index	-1.59*	1.62*	-1.17	-0.25	0.38	-1.32	0.75	1.58*	0.71	1.072

Where, * and ** Significant at 5% and 1% levels, respectively

Table 5: Estimates of specific combining ability effects of hybrids for different characters

Sr. No.	Crosses	Days to anthesis	Days to maturity	Plant height	No. of effective tillers / plant	Length of main spike	No. of spikelets / main spike	Grain filling period	No. of grains / main spike	100-grain weight	Grain yield / plant	Biological yield / plant	Harvest Index
1	AKAW 5104 × CG 1036	1.27	1.39	-3.39*	-1.20**	-0.11	-1.36*	-0.77	-3.26*	0.17	-1.25*	-3.18**	0.39
2	AKAW 5104 × DBW 187	0.50	5.01*	10.56**	2.09**	1.07**	3.38**	2.92**	7.97**	0.55**	2.21**	6.22**	-0.25
3	AKAW 5104 × GW 547	0.30	0.60	3.00	1.94**	0.87**	3.39**	0.58	9.28**	0.90**	4.07**	1.83	8.37**
4	AKAW 5104 × HD 3377	0.60	0.56	9.48**	0.92*	0.66*	1.57*	1.62*	4.72**	0.31*	0.92	0.26	2.14
5	AKAW 5104 × HI 1625	1.90	4.84*	-8.27**	-0.46	-0.18	-1.28*	2.18**	-2.51	-0.36*	-0.55	-3.68**	2.99
6	AKAW 5104 × MP 1358	2.42	0.94	-2.88	-0.87	-0.65*	-2.15**	0.17	-5.91**	-0.76**	-1.67**	-3.58**	-0.64
7	AKAW 5104 × UP 2968	-0.92	1.26	-8.97**	0.60	0.31	0.24	3.03**	2.32	0.05	0.11	-0.58	1.13
8	CG 1036 × DBW 187	5.35**	7.82**	-1.36	-0.86	-0.01	-0.63	3.35**	-0.80	0.04	-0.87	-1.10	-0.68
9	CG 1036 × GW 547	1.48	-2.24	-1.32	0.32	0.01	0.14	-2.71**	0.21	0.33*	0.59	-0.32	1.67
10	CG 1036 × HD 3377	-1.15	3.32	-0.27	0.63	0.12	0.65	3.12**	0.59	-0.08	-0.53	-1.29	0.23
11	CG 1036 × HI 1625	3.08**	7.20**	0.34	1.58**	0.70*	2.64**	2.08**	6.21**	0.30*	2.07**	2.16	3.77
12	CG 1036 × MP 1358	-3.13*	-1.63	6.42**	1.71**	0.73*	2.44**	0.20	7.20**	0.73**	3.03**	3.81**	3.95
13	CG 1036 × UP 2968	-4.34**	-3.25	2.81	2.12**	0.56	3.43**	0.86	7.77**	0.70**	3.54**	5.46**	2.90
14	DBW 187 × GW 547	-1.49	-4.70*	-5.04**	0.40	-0.15	-0.03	-4.09**	-0.99	-0.30*	-0.83	-4.88**	3.20
15	DBW 187 × HD 3377	5.21**	0.26	-1.52	2.05**	1.07**	4.08**	-3.66**	10.84**	1.13**	5.20**	9.04**	3.37
16	DBW 187 × HI 1625	4.84**	6.68**	1.98	-0.56	0.01	-0.62	-1.50*	-0.56	0.27	-0.38	-0.32	-0.92
17	DBW 187 × MP 1358	-1.17	-2.82	2.32	0.06	0.24	0.25	1.36*	0.99	-0.01	0.17	-1.90	3.23
18	DBW 187 × UP 2968	-5.31**	-6.17**	2.05	-1.13*	-0.39	-1.20	-0.58	-3.16*	-0.21	-1.42*	-0.02	-3.73
19	GW 547 × HD 3377	-1.78	3.53	-3.66*	-0.03	-0.36	-0.55	3.74**	-2.95*	-0.51**	-1.16*	1.68	-5.01*

