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Analysis of Heterosis Heterotic Potential Combining Ability and Its Correlation with Grain Yield and Physiological Traits in Bread Wheat (*Triticum aestivum* L.)

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Abstract: To utilize heterosis and combining ability for grain yield and its attributing traits along with three physiological traits *viz.*, leaf area index, chlorophyll fluorescence and chlorophyll content in bread wheat (*Tritium aestivum* L.) the crosses were attempted during *rabi*, 2019-20 in a half diallel mating scheme among 8 wheat varieties and the study was carried out during *rabi*, 2020-21 at Block No. D-13 field of Mahua block, Simradha research farm, Rani Lakshmi Bai Central Agricultural University, Jhansi. Analysis of variance showed significant differences for treatments. Based on *per se* performance the hybrids NW 5054 x PBW 723 (23.3 g), and HI 1544 x NIAW 34 (23.14 g), were identified for the higher grain yield. The hybrid HI 544 x NIAW 34 (18.41%) was identified as the best heterotic cross for grain yield per plant and its component traits. The hybrids HI 1544 x NIAW 34 (3.40) and HI 1544 x GW 322 (2.76), as well as the parents HD 3086 (21.85) and PBW 723 (20.68), were identified as superior economic hybrids and parents based on SCA/GCA effects, *per se* performance for grain yield per plant, and its component trait in bread wheat. Days to heading, flag leaf length, biological yield per plant, harvest index, number of grains per spike, 1000 grain weight, spike length, leaf area index, chlorophyll fluorescence, and chlorophyll content were all positively correlated with grain yield per plant.

Keywords: heterosis; heterobeltiosis; combining ability; half-diallel; correlation; grain yield; physiological traits and wheat

1. Introduction

Although hybrid breeding is well established in many outcrossing species, it is still in its early stages in wheat (Gupta *et al.*, 2019). The use of heterosis in maize and rice has achieved tremendous success (Garcia *et al.*, 2008; Li *et al.*, 2008; Song *et al.*, 2010). Due to the yield increase of 3.5–15%, even if the hybrid wheat area is less than 0.2% of the global total, the promising heterosis is nevertheless expected to make significant contributions to addressing future population growth (Longin *et al.*, 2012; Ni *et al.*, 2017).

For hybrid bread and durum wheat, mid-parent heterosis for grain yield of about 10% has been recorded (Gowda *et al.*, 2010; Thorwarth *et al.*, 2018). Breeding for heterosis paves the road to override the yield constraints. It is possible to increase wheat productivity by creating new cultivars with greater genetic diversity and improved performance in a variety of agroclimatic situations. Techniques for analyzing genotypes for all possible cross combinations were invented by researchers (Griffing, 1956; Hayman, 1954; Mather and Jinks, 1982). By 2050, the demand for wheat is anticipated to have increased by 50% from where it is currently. In the meantime, the crop is endangered by new and more aggressive pests and diseases, diminishing water supplies, a lack of land that may be used, and unpredictable weather, particularly heat (IIWBR Vision, 2050).

The application of heterosis is mostly determined by its direction and magnitude. Knowledge of combining ability is vital in selecting appropriate parents for hybridization, understanding quantitative trait inheritance, and identifying potential crossovers for later usage in breeding programmes. The public and corporate sectors have become more interested in hybrid wheat breeding over the past ten years (Boeven and Longin, 2019). Increasing heterosis is thought to be an important strategy for increasing wheat's potential yield (Noorka *et al.,* 2013). The majority of heterotic effects are given to cross-pollinated crops, however, for the breeding of better varieties, the phenomenon is becoming more prominent in self-pollinated crops like wheat (Kumar *et al.,* 2014; Singh *et al.,* 2004). The identification of better-performing wheat genotypes and general combiners for grain yield and its components is required. Superior cross combinations with high SCA effects will aid in the start-up of a niche-specific breeding program. Combining ability analysis provides important information about the type of gene action related to the inheritance of different traits and, as a result, the breeding approach to be used. The essence of gene action may aid in predicting selection efficacy in light of various types of gene action and their magnitude and implications. It is critical to comprehend the genetic architecture of characters. It explains the purpose and scope of various types of gene behaviour to eliminate less productive crosses in the first generations.

The main objectives of the proposed investigation were as follows: [1] Measuring the degree of heterosis in the F_1 generation for grain yield and physiological traits [2] Estimation of combining ability effects in F_1 generation for grain yield and physiological traits [3] Determining the superior cross combinations for situations when water is limited.

2. Materials and methods

The important attributes of these *elite* genotypes are tabulated in (Table 1).

Table 1. Details of eight wheat varieties used in the study.

S.N.	Parent	Symbol	Release station	Parentage	Main character
1	HD 3086	P1	ICAR-IARI, New Delhi	DBW14/HD2733//HUW468	High yield under irrigated and water-limited conditions
2	HI 1544	P2	ICAR-IARI, Indore	HINDI62/BOBWHI TE/CPAN 2099	Better agronomic base
3	DBW 110	P3	ICAR-IIWBR, Karnal	KIRITAT/4/2*SERI *2/3/KAUZ*2/BOW //KAUZ	Suitable for water stress
4	GW 322	P4	RARS, Bijapur, Gujarat	GW 173/GW 196	Better agronomic base
5	K 1006	P5	CSAUA&T, Kanpur	PBW343/HP1731	Better agronomic base
6	NW 5054	P6	NDUA&T, Faizabad	THELIN//2*ATTILA*2PASTOR	Better agronomic base
7	PBW 723	P7	PAU, Ludhiana	Unnat PBW343	Better agronomic base
8	NIAW 34	P8	MPKV, Niphad	CNO 79/PRL "S"	Suitable for water stress

2.1. Site of experiment

The crosses were attempted in rabi 2019-20, and the research trial was carried out in rabi 2020-21 at Block No. D-13 field of Mahua block, Simradha research farm, Rani Lakshmi Bai Central Agricultural University, Jhansi, which is geographically located between 25o31'02.5''N latitude and 78o33'05.11''E longitude and at an elevation of 227 meters above mean sea level.

2.2. Experimental materials

The eight elite wheat genotypes were crossed in half diallel (excluding reciprocals) according to Griffing 1956 method 2 and Model I design. The F_1 generation and parents were sowed in paired rows of 2 m length and 30 cm row to row distance using a randomised full block design with two replications.

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2.3. Analysis of characters

Five plants were chosen at random from each parent and F_1 and the following quantitative traits were recorded. During rabi, 2020-2021, the parents and hybrids were assessed for fourteen quantitative traits, including days to heading (DH), days to maturity (DM), flag leaf length (FLL), flag leaf width (FLW), spike length (SL), peduncle length (PL), awn length (AL), number of tillers per meter (NTM), plant height (PH), number of grains per spike (NGPS), 1000 grain weight (TGW), grain yield per plant (GYPP), biological yield per plant (BYPP) and harvest index (HI), as well as three physiological traits, including leaf area index (LAI), chlorophyll fluorescence (CF), and chlorophyll content (CC). Using par measurements above and below the canopy, the Sun scan canopy analysis system was used to estimate the leaf area index for each row between 11:00 AM and 2:00 PM. For photosynthesis, the efficiency of PS II photochemistry and chlorophyll inflorescence (Fv/Fm) were measured, and light intensity can be multiplied to estimate the rate of linear electron transport. The total Chlorophyll Content of randomly selected plants was measured using a SPAD meter.

2.4. Statistical analysis

Under the common statistical methodology presented by Panse & Sukhatme, (1985) the analysis of variance (ANOVA) for Randomized Block Design (RBD) was carried out individually for each of the traits under consideration on a mean basis. The heterosis for each attribute was calculated using the average mean of each hybrid over two replications. The effects of relative heterosis were calculated using the formula (Singh & Chaudhary, 1977). The Fonseca and Patterson (1968) scheme were used to evaluate heterobeltiosis/better parent heterosis. Griffing (1956) offered four methods of analysis, depending on the study's materials. Eisenhart's model (Fixed effect) and Model II (Random effect) were also taken into account by Griffing (1956) when describing the analysis strategy for combining ability.

3. Results and Discussion

3.1. Results of Analysis of Variance

Table 2 displays the mean values, grand mean (GM), and standard error of the mean (SEm) of the parents and their crosses. The hybrids exhibited higher mean values than the parents for the majority of the traits, according to a comparison of the mean values of the parents and the F_1 generations.

Table 2. Grand mean, mean ± SE (m) and range for twenty-five characters in parents and F_1 in bread wheat.

		Parents		F_1s	
Characters	**GM**	**Mean ± SE(m)**	**Range**	**Mean ± SE(m)**	**Range**
Days to heading	89.85	90.50 ± 0.97	88 – 93.50	89.66 ±0.97	85.50 – 92.50
Days to maturity	130.40	131.19 ± 1.03	128.50 – 133.50	130.17 ± 1.03	127.0 – 134.5
Flag leaf length (cm)	22.37	22.21± 0.76	19.90– 23.80	22.42 ± 0.76	19.65 – 25.90
Flag leaf width (cm)	1.96	1.96 ± 0.05	1.77 – 2.07	1.95 ± 0.05	1.69 – 2.18
Spike length (cm)	12.38	11.92 ± 0.30	10.90 – 13.30	12.51 ± 0.30	10.78 – 13.45
Peduncle length (cm)	31.62	29.06 ± 0.79	25.15 – 34.35	32.35 ± 0.79	28.60 – 36.65
Awn length (cm)	6.61	6.47 ± 0.28	5.54 – 7.00	6.65 ± 0.28	5.85 – 7.88
Number of tillers /m	136.83	132.81 ± 6.86	117.50 - 177	137.98 ± 6.86	103.00 – 191.50
Plant height (cm)	90.29	87.31 ± 1.11	80.90 – 96.30	91.14 ± 1.11	81.65 – 100.20
No. of grains per spike	66.65	64.4 ± 1.80	59.00 – 69.00	67.3 ± 1.80	57.0 – 77.0
1000 grain weight (g)	43.31	40.96 ± 1.14	40.00 – 42.50	43.99 ± 1.14	39.85 – 46.80
Grain yield per plant (g)	20.56	19.95 ± 0.81	17.37 – 21.85	20.73 ± 0.81	14.99 – 23.41
Biological yield per plant (g)	49.73	50.12 ± 2.09	45.15 – 54.78	49.61 ± 2.09	36.37 – 58.48
Harvest Index (%)	0.41	0.40 ± 0.01	0.39 – 0.41	0.42 ± 0.01	0.38 – 0.44
Leaf Area Index	1.85	1.71 ± 0.08	1.28 – 2.18	1.89 ± 0.08	1.18 – 2.30
Chlorophyll fluorescence	0.74	0.73 ± 0.01	0.72 – 0.75	0.75 ± 0.01	0.71 – 0.78
Chlorophyll content	40.03	39.53 ± 0.96	38.18 – 42.28	40.18 ± 0.96	31.68 – 45.31

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For all of the above-mentioned characteristics, the results revealed significant differences in genotype mean squares. Furthermore, mean squares due to parents and differences between crosses were significant for the examined traits. These results indicated that the parental genotypes' means were generally different.

The genotype DBW 110 showed early maturity at 128.5 days, and the parent GW 322 demonstrated early heading at 88 days. The greatest flag leaf length was seen in the parent K 1006 (23.80 cm) and the hybrid HD 3086 x HI 1544 (25.90 cm), whereas the maximum flag leaf width was seen in the parent NW 5054. (2.07 cm). Spike length, peduncle length, awn length, and the number of tillers/m all had general mean values of 12.38 cm, 31.62 cm, 6.61 cm, and 136.83 cm, respectively. The parent HD 3086 in this study had the maximum grain yield (21.85 g), followed by NW 5054 (20.68 g) and PBW 723 (PBW 723). (20.55 g). In terms of peduncle length, awn length, and the number of grains per spike, the parent HD 3086 also exhibited higher mean values. The parent K 1006 (2.18) had the greatest mean value for the leaf area index (LAI), followed by NIAW 34 (1.91) and GW 322. (1.85). Maximum chlorophyll fluorescence was shown by the parent NIAW 34 (0.75), followed by K 1006 (0.74) and HD 3086 (0.72). (0.74). The parent NIAW 34 (42.28) and GW 322 had the highest levels of chlorophyll (41.35). Days to heading, awn length, leaf area index, chlorophyll fluorescence, and chlorophyll content all exhibited high mean values in the parent NIAW 34. Though it was also determined that the parent GW 322 was the best parent for days to heading, days to maturity, the number of tillers per meter, 1000 grain weight, harvest index, LAI, chlorophyll fluorescence, crude protein hemicellulose, and low cellulose. The best cross combinations for chlorophyll fluorescence were HD 3086 x NIAW 34 (0.78) and NW 5054 x PBW 723 (0.77). For chlorophyll content, the cross HD 3086 x NIAW 34 was likewise shown to be superior. The top two identified cross combinations for chlorophyll content were PBW 723 and NIAW 34 (45.31) and HD 3086 x NIAW 34 (44.81).

3.2. Heterosis and better parent heterosis

It is widely acknowledged that the commercialization of heterosis in crops marked a turning point in plant breeding. Even though heterosis in wheat is a long-known phenomenon. Utilizing hybrid vigor in self-pollinated crops like wheat depends on the direction and strength of relative heterosis as well as the manner of gene activity and better parent heterosis. Wheat heterosis was initially examined by Freeman, (1919). Later, it was noted for numerous quantitative characteristics, including grain yield and its features, by Engledow and Pal (1934), Briggle (1963), Jhonson *et al.*, (1966) and Bitzer *et al.*, (1967). Identification of heterotic hybrids that might offer ascent to the required segregant in later generations is the aim of wheat heterosis research. Heterosis swaps favorable dominant genes from one parent for the unfavorable recessive genes of one line or parent. It is impossible to fix all advantageous dominant genes in a single homozygous line because some nasty recessive and favorable dominant genes are connected (Falconer, 1981).

The overall range of heterosis varied from -28.61 for grain yield per plant to 30.58 for leaf area index and better parent heterosis ranged from -36.49 for leaf area index to 22.78 for the number of effective tillers/m. Days to heading heterosis ranged from -5.0% (HI 1544 x NW 5054) to 2.81%. (GW 322 x NW 5054). It was significant in two crosses GW 322 x K 1006 (−3.62%) and the cross HI 1544 x NW 5054 (−5.0%) both had highly significant negative heterosis (Tables 3 and 4). Eight crosses, with heterobeltiosis for early heading ranging from −5.46% (GW 322 x K 1006) to −3.24%, showed significant heterobeltiosis (HD 3086 x DBW 110) (Tables 3 and 4). Seventeen crosses had negative heterosis for days to maturity, varying from −3.21% (HD 3086 x NW 5054) to −0.19% (GW 322 x K 1006), but significant negative heterosis could not be seen (Tables 3 and 4). Six crosses had significant days to maturity heterobeltiosis. Flag leaf length and width heterosis ranged from −12.37% (HI 1544 x K 1006) to 15.88% (HD 3086 x HI 1544) and from -10.95 (HI 1544 x NW 5054) to 9.02%. (NW 5054 x PBW 723) (Tables 3 and 4). Flag leaf length and width showed significant positive heterobeltiosis in six and twelve crosses, ranging from 2.65% (HD 3086 x GW 322) to 13.35% (HD 3086 x HI 1544) and 0.24% (NW 5054 x NIAW 34) to 5.46% (GW 322 x K 1006), respectively. The hybrid HD 3086 x HI 1544 (13.35%) had the highest positive heterobeltiosis for flag leaf length (Tables 3 and 4).