Sr. No.	Cross												
20	GW 547 × HI 1625	-0.75	1.48	4.54**	1.12*	0.29	1.42*	-0.37	3.92**	0.61**	1.26*	1.53	1.44
21	GW 547 × MP 1358	-4.56**	-3.49	1.19	0.65	-0.06	0.42	-0.51	0.51	0.22	0.22	-0.82	1.13
22	GW 547 × UP 2968	-3.04*	0.23	5.02**	1.52**	1.51**	2.54**	3.68**	6.82**	0.70**	2.50**	4.38**	1.21
23	HD 3377 × HI 1625	1.61	4.77*	-0.06	1.70**	0.68*	2.64**	3.93**	5.10**	0.25	1.76**	6.33**	-2.12
24	HD 3377 × MP 1358	0.94	1.47	-8.52**	-1.34**	-0.66*	-2.58**	1.59*	-5.63**	-0.33*	-2.07**	-1.29	-4.78*
25	HD 3377 × UP 2968	-6.07**	-10.48**	1.19	-0.76	-0.29	-1.17	-3.08**	-1.35	-0.37*	-0.92	-3.39**	1.70
26	HI 1625 × MP 1358	-4.90	-0.37	0.09**	-0.42**	0.26*	0.41**	3.88**	2.01**	0.10*	-0.13*	-3.61	4.44*
27	HI 1625 × UP 2968	5.48**	1.67	-2.02	-1.11*	-0.63*	-2.21**	-3.45**	-4.97**	-0.18	-1.77**	-1.19	-3.95
28	MP 1358 × UP 2968	1.68	5.24*	0.27	1.85**	0.54	2.97**	0.34	7.19**	0.61**	3.13**	6.76**	0.72
	SE ±	1.35	2.06	1.67	0.46	0.32	0.64	0.69	1.34	0.15	0.57	1.12	2.17

Where, * and ** Significant at 5% and 1% levels, respectively.

547 (4.07) and CG 1036 × UP 2968 (3.54). Hybrid DBW 187 × HD 3377 was also found good specific combiner for number of effective tillers per plant, length of main spike, number of spikelets per main spike, grain filling period, number of grains per main spike, 100-grain weight and biological yield per plant. Likewise, the cross AKAW 5104 × GW 547 exhibited significant sca effect for number of spikelets per main spike, number of grains per main spike, 100-grain weight and harvest index.

The significant sca effects for grain yield and different component traits were also recorded by several workers *viz.*, Motawea (2017), Ayoob (2019), Dedaniya (2019), Dhoot *et al.* (2020) and Tiwari *et al.* (2024).

Evaluation of the hybrids on the basis of sca effects is the second most important criteria because sca effects of the hybrids has been attributed to the combination of positive favourable genes from different parents due to presence of linkage in repulsion phase. The specific combining ability is associated with interaction effects, which may be due to dominance and epistatic components of variation that are non-fixable in nature. Hence, sca can be utilized in generation like F_1 for the development of superior F_1 hybrids.

In the present study estimate of sca effects revealed that none of the crosses was consistently superior for all characters. Among 28 hybrids studied, ten hybrids exhibited significant positive specific combining ability effects for grain yield per plant. The highest sca effect for grain yield per plant was exhibited by the cross DBW 187 × HD 3377 (poor × average), followed by AKAW 5104 × GW 547 (poor × good) and CG 1036 × UP 2968 (good × good).

The gca effects of the parents and sca effects of their crosses in the present study indicated that the crosses between two good general combiners were not always the best in their sca effects. The best specific cross combinations for different characters in present study were the combinations of good × good, poor × good, poor × average, good × poor, average × poor, good × average and poor × average general combiners. This indicated the inconsistent expression of sca effect in specific crosses irrespective of gca effect of the parents.

Better performance of hybrids involving average × poor general combiners indicated dominance × dominance (epistasis) type of gene action (Jinks, 1954). Such cross

could be utilized in the production of high yielding homozygous lines (Darrah and Hallauer, 1972). Crosses which were involved at least one good general combiner, indicating additive × dominance type of gene interaction, which could produce desirable transgressive segregants in subsequent generations.

The crosses where poor × good general combiners producing high sca effects may be attributed due to presence of genetic diversity in the form of heterozygous loci for specific traits. Thus, the ideal crosses would be the one, which have good per se performance, high heterosis or heterobeltiosis, at least one good general combiner parent and high sca effects.

This suggested that information on gca effects should be supplemented by sca effects and hybrid performance of cross combinations to predict the transgressive type possibly made available in segregating generations. Selection is rapid if gca effects of parents and sca effects of crosses are in same direction. If crosses showing high sca effects involve at least one parent possessing good gca effects and high mean value, they could be exploited for practical breeding. However, high sca effects would not necessarily mean a high performance by the hybrid and the estimation of sca effects seemed to be superflous, as no additional information was obtained by doing so. Therefore, it is suggested that the selection of parents for further breeding programme should be based on gca effects and due consideration should be given to mean value of the cross combinations while selecting crosses for specific combining ability effects.