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Table 3. Mean (%) and range of heterosis and heterobeltiosis for twenty-five characters in bread wheat.

Characters	MP Mean	MP Range	BP Mean	BP Range
Days to heading	-0.92	-5.00 – 2.81	-2.14	-5.46 – 1.67
Days to maturity	-0.77	-3.21 – 1.72	-1.48	-3.76 – 1.14
Flag leaf length	1.04	-12.37 – 15.88	-2.42	-14.12 – 13.35
Flag leaf width	-0.60	-10.95 – 9.02	-2.95	-12.56 – 5.46
Spike length	5.05	-6.51 – 16.26	0.81	-11.32 – 13.97
Peduncle length	11.53	-4.96 – 24.38	5.10	-9.75 – 20.16
Awn length	2.83	-10.86 – 24.51	-0.98	-12.50 – 15.81
Number of effective tillers /m	4.34	-23.70 – 29.61	-2.23	-35.03 – 22.78
Plant height	4.45	-5.74 – 15.78	1.17	-7.85 – 12.31
No. of grains per spike	4.57	-10.94 – 14.96	1.53	-17.39 – 11.59
1000 grain weight	7.39	-0.75 – 14.78	6.00	-1.12 – 13.73
Grain yield per plant	3.75	-26.19 – 18.41	0.15	-27.26 – 15.21
Biological yield per plant	-1.07	-28.61 – 8.18	-4.00	-28.31 – 7.79
Harvest Index	4.86	-3.80 – 10.13	3.78	-6.17 – 10.13
Leaf Area Index	9.89	-24.80 – 30.58	0.51	-36.49 – 18.92
Chlorophyll fluorescence	1.87	-3.40 – 5.88	1.12	-4.05 – 5.52
Chlorophyll content	1.64	-18.84 – 17.30	-0.45	-20.22 – 16.60

Table 4. The extent of heterosis (%) for days to heading, days to maturity, flag leaf length, flag leaf width and spike length in bread wheat.

	Days to heading		Days to Maturity		Flag leaf length		Flag leaf Width		Spike length	
Crosses	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
HD 3086 x HI 1544	0.27	-1.08	0.19	-0.38	15.88**	13.35**	2.79**	-3.01	15.74**	12.02**
HD 3086 x DBW 110	-1.92	-3.24*	-1.15	-2.28	7.89**	4.81**	-0.13	-5.32	9.66**	7.41**
HD 3086 x GW 322	0.28	-2.16	-0.57	-0.76	4.39**	2.65*	-3.45	-9.00	11.70**	8.58**
HD 3086 x K 1006	-2.17	-2.70	0.00	0.00	2.85*	-1.37	-5.42	-11.17	7.59**	5.81**
HD 3086 x NW 5054	-0.82	-2.16	-3.21	-3.76*	6.44**	3.46**	-4.17	-11.11	7.41**	0.75
HD 3086 x PBW 723	-1.61	-2.14	1.51	0.75	5.39**	0.69	-8.40	-11.98	-3.67	-8.90
HD 3086 x NIAW 34	-2.76	-4.86**	-2.29	-2.66	-8.93	-11.11	-5.35	-10.15	6.93**	6.01**
HI 1544 x DBW 110	-0.56	-0.56	-1.74	-2.31	-4.49	-9.19	-8.31	-8.77	-6.51	-11.32
HI 1544 x GW 322	-1.69	-2.78*	-1.53	-1.91	2.53	1.97	2.13**	2.00**	9.59**	9.09**
HI 1544 x K 1006	-1.38	-2.19	1.72	1.14	-12.37	-14.12	-6.23	-6.70	4.14**	-0.83
HI 1544 x NW 5054	-5.00**	-5.00**	-2.66	-3.76*	-12.17	-12.74	-10.95	-12.56	3.31**	-6.02
HI 1544 x PBW 723	-0.27	-2.14	-0.95	-2.25	3.63**	-3.06	6.00**	4.01**	1.47**	-6.23
HI 1544 x NIAW 34	-0.84	-1.67	-1.34	-1.53	0.76	0.54	2.40**	1.75**	6.04**	3.49**
DBW 110 x GW 322	1.12	0.00	0.96	0.00	-9.03	-13.05	1.64**	1.00**	-5.40	-9.88
DBW 110 x K 1006	-2.48	-3.28*	0.00	-1.14	-0.90	-7.56	-5.26	-6.20	-0.83	-1.23
DBW 110 x NW 5054	-1.67	-1.67	-1.72	-3.38*	-3.09	-8.42	-5.81	-7.97	-4.52	-8.65
DBW 110 x PBW 723	0.27	-1.60	0.76	-1.12	8.15**	6.31**	6.03**	4.56**	4.64**	1.79**
DBW 110 x NIAW 34	-0.28	-1.11	0.00	-0.77	-2.64	-7.63	-4.94	-5.06	8.90**	5.76**
GW 322 x K 1006	-3.62*	-5.46**	-0.19	-0.38	4.09**	1.47	5.85**	5.46**	9.33**	4.56**
GW 322 x NW 5054	2.81	1.67	-1.52	-2.26	0.11	-1.08	5.65**	3.86**	4.53**	-4.51
GW 322 x PBW 723	0.83	-2.14	0.57	-0.37	10.59**	3.98**	3.83**	1.75**	6.92**	-0.78
GW 322 x NIAW 34	-0.28	-0.56	-0.57	-0.76	2.74*	1.96	-0.25	-1.00	16.26**	13.97**
K 1006 x NW 5054	-2.48	-3.28*	-2.84	-3.38*	-2.45	-3.78	-3.55	-4.83	-2.56	-7.14
K 1006 x PBW 723	-1.62	-2.67	1.13	0.37	10.98**	1.89	7.75**	5.21**	4.82**	1.56**
K 1006 x NIAW 34	-2.78	-4.37**	-3.05	-3.42*	-8.45	-10.08	-3.64	-4.71	8.09**	5.39**
NW 5054 x PBW 723	0.82	-1.07	0.19	0.00	8.01**	0.43	9.02**	5.07**	2.87**	1.13*
NW 5054 x NIAW 34	1.96	1.11	-0.57	-1.50	-3.69	-4.10	2.72**	0.24**	5.86**	-1.50
PBW 723 x NIAW 34	0.00	-2.67	-2.65	-3.75*	2.92*	-3.92	3.34**	2.03**	9.05**	3.11**

**Significant at 1 per cent, *significant at 5 per cent level.

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The hybrid GW 322 x K 1006 (5.46%) revealed the most significant heterobeltiosis for flag leaf width (Tables 3 and 4). Spike length heterosis was noteworthy in the context of twenty-two crosses. The highest significant positive heterosis for spike length was found in the cross GW 322 x NIAW 34 (16.26%), followed by HD 3086 x HI 1544 (15.74%) and HD 3086 x GW 322 (11.70%). (Tables 3 and 4). The hybrid DBW 110 x K 1006 (24.38%) showed the highest positive heterosis for peduncle length, followed by DBW 110 x GW 322, HI 1544 x NIAW 34 (19.37%), PBW 723 x NIAW 34 (18.53%), and HI 1544 x PBW 723 (16.84%), in that order (Tables 3 and 5). The magnitude of heterobeltiosis for peduncle length was significant in seventeen crosses. The cross DBW 110 x K 1006 (20.16%), was identified with the highest significant positive heterobeltiosis for peduncle length. (Table 5). Significant maximum heterosis for awn length was depicted bt the hybrids GW 322 x PBW 723 (24.51%) and PBW 723 x NIAW 34 (17%) showed the greatest positive heterosis values (Table 5)

Table 5. Extent of heterosis (%) for peduncle length, awn length, no. of effective tillers/m and plant height in bread wheat.

	Peduncle length		Awn length		No. of effective tillers/m		Plant height	
Crosses	MP	BP	MP	BP	MP	BP	MP	BP
HD 3086 x HI 1544	9.65**	0.69	1.86**	-2.14	20.90	16.60	-5.74**	-7.85**
HD 3086 x DBW 110	8.86**	3.05**	7.01**	3.57**	-23.70	-28.22	10.93**	7.81**
HD 3086 x GW 322	5.03**	0.69	3.62**	2.14**	16.73	13.04	15.78**	12.09**
HD 3086 x K 1006	11.50**	9.17**	3.67**	-7.14	-12.69	-25.14	12.98**	12.31**
HD 3086 x NW 5054	-4.96	-8.44	0.72	-0.71	9.74	8.33	0.99	-4.21*
HD 3086 x PBW 723	8.11**	-3.24	1.95**	-6.43	-9.23	-11.61	1.33	0.92
HD 3086 x NIAW 34	4.59**	-4.34	-5.07	13.37**	19.19	17.97	0.17	-0.91
HI 1544 x DBW 110	12.24**	8.69**	-8.46	-9.16	-17.62	-25.09	-2.03	-6.85**
HI 1544 x GW 322	16.25**	11.13**	-4.91	-7.35	23.31	22.78*	1.90	-3.48*
HI 1544 x K 1006	23.93**	16.07**	6.76**	-0.78	-21.90	-35.03	-4.89*	-6.47**
HI 1544 x NW 5054	15.45**	2.47*	-2.64	-5.15	25.77*	22.00*	7.31**	4.05*
HI 1544 x PBW 723	16.84**	13.59**	-2.44	-6.98	6.37	0.00	5.77**	3.81*
HI 1544 x NIAW 34	19.37**	18.85**	-3.85	-6.32	2.73	1.24	0.59	-0.61
DBW 110 x GW 322	19.56**	17.98**	-10.86	-12.50	20.99	10.45	9.88**	9.44**
DBW 110 x K 1006	24.38**	20.16**	-1.57	-9.16	17.00	5.93	12.73**	8.93**
DBW 110 x NW 5054	13.57**	3.78**	-0.37	-2.21	18.44	10.80	10.82**	2.34
DBW 110 x PBW 723	6.76**	0.60	11.61**	5.65**	-5.42	-8.71	0.94	-2.27
DBW 110 x NIAW 34	14.54**	10.45**	4.87**	2.94**	5.10	-3.14	6.21**	2.15
GW 322 x K 1006	7.20**	4.92**	-1.13	-10.29	29.61*	8.19	10.25**	6.13**
GW 322 x NW 5054	4.64**	-3.20	5.88**	5.88**	23.61	20.40*	9.03**	0.31
GW 322 x PBW 723	9.29**	1.71	24.51**	15.81**	9.52	3.37	-2.80	-6.26**
GW 322 x NIAW 34	11.33**	5.99**	2.21**	2.21**	2.71	1.65	10.82**	6.17**
K 1006 x NW 5054	9.95**	3.78**	15.07**	4.41**	12.25	-4.24	6.84**	1.92
K 1006 x PBW 723	11.05**	1.31	2.72**	0.00	-12.08	-22.88	-1.00	-1.19
K 1006 x NIAW 34	12.65**	5.08**	-1.94	-11.03	-19.46	-32.20	-1.62	-2.10
NW 5054 x PBW 723	10.59**	-4.22	16.05**	7.94**	-7.16	-10.11	1.20	-3.63*
NW 5054 x NIAW 34	2.06	-9.75	-2.94	-2.94	-1.63	-3.20	2.28	-1.97
PBW 723 x NIAW 34	18.53**	15.72**	17.00**	8.82**	-11.59	-15.73	3.99*	3.28*

**Significant at 1 per cent, *significant at 5 per cent level.

Significant heterosis for number of effective tillers per meter ranged from −23.70% (HD 3086 x DBW 110) to 29.61% (GW 322 x K 1006) and Maximum significant positive heterosis was shown by the cross GW 322 x K 1006, followed by HI 1544 x NW 5054 (Tables 3 and 5). in three crosses, showed significant heterobeltiosis for the number of effective tillers per meter (Table 5). The heterosis of plant height ranged from −5.74% (HD 3086 x HI 1544) to 15.78%. (HD 3086 x GW 322). Among sixteen significant heterotic crosses for plant height two of which showed negative plant height heterosis: HD 3086 x HI 1544 (-5.74%) and HI 1544 x K 1006 (−4.89%) (See Table 3; Table 5). The hybrid HD 3086 x HI 1544 (−7.85%) showed the maximum negative heterobeltiosis estimations (Table 5). The

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estimations of heterosis for the number of grains per spike ranged from 6.98% (GW 322 x K 1006) to 14.96% (HI 1544 x NIAW 34). Cross HI 1544 x NIAW 34 had the highest significant positive heterosis (14.96%), followed by HD 3086 x GW 322 (14.93%), PBW 723 x NIAW 34 (13.11%), GW 322 x NIAW 34 (12.11%), and HD 3086 x HI 1544 (10.95%). (Tables 3 and 6). Heterobeltiosis for the number of grains per spike showed significant in twelve crosses, ranging from 5.88% (HI 1544 x GW 322) to 11.59% (HD 3086 x GW 322) (Tables 3 and 6). For 1000 grain weight, the hybrid HD 3086 x NW 5054 showed the most significant positive heterosis (14.78%) (Table 6). According to Table 3, grain yield per plant heterosis ranged from −26.19% (HI 1544 x NW 5054) to 18.41% (HI 1544 x NIAW 34) and was significant in nineteen crosses. The most promising hybrid was identified as HI 1544 x NIAW 34 (18.41%), followed by HI 1544 x GW 322 (15.36%), and PBW 723 x NIAW 34 (13.97%) and the hybrid HI 1544 x NIAW 34 displayed the highest positive heterobeltiosis (15.21%) for this trait (Tables 3 and 6).

Table 6. The extent of heterosis (%) for no. of grains per spike, 1000 grain weight, grain yield per plant and biological yield/plant in bread wheat.

	No. of grains per spike		1000 grain weight		Grain yield/plant		Biological yield/plant	
Crosses	**MP**	**BP**	**MP**	**BP**	**MP**	**BP**	**MP**	**BP**
HD 3086 x HI 1544	10.95**	10.14**	13.35**	13.00**	7.92**	3.55**	0.83	-2.82
HD 3086 x DBW 110	9.16**	3.62	11.28**	9.72**	12.20**	0.69	6.15	-3.18
HD 3086 x GW 322	14.93**	11.59**	9.03**	7.29**	9.70**	4.00**	0.69	-4.67
HD 3086 x K 1006	6.02	2.17	12.04**	11.57**	10.50**	7.14**	3.28	-0.62
HD 3086 x NW 5054	8.21*	5.07	14.78**	13.73**	7.23**	4.35**	1.36	-2.04
HD 3086 x PBW 723	-8.33	-12.32	8.23**	7.90**	4.76**	1.65	-2.61	-5.55
HD 3086 x NIAW 34	-10.94	-17.39	3.13	2.07	-0.50	-7.00	-4.76	-10.58
HI 1544 x DBW 110	0.00	-4.41	9.15**	7.95**	-19.96	-25.37	-22.51	-26.83
HI 1544 x GW 322	8.27*	5.88*	6.71**	4.71**	15.36**	13.92**	6.95	4.98
HI 1544 x K 1006	-3.03	-5.88	6.55**	5.78**	-15.15	-16.06	-18.03	-18.18
HI 1544 x NW 5054	-3.76	-5.88	13.41**	12.71**	-26.19	-27.26	-28.61	-28.81
HI 1544 x PBW 723	8.40*	4.41	4.89*	4.89**	7.97**	6.74**	0.96	0.32
HI 1544 x NIAW 34	14.96**	7.35**	10.84**	10.02**	18.41**	15.21**	7.80*	4.91
DBW 110 x GW 322	0.79	-1.54	2.67	-0.35	-11.06	-16.09	-12.71	-16.09
DBW 110 x K 1006	-4.76	-6.25	3.07	1.20	-1.76	-9.31	-5.38	-10.51
DBW 110 x NW 5054	-5.51	-7.69	2.36	1.86	-10.38	-17.56	-6.32	-11.77
DBW 110 x PBW 723	8.00*	7.14**	6.30**	5.13**	5.42**	-2.75	-0.54	-6.65
DBW 110 x NIAW 34	9.09**	6.45*	-0.75	-1.12	0.47	-3.84	-3.06	-6.02
GW 322 x K 1006	6.98*	6.15*	7.14**	5.88**	9.48**	12.10**	7.54*	5.74
GW 322 x NW 5054	7.69*	7.69**	9.77**	7.06**	10.30**	7.38**	4.86	2.65
GW 322 x PBW 723	4.69	3.08	7.43**	5.41**	9.99**	7.40**	7.20	4.57
GW 322 x NIAW 34	12.10**	6.92*	6.28**	3.53*	4.55**	2.99*	3.97	3.06
K 1006 x NW 5054	-10.08	-10.77	6.84**	5.42**	7.95**	7.55**	0.82	0.36
K 1006 x PBW 723	8.66**	7.81**	6.07**	5.30**	11.57**	11.48**	4.30	3.46
K 1006 x NIAW 34	4.88	0.78	6.36**	4.82**	-0.77	-4.46	-4.42	-6.82
NW 5054 x PBW 723	9.38**	7.69**	7.26**	6.60**	13.04**	12.70**	8.18*	7.79*
NW 5054 x NIAW 34	8.06*	3.08	5.08*	4.95**	10.01**	5.54**	7.46*	4.30
PBW 723 x NIAW 34	13.11**	9.52**	7.76**	6.97**	13.97**	9.66**	6.58	3.08