Conclusion

On the basis of heterotic response and combining ability estimate for grain yield and its attributing traits, the crosses *viz.,* DBW 187 × HD 3377, AKAW 5104 × GW 547 and CG 1036 × UP 2968 appeared to be most superior. From the present finding it can be concluded that sufficient variation was present in the material for grain yield and its components. Both additive and non-additive components were important for inheritance of different characters studied. The presence of non-additive gene action enhances chance of making improvement through heterosis breeding. The pre-dominance of non-additive gene action suggests the simultaneous exploitation of the gene action by adopting selective intermating and selection of superior hybrids, which can accumulate more

non-additive genetic variability. Now when the gene action of all characters attributing to grain yield are known, the crop improvement can be done by adopting biparental mating followed by selection. When there is presence of epistasis recombination breeding methods like pedigree or biparental mating or diallel selective mating system may prove to be effective in improvement of grain yield and its attributing traits in bread wheat. Overall, recognizing and leveraging non-additive gene action offers a promising avenue for accelerating genetic gains and enhancing productivity in wheat.

Authors' Contributions

All authors contributed equally for preparing the final version of the manuscript.

Conflict of Interest

Authors declare no conflict of interest.

Ethical Approval

The article doesn't contain any study involving ethical approval.

Generative AI or AI/Assisted Technologies use in Manuscript Preparation

No

References

1. Abdo ER and A Khaled. 2024. Heterosis and combining ability for some important characters in half diallel crosses of bread wheat (*Triticum aestivum* L.). *Migration Letters*, **21**(**S5**)**:** 1786–1810.

2. Ayoob MH. 2019. Combining ability analysis, estimation of heterosis and some genetic parameters using half diallel cross in bread wheat (*Triticum aestivum* L.). *Journal of education science,* **29**(**1**)**:** 93-106.

3. Burdak A, V Prakash, BL Kakralya, D Gupta and R Choudhary. 2023. Heterotic performance and inbreeding depression for yield and component traits in bread wheat (*Triticum aestivum* L. Em. Thell.). *International Journal of Environment and Climate Change,* **13**(**3**): 56-64.

4. Chaudhary NK, LK Gangwar, Pooran Chand, SK Singh, M Kumar, Shiva Mohan and P Kushawaha. 2022. Analysis of combining ability for yield and its contributing traits in bread wheat (*Triticum aestivum* L.). *The Pharma Innovation Journal,* **11**(**5**)**:** 2500-2504.

5. Dahiya N, I Delvadiya, SD Murakonda and A Dahiya. 2023. Heterosis and combining ability analysis for yield and its component traits in bread wheat (*Triticum aestivum* L.). *International Journal of Plant & Soil Science,* **35(18)** : 499-517.

6. Darrah LL and AR Halluer. 1972. Genetic effects estimated from generation mean analysis in four diallel sets on maize inbreds. *Crop Science*, **12:** 615-621.

7. Dedaniya AP, AG Pansuriya, DM Vekaria, JT Memon and TA Vekariya. 2018. Estimation of heterosis in different crosses of bread wheat (*Triticum aestivum* L.). *International Journal of Chemical Studies,* **6(3)**: 3622-3628.

8. Dedaniya AP, AG Pansuriya, DM Vekaria, JT Memon and TA Vekariya. 2019. Combining ability analysis for yield and its components in bread wheat (*Triticum aestivum* L.). *Electronic Journal of Plant Breeding,* **10(3):** 1005-1010.

9. Dhoot M, H Sharma, RB Dubey, VK Badaya and R Dhoot. 2020. Combining ability analysis for yield and some of its associated characters in late sown condition in bread wheat (*Triticum aestivum* L. em. Thell). *Journal of Pharmacognosy and Phytochemistry,* **9(2):** 283-286.

10. Dudhat H, AG Pansuriya, DM Vekaria, H Dobariya, JB Patel, C Singh and IB Kapadiya. 2022. Heterosis for grain yield and its attributing traits in bread wheat (*Triticum aestivum* L.). *Journal of Cereal Research,* **14(2):** 150-160.

11. El-karamity AE, M Sarhan, Kh. And HM Fouad. 2025. Heterosis and combining ability of F₁ bread wheat diallel crosses. *Journal of plant production,* **16(1):** 13-19.

12. Elwasef I, MA El-Hennawy and A Fathiyah. 2023. Genetic analysis and heterosis for grain yield and some agronomic traits in F₁ and F₂ generations of bread wheat. *Archives of Agriculture Sciences Journal,* **6(1)**.

13. Fareed G, DAA Keerio, SN Mari, MA Arain, S Ullah, AA Mastoi, M Adeel, MA Mengal, SA Shah, and MI Badini. 2024. Estimation of hetrosis in F₁ hybrids of bread wheat genotypes. *Journal of Applied Research in Plant Sciences*, **5(01)**: 120-123.