**Significant at 1 per cent, *significant at 5 per cent level.

In four distinct crosses, heterosis was significant biological yield per plant and maximum was found in the cross NW 5054 x PBW 723 (8.18%) (Table 6). The biological yield per plant heterobeltiosis ranged from −28.81% (HI 1544 x NW 5054) to 7.79% (HI 1544 x NW 5054). The hybrid NW 5054 x PBW 723 (7.79%) had the highest percentage of positive heterobeltiosis (Tables 3 and 6). Except for the DBW 110 x NW 5054 cross, harvest index was significant in all crosses and showed positive heterosis. For the leaf area index, the amount of heterosis was significant in twenty-three crosses, all of which showed positive heterosis. The cross HD 3086 x DBW 110 showed the most significant positive heterosis (30.58%) (Tables 3 and 7).

Table 7. The extent of heterosis (%) for harvest index, LAI, chlorophyll fluorescence and chlorophyll content in bread wheat.

	Harvest Index		Leaf Area Index		Chlorophyll fluorescence		Chlorophyll content	
Crosses	**MP**	**BP**	**MP**	**BP**	**MP**	**BP**	**MP**	**BP**
HD 3086 x HI 1544	6.92**	6.25**	28.37**	18.29**	3.42**	2.72**	8.01**	6.35**
HD 3086 x DBW 110	5.73**	3.75**	30.58**	12.86**	-0.34	-0.68	5.15**	4.96**
HD 3086 x GW 322	8.75**	8.75**	22.22**	18.92**	2.72**	2.72**	2.64	-0.73
HD 3086 x K 1006	6.83**	6.17**	11.34**	0.46**	3.05**	2.70**	17.30**	16.60**
HD 3086 x NW 5054	5.59**	4.94**	11.28**	5.41**	3.78**	2.72**	8.84**	8.65**
HD 3086 x PBW 723	7.50**	7.50**	10.14**	8.57**	4.11**	3.40**	9.98**	9.55**
HD 3086 x NIAW 34	4.40**	3.75**	-2.87	-6.82	4.73**	3.87**	10.76**	5.98**
HI 1544 x DBW 110	3.85**	2.53**	1.82**	-5.08	-0.34	-0.68	-6.04	-7.65
HI 1544 x GW 322	8.18**	7.50**	30.53**	17.30**	2.74**	2.04**	3.25	1.39
HI 1544 x K 1006	3.75**	2.47**	12.33**	-5.75	2.39**	1.35**	-6.81	-8.78
HI 1544 x NW 5054	3.75**	2.47**	21.31**	17.46**	1.73**	1.38**	-18.84	-20.22
HI 1544 x PBW 723	6.92**	6.25**	16.85**	9.12**	3.45**	3.45**	0.70	-0.46
HI 1544 x NIAW 34	10.13**	10.13**	30.18**	15.49**	2.72**	1.34**	6.95**	3.89**
DBW 110 x GW 322	1.91**	0.00	-24.80	-36.49	1.02**	0.68**	-6.44	-9.67
DBW 110 x K 1006	3.80**	1.23**	-13.33	-31.26	-3.40	-4.05	-4.56	-4.95
DBW 110 x NW 5054	-3.80	-6.17	-14.04	-22.22	0.00	-0.68	-4.59	-4.60
DBW 110 x PBW 723	5.73**	3.75**	2.52**	-10.29	2.41**	2.05**	10.45**	9.81**
DBW 110 x NIAW 34	3.85**	2.53**	-10.06	-24.93	-0.34	-1.34	3.50*	-1.14
GW 322 x K 1006	1.86**	1.23**	0.62**	-6.90	1.02**	0.68**	0.60	-3.26
GW 322 x NW 5054	5.59**	4.94**	14.74**	6.22**	3.78**	2.72**	-0.56	-3.99
GW 322 x PBW 723	2.50**	2.50**	5.07**	0.81**	0.68**	0.00	0.31	-2.61
GW 322 x NIAW 34	0.63**	0.00	1.20**	-0.26	-0.68	-1.34	-9.48	-10.48
K 1006 x NW 5054	7.41**	7.41**	22.67**	5.75**	2.05**	0.68**	-17.37	-17.71
K 1006 x PBW 723	6.83**	6.17**	13.55**	1.15**	-0.34	-1.35	-3.26	-4.21
K 1006 x NIAW 34	3.75**	2.47**	10.05**	3.22**	2.36**	2.01**	-1.73	-6.50
NW 5054 x PBW 723	4.35**	3.70**	0.76**	-2.94	5.88**	5.52**	14.79**	14.14**
NW 5054 x NIAW 34	2.50**	1.23**	24.71**	13.91**	1.71**	0.00	10.71**	5.76**
PBW 723 x NIAW 34	6.92**	6.25	19.28**	12.86**	2.04**	0.67**	11.57**	7.17

**Significant at 1 per cent, *significant at 5 per cent level.

For chlorophyll fluorescence, the magnitude of heterosis ranged from -3.40% (DBW 110 x K 1006) to 5.88%. (NW 5054 x PBW 723). It was prominent in 21 crossings. The hybrid NW 5054 x PBW 723 had the highest level of significant positive heterosis (5.88%) (Tables 3 and 7). Nineteen crosses showed significant heterobeltiosis for chlorophyll fluorescence. The cross NW 5054 x PBW 723 had the highest positive heterobeltiosis (5.52) (Tables 3 and 7). For chlorophyll content, the relative heterosis ranged from -18.84 (HI 1544 x NW 5054) to 17.30%. (HD 3086 x K 1006). In twelve crosses, it was significant. The cross HD 3086 x K 1006 had the highest level of significant positive heterosis (17.30%) for this character (Tables 3 and 7). The percentage of significant positive heterobeltiosis for chlorophyll content was found in ten crosses. The hybrid HD 3086 x K 1006 has the greatest estimated positive heterobeltiosis (16.60%) for chlorophyll content (Table 7).

Significant heterosis and heterobeltiosis for grain yield and yield governing traits in bread wheat were observed by Kumar *et al.,* (2014), Jain and Sastry, (2012), Mehta, (2013), Baloch, (2016), Hei *et al.,* (2016), Murugan and Kannan, (2017) and Askander *et al.,* (2021).

3.3. Combining ability

Estimating general and specific combining abilities aid in determining the breeding potential of genotypes. While the review shows that different genotypes can reliably pass on their genetic potential to F_1 offspring when used as parents, the latter reveals unexpected favorable or unfavorable genic interactions in different genotypes. Breeders can use this information to identify superior donor parents based on the GCA effect and *per se* performance, as well as prospective crosses for use in improvement efforts. In self-pollinated crops like wheat, where pure line breeding is essential, hybrids with high *per se* and SCA effects are more likely to exhibit transgressive segregation and contribute to the formation of superior pure lines. Furthermore, in some inbred species where commercial hybrids are possible, such crossings could be used to create new hybrid variants. Based on the findings, a half-diallel set of 8 parents and 28 F_1s was used to estimate combining ability effects using method 2, Model I. (Griffing, 1956).

3.3.1. Results of Analysis of Variance

The *per se* performance due to GCA and SCA was significant in all seventeen traits (Table 2). GCA effects were estimated to be greater than SCA effects for day to heading, days to maturity, flag leaf length, flag leaf width, spike length, awn length, the number of effective tillers per meter, plant height, the number of grains per spike, thousand grains weight, grain yield per plant, biological yield per plant, harvest index, leaf area index, chlorophyll fluorescence.

The combining ability study found that variance related with general as well as specific combining ability was significant for all investigated characteristics (Table 2).

The importance of additive and non-additive gene effects is shown in the significant variation attributed to both general and specific combining abilities. However, general combining ability impacts of extraordinarily high magnitude revealed that additive gene activity played the main role. The exceeding unity of GCA and SCA values supports this result, showing that additively play an important role in the inheritance of these traits. As a result, selection in the early generation could be used successfully to improve these characteristics.

Researchers such as Akram *et al.*, (2011), Raj and Kandalkar, (2013), Ammar *et al.*, (2014), Saeed and Khalil, (2017), Ingle *et al.*, (2018), Rajput and Kandalkar, (2018), Sharma *et al.*, (2019) and Srivastava *et al.*, (2020) observed variance in wheat for several yields and its component traits.

3.3.2. General and Specific Combining ability

Breeders can use this information to identify superior donor parents based on the GCA effect and *per se* performance, as well as prospective crosses for use in improvement efforts. In self-pollinated crops like wheat, where pure line breeding is essential, hybrids with high *per se* and SCA effects are more likely to exhibit transgressive segregation and contribute to the formation of superior pure lines (Table 8). Furthermore, in some inbred species where commercial hybrids are possible, such crossings could be used to create new hybrid variants.

GCA effects were estimated to be greater than SCA effects for day to heading, days to maturity, flag leaf length, flag leaf width, spike length, awn length, the number of effective tillers per meter, plant height, the number of grains per spike, thousand grains weight, grain yield per plant, biological yield per plant, harvest index, leaf area index, chlorophyll fluorescence (Tables 8 and 9).

Table 8. Analysis of variance for combining ability for twenty-five characters in F_1 generation in bread wheat.

Character	Mean Square F_1		
	GCA	SCA	Error
	(7)	(28)	(35)
Days to 50% heading	17.40**	3.86*	1.87
Days to maturity	18.80**	5.62*	1.95
Flag leaf length	5.12**	3.60**	1.15
Flag leaf width	0.07**	0.02**	0.00

Spike length	2.30**	0.80**	0.18
Peduncle length	34.43**	9.13**	1.25
Awn length	1.15**	0.40**	0.16
Number of effective tillers /m	1723.59**	708.18**	94.15
Plant height	103.44**	43.83**	2.45
No. of grains per spike	68.95**	42.72**	6.50
1000 grains weight	11.08**	6.94**	2.60
Grain yield per plant	26.55**	7.44**	1.32
Biological yield per plant	102.29**	32.76**	8.72
Harvest Index	0.0005**	0.0003**	0.00
Leaf Area Index	0.63**	0.09**	0.01
Chlorophyll fluorescence	0.0007**	0.0003**	0.00
Chlorophyll content	41.74**	17.17**	1.84

**Significant at 1 per cent, *significant at 5 per cent level.

Table 9. Estimation of GCA effects for days to heading, days to maturity, flag leaf length width, spike length, peduncle length, awn length, no. of effective tillers per meter and plant height.

Genotype	DH	DM	FL	FW	SL	PL	AL	NETPM	PH
HD3086	0.79*	0.14	0.42	-0.13	0.10	0.34	0.23**	-4.90	-0.06
HI1544	-0.51	-0.71*	0.02	0.00	-0.54	-0.34	-0.23	-7.25	-0.82*
DBW110	-0.16	-1.01**	-1.06	-0.02	-0.22	0.27	-0.07	4.10	-1.37**
GW322	0.71*	0.24	0.40	0.06**	-0.27	-0.14	0.16	5.55**	-1.26**
K1006	-0.41	0.44	0.49*	0.01	0.01	1.38**	-0.45	17.50**	0.41
NW5054	-0.06	-0.01	0.16	0.05**	0.49**	1.92**	0.24**	2.90	5.30**
PBW723	1.94**	1.94**	-0.25	0.04**	0.37**	-2.06	0.01	-7.50	-1.94**
NIAW34	-0.86**	-1.01**	-0.17	0.00	0.07	-1.38	0.10	-10.40	-0.26
SE (gi)	0.29	0.30	0.22	0.01	0.09	0.23	0.08	2.03	0.33

**Significant at 1 per cent, *significant at 5 per cent level.

GCA effects for days to heading revealed that both parents, NIAW 34 (-0.86) and GW 322 (-0.7), had negative significant GCA effects, indicating that they are good general combiners for days to heading. These two parents' mean performance was equally compatible with their GCA effects. Two crossings, HI 1544 x NW 5054 (-3.77) and GW 322 x K 1006 (-2.22), demonstrated significant negative SCA effects (Tables 9 and 10). For days to maturity, the parents NIAW 3034 (-1.01), DBW 110 (-1.01), and HI 1544 (-0.713) had significant negative GCA effects. In the first generation, four hybrids had significant negative SCA impacts. Cross K 1006 x NIAW 34 (-2.82) and PBW 723 x NIAW 34 (-2.82) showed the most significant negative significant SCA effects (Tables 9 and 10).

Table 10. Estimation of SCA effects for days to heading, days to maturity, flag leaf length width, spike length, peduncle length, awn length, no. of effective tillers per meter, plant height.

Crosses	DH	DM	FL	FW	SL	PL	AL	NETPM	PH
HD3086xHI1544	1.38	1.17	3.09**	0.12**	1.12**	0.43	0.24	22.82**	-6.06**
HD3086xDBW110	-0.97	-1.03	1.17	0.07	0.80**	0.57	0.48	-33.03	4.29**
HD3086xGW322	0.58	-0.28	0.02	-0.06	0.45	0.22	0.15	5.52	7.88**
HD3086xK1006	-0.22	0.52	0.20	-0.04	0.27	1.41	0.11	-16.93	7.56**
HD3086xNW5054	-0.07	-2.53*	1.01	-0.03	0.44	-2.43	-0.13	3.17	-3.27**
HD3086xPBW723	-1.07	2.02*	-0.55	-0.17	-1.05	0.90	-0.31	-6.43	-0.39
HD3086xNIAW34	-1.77	-1.53	-2.22	-0.05	-0.19	-0.14	-0.39	25.97**	-2.47*
HI1544xDBW110	0.33	-1.68	-0.58	-0.11	-0.84	-0.65	-0.36	-26.18	-3.85**
HI1544xGW322	-1.12	-1.43	0.52	0.03	0.43	1.31	-0.25	10.37	-0.9
HI1544xK1006	0.58	2.87**	-2.44	-0.09	0.104	2.74**	0.46	-32.08	-5.28**
HI1544xNW5054	-3.77**	-1.68	-2.34	-0.19	0.18	2.00**	-0.17	20.02**	5.43**
HI1544xPBW723	0.23	-1.13	0.01	0.08	-0.16	1.03	-0.40	11.42	6.37**
HI1544xNIAW34	0.03	-0.18	0.86	0.08	-0.05	1.75*	-0.12	3.32	0.69
DBW110xGW322	1.03	1.37	-2.06	0.03	-0.93	2.69**	-0.75	12.02	1.59