14. Griffing B. 1956. Concept of general and specific combining ability in relation to diallel crossing systems, *Austalian Journal of Biological Sciences,* **9(4):** 463-493.

15. ICAR-IIWBR. 2024. Agricultural data. Available at https://iiwbr.org.in/#:~:text=In%20India%2C%20wheat%20is%20grown,during%20the%20year%202023%2D24. Accessed on 26ᵗʰ December, 2024.

16. Joshi A and A Kumar. 2020. Heterosis for yield and its contributing traits in wheat. *Journal of Crop and Weed.* **16(3)**: 09-22.

17. Khan R, B Prasad and B Bhatt. 2023. Study of heterosis for grain yield and its components in wheat (*Triticum aetivum* L. em. Thell.). *Environment Conservation Journal,* **25(1):** 56-61.

18. Khokhar AA, WA Jatoi, FG Nizamani, RA Rind, MM Nizamani, HF Wang, A Mehmood and MU Khokhar. 2019. Study of heterosis analysis in F₁ population of bread wheat. *Pure and Applied Biology,* **8(2):** 1757-1770.

19. Kumar P, SS Nagar, C Singh, V Gupta, G Singh and BS Tyagi. 2019. Assessment of heterosis and inbreeding depression for agro-morphological traits in bread wheat. *Journal of Wheat Research*, **11(2):** 125-130.

20. Mahmud J, S Hossain, A Hossain and Md. Abdullah Al Bari. 2023. Combining abilities of spring wheat (*Triticum aestivum* L.) for grain yield and related traits. *Scientific Journal,* **5(6):** 2595-9433.

21. Motawea MH. 2017. Estimates of heterosis, combining ability and correlation for yield and its components in bread wheat. *Journal of Plant Production, Mansoura University*, **8(7):** 729-737.

22. Ocaktan H, H Gungor and Z Dumlipinar. 2024. Heterosis and diallel analysis of yield and yield components of bread wheat F₁ generation. *Black Sea Journal of Agriculture,* **7(4):** 363-376.

23. Patel PU, BC Patel, MP Sidapara and DD Sharma. 2020. Combining ability and gene action studies for yield and its component traits in bread wheat (*Triticum aestivum* L.). *International Journal of Current Microbiology and Applied Sciences,* **9(5):** 2463-2469.

24. Puri P, SR Ramgiry, RS Sikrwar and S Tiwari. 2025. Analysis of heterosis and combining ability for seed yield and its components in bread wheat (*Triticum aestivum* L.). *International Journal of Plant and Soil Science,* **37(01)**: 194-207.

25. Reddy BR, B Kumar, R Kumar and H Thota. 2023. Analysis of heterotic potential for yield and its contributing traits in wheat (*Triticum aestivum* L.). *International Journal of Environment and Climate Change,* **13(9):** 388-400.

26. Saini M, V Kumar, S Patel, S Chaturvedi, S Singh and Yadav R. 2023. Analysis of heterotic potential combining ability and its correlation with grain yield and physiological traits in bread wheat (*Triticum aestivum* L.). www.preprints.org

27. Saren D, AB Mandal and C Soren. 2018. Heterosis studies in bread wheat (*Triticum aestivum* L.). *Journal of Agriculture and Veterinary Sciences,* **11(9):** 80-84.

28. Sharma V, NS Dodiya, RB Dubey, SG Khandagale and N Shekhawat. 2018. Estimation of heterosis for yield and some yield components in bread wheat. *Journal of Pharmacognosy and Phytochemistry,* **7(6):** 1742-1745

29. Singh M, K Kaur, V Kumar and R Kaur. 2022. Genetic analysis in F_1 generation of diallel crosses for yield components in hexaploid wheat (*Triticum aestivum* L.). *Agriways,* **6(2)**: 17-26.

30. Singh N, SV Singh and M Singh. 2024. Heterosis and inbreeding depression for grain yield and yield contributing characters in wheat (*Triticum aestivum* L.). *Electronic Journal of Plant Breeding,* **15(1)**: 246-254.

31. Thomas N, S Marker, GM Lal and A Dayal. 2017. Study of heterosis for grain yield and its components in wheat (*Triticum aestivum* L.) over normal and heat stress condition. *Journal of Pharmacognosy and Phytochemistry,* **6(4):** 824-830.

32. Tiwari U, SV Singh, S Nageshwar Tripathi, MK Shukla, P Awasthi, M Tiwari, PK Saini and A Pandey. 2024. Identification of good combiner with heterotic group in bread wheat (*Triticum aestivum* L.). *Journal of Food Chemistry and Nanotechnology,* **10(1):** 2-10.