DBW110xK1006	-0.77	0.17	0.20	-0.06	-0.16	3.38**	-0.14	29.07**	5.92**
DBW110xNW5054	-1.12	-0.88	-0.27	-0.08	-0.49	1.84*	-0.13	15.17*	4.34**
DBW110xPBW723	0.38	0.67	0.83	0.09*	0.55	-1.23	0.37	-2.43	-1.85
DBW110xNIAW34	0.18	1.12	0.06	-0.06	0.63	0.88	0.36	8.47	1.54
GW322xK1006	-2.22*	-0.08	0.90	0.10*	0.48	-0.87	-0.23	31.62**	3.36*
GW322 x NW5054	2.43**	-0.63	-0.02	0.09*	0.11	-0.16	0.19	5.22	2.27*
GW322 x PBW723	0.43	0.42	0.98	-0.02	0.27	0.27	1.09**	3.12	-5.44**
GW322 x NIAW34	-0.27	0.37	0.81	-0.03	0.88**	0.84	0.07	-8.98	4.98**
K1006x NW5054	-0.87	-2.33*	-0.11	-0.05	-0.52	0.73	0.70**	12.27	2.15*
K1006 xPBW723	-0.37	1.22	1.64*	0.11*	0.29	-0.04	-0.33	-10.33	-2.36*
K1006 x NIAW34	-1.07	-2.83**	-1.29	-0.05	0.25	0.42	-0.22	-23.93	-3.99**
NW5054 xPBW723	0.78	1.17	0.97	0.13**	0.21	1.42	0.48	-12.23	-0.84
NW5054x NIAW34	1.38	1.17	3.09**	0.12**	1.12**	-1.17	-0.35	-8.33	-0.93
PBW723 x NIAW34	-0.97	-1.03	1.17	0.07	0.80**	2.36**	0.67*	-6.43	3.11**
SE (ij)	0.58	-0.28	0.02	-0.06	0.45	0.72	0.26	6.22	1.00

**Significant at 1 per cent, *significant at 5 per cent level.

Only parent K 1006 had a significant positive GCA impact on flag leaf length. Three crossings in the F_1 generation showed significant SCA effects: HD 3086 x HI 1544 (3.09), NW5054 x NIAW34 (3.09) and K 1006 x PBW 723 (1.63). (Tables 9 and 10). The parents GW 322, NW 5054 and PBW 723 showed a positive significant GCA effect on flag leaf width. In F_1 generation, six crosses revealed significant SCA effects the cross NW 5054 x PBW 723 (0.13) had the most significant positive effects (Tables 9 and 10). The parent NW 5054 (0.49) and PBW 723 (0.37) both had significant positive GCA effects for spike length. The hybrids HD 3086 x HI 1544 (1.12), GW 322 x NIAW 34 (0.88), and HD 3086 x DBW 110 (0.80) showed a considerable positive SCA effect in the F_1 generation. (Tables 9 and 10). When the GCA effects for peduncle length were estimated, the parents, NW 5054 (1.92) and K 1006 (1.38) showed significant positive impacts. SCA effect estimates were highly significant in seven crosses. The combination DBW 110 x K 1006 (3.38%) demonstrated the most significant SCA effects on peduncle length (Tables 9 and 10). The parents NW 5054 (0.24) and HD 3086 (0.23) had considerable positive GCA effects in the hybrids for awn length. The cross GW 322 x PBW 723 (1.09) demonstrated excellent specific combining ability (Table 9 and Table 10). For the number of effective tillers per meter, the parent GW 322 (17.5) and K 1006 (5.55) showed considerable significant GCA impacts. The crosses GW 322 x K 1006 (31.62), DBW 110 x K 1006 (29.07) and HD 3086 x NIAW 34 (25.97) revealed significant positive SCA effects (Tables 9 and 10)

Plant height was significantly reduced by the parent's PBW 723 (-1.94), DBW 110 (-1.37), GW 322 (-1.26) and HI 1544 (-0.82). The negative magnitude for general combining ability was highest in the parent PBW 723 (-1.94). (Tables 9 and 10). Three parents had significant GCA effects in the F_1 generation for the number of grains per spike. Eight crosses demonstrated statistically significant SCA effects. The cross HD 3086 x GW 322 (6.17) had the most significant positive SCA effects, followed by HI 1544 x NIAW 34 (5.82), HD 3086 x HI 1544 (4.92), and HD 3086 x DBW 110 (4.72). (Tables 11 and 12). GCA impacts calculated for 1000 grain weight revealed that parents HD 3086 (0.92) and GW 322 (0.69) had considerable positive GCA effects. Only three of the twenty-eight crosses showed positive meaningful SCA effects. For this trait, the hybrid HD 3086 x NW 5054 (2.54) had the highest specific combining ability (Tables 11 and 12). The parents HD 3086 (1.48) and PBW 723 (1.10) had considerable positive GCA impacts for grain yield per plant, rendering them the superior combiners. Four hybrids showed significant SCA effects for the trait. The cross HI 1544 x NIAW 34 (3.39) demonstrated the highest SCA effect, followed by HI 1544 x GW 322 (2.76), HD 3086 x DBW 110 (2.26) and NW 505 x PBW 723 (1.56), respectively (Tables 11 and 12).

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Table 11. Estimation of GCA effects for no. of grains per spike, 1000 grain weight and grain yield per plant biological yield per plant, harvest index, leaf area index, chlorophyll fluorescence, chlorophyll content.

Genotype	NGPS	TGW	GYPP	BYPP	HI	LAI	CF	CC
HD3086	2.31**	0.92**	1.48**	2.93**	0.006**	0.08**	0.008**	1.54**
HI1544	2.11**	0.50	-0.70	-1.93	0.002	-0.01	-0.001	-0.80
DBW110	-2.19	-1.22	-2.30	-4.23	-0.012	-0.39	-0.01	-1.07
GW322	1.86**	0.69*	0.257	0.72	-0.001	0.04	0	0.05
K1006	-1.69	0.13	0.20	0.03	0.004*	0.22**	0	-1.74
NW5054	-0.84	0.03	0.08	0.23	0	-0.05	-0.002	-1.23
PBW723	0.01	-0.19	1.10**	2.24**	0.004*	-0.01	0	1.0**
NIAW34	-1.59	-0.87	-0.12	0.01	-0.002	0.10**	0.006*	2.22**
SE (gi)	0.53	0.34	0.24	0.62	0.002	0.02	0.003	0.28

**Significant at 1 per cent, *significant at 5 per cent level.

Table 12. Estimation of SCA effects for no. of grains per spike, 1000 grain weight and grain yield per plant, biological yield per plant, harvest index, leaf area index, chlorophyll fluorescence, chlorophyll content.

Crosses	NGPS	TGW	GYPP	BYPP	HI	LAI	CF	CC
HD3086xHI1544	4.92**	1.76	1.29	2.50	0.00	0.15	0.006	1.58
HD3086xDBW110	4.72**	2.13*	2.26**	4.61*	0.008	0.43**	-0.009	0.05
HD3086xGW322	6.17**	0.67	0.43	-1.16	0.02*	0.23**	0.004	-0.58
HD3086xK1006	3.22	1.93	1.18	1.75	0.008	0.03	0.01	5.22**
HD3086xNW5054	4.37*	2.54*	0.69	0.77	0.006	-0.03	0.007	1.62
HD3086xPBW723	-8.48	0.35	-0.93	-3.16	0.01	-0.02	0.009	0.08
HD3086xNIAW34	-10.38	-1.36	-1.60	-3.68	0.00	-0.26	0.02*	1.01
HI1544xDBW110	-1.58	1.55	-2.57	-6.39	0.00	-0.05	-0.005	-1.38
HI1544xGW322	1.37	-0.01	2.76**	4.82*	0.02*	0.29**	0.009	2.61**
HI1544xK1006	-3.08	-0.05	-2.83	-6.25	-0.004	-0.01	0.009	-1.16
HI1544xNW5054	-3.93	2.26*	-4.89	-11.65	0.0	0.06	-0.004	-6.24
HI1544xPBW723	2.22	-0.73	0.98	1.59	0.006	0.02	0.009	-0.59
HI1544xNIAW34	5.82**	2.06	3.40**	5.50**	0.02**	0.25**	0.007	2.44**
DBW110xGW322	-2.33	-0.44	-2.09	-5.15	0.0	-0.33	0.009	-1.66
DBW110xK1006	-2.78	-0.23	0.15	-0.21	0.005	-0.19	-0.02	-0.63
DBW110xNW5054	-3.63	-0.97	-1.29	-0.64	-0.02	-0.19	-0.004	-1.00
DBW110xPBW723	3.02	1.09	0.62	0.31	0.01	0.07	0.013	2.80**
DBW110xNIAW34	3.12	-1.37	0.12	-0.31	0.006	-0.14	-0.002	0.62
GW322xK1006	2.17	0.86	0.94	3.06	-0.006	-0.08	0.002	1.66
GW322 x NW5054	2.32	1.47	1.31	1.78	0.01	0.13	0.01	0.84
GW322 x PBW723	-1.53	0.98	0.15	1.13	-0.006	-0.01	-0.008	-0.82
GW322 x NIAW34	2.57	0.87	-0.53	-0.02	-0.010	-0.09	-0.01	-4.46
K1006x NW5054	-6.13	0.28	1.40	1.30	0.02*	0.28**	0.004	-5.38
K1006 xPBW723	4.02*	0.44	1.05	1.25	0.01	0.14	-0.012	-1.99
K1006 x NIAW34	1.12	0.93	-1.03	-2.58	0.001	0.07	0.012	-0.98
NW5054 xPBW723	4.17*	0.45	1.56*	3.28	0.003	-0.14	0.02**	4.64**
NW5054x NIAW34	2.77	-0.07	1.30	3.33	-0.001	0.26**	-0.002	3.69**
PBW723 x NIAW34	3.92*	1.50	0.99	1.08	0.01	0.20**	0.001	2.06*
SE (ij)	1.63	1.03	0.74	1.89	0.01	0.08	0.008	0.87

**Significant at 1 per cent, *significant at 5 per cent level.

A look at Table 11 reveals that the parents HD 3086 (1.48) and PBW 723 (1.10) had considerable positive GCA effects for biological yield per plant. SCA effect estimation revealed that crossings HI 1544 x NIAW 34 (5.50), HI 1544 x GW 322 (4.8), and HD 3086 x DBW 110 (4.6) had significant positive

SCA impacts (Table 12). The effects of general and specific combining ability estimated for harvest index revealed that the parent HD 3086 (0.006) was a competent general combiner, followed by the parent PBW 723 (0.004) and K 1006 (0.004). Only four crossings had a significant SCA effect on the harvest index. The cross HI 1544 x NIAW 34 (0.022) showed the most significant SCA effects (Tables 11 and 12). In the F_1 generation, the parents K1006 (0.22), NIAW 34 (0.105), and HD 3086 (0.08) had a strong GCA effect on the leaf area index. In the F_1 generation, seven crosses showed positive SCA effects. The cross HD 3086 x DBW 110 (0.43) exhibits the most significant positive SCA effect (Tables 11 and 12). The parent HD 3086 (0.008) and NIAW 34 (.006) demonstrated a significant positive GCA effect for chlorophyll fluorescence. The results showed that parent HD 3086 (0.008) was the best combiner for chlorophyll fluorescence. In the F_1 generation, two crosses HD 3086 x NIAW 34 (0.02) and NW 5054 x PBW 723 9 (0.02) had the most significant favorable SCA effects (Tables 11 and 12). The parents NIAW 34 (2.22), HD 3086 (1.54), and NW 5054 all had significant positive GCA impacts on chlorophyll content (1.0). Seven F_1 hybrids showed excellent positive SCA effects. The cross HD 3086 x K 1006 had the highest significant positive SCA effects (5.22), followed by NW 5054 x PBW 723 (4.64), NW 5054 x NIAW 34 (3.69) and DBW 110 x PBW 723 (2.80). (Tables 11 and 12).

3.4. Correlation

[1] Days to 50% heading were significantly correlated with days to maturity (0.59**), grain yield per pant (0.39*), and biological yield per plant (0.43**) (Table 7), but not with peduncle length (-0.34*). [2] Days to maturity (0.59**) and biological yield per plant (0.34**) were both significantly correlated with days to maturity (Table 7). [3] Flag leaf length (0.34*), spike length (0.35*), grain yield per plant (0.71**), biological yield per plant (0.700**), number of grains per spike (0.58**), 1000 grain weight (0.43**), harvest index (0.47**), and leaf area index (0.52**) were all positively correlated (Table 7). [4]1000 grain weight correlated positively with flag leaf length (0.43**), number of grains per spike (0.58**), peduncle length (0.34*), grain yield per plant (0.39*), harvest index (0.67**), and leaf area index (0.54**) (Table 7).[5]Days to heading (0.39*), flag leaf length (0.71*), spike length (0.48**), biological yield per plant (0.96**), number of grains per spike (0.56**), thousand-grain weight (0.39*), harvest index (0.71**), leaf area index (0.64**), chlorophyll fluorescence (0.40*), and chlorophyll content (0.55**) were all significantly positive correlated with grain yield (Table 7). [6] The leaf area index was associated with flag leaf length (0.52**), number of grains per spike (0.36*), 1000 grain weight (0.54**), grain yield per plant (0.64**), biological yield per plant (0.51**), harvest index (0.70**), and chlorophyll fluorescence (0.44**) in a significantly positive way (Table 7). [7] There was a significant positive correlation between chlorophyll fluorescence and grain yield per plant (0.40*), harvest index (0.60**), thousand-grain weight (0.41*), leaf area index (0.44**), and chlorophyll content (-0.38*) (Table 7). [8] Grain yield per plant (0.55**), biological yield per plant (0.56**), harvest index (0.34*), number of grains per spike (0.371*), chlorophyll fluorescence (0.562**) and effective tiller number per meter (-0.38*) were found to be significantly positively correlated with chlorophyll content (Table 13).

Sokoto *et al.*, (2012), Kumar *et al.*, (2014), Ayer *et al.*, (2017), Zare *et al.*, (2017), Ahmad *et al.*, (2017), Ojha *et al.*, 2018, Upadhyay, (2020), and Kiran and Singh, (2020) all found a significant positive correlation between grain yield and its influencing traits.

Table 13. Simple correlations for seventeen characters in bread wheat.

	DH	DM	FLL	FLW	AL	PL	NTM	PH	GYP	BYPP	HI	NGPS	TGW	SL	LAI	CF	CC
DH																	
DM	0.59**																
FLL	0.17^{NS}	0.20^{NS}															
FLW	0.14^{NS}	0.23^{NS}	0.34*														
AL	0.17^{NS}	0.01^{NS}	0.25^{NS}	0.021^{NS}													
PL	-0.34*	-0.15^{NS}	-0.00^{NS}	-0.131^{NS}	0.02^{NS}												
NTM	-0.25^{NS}	-0.06^{NS}	0.10^{NS}	0.131^{NS}	-0.30^{NS}	0.36*											
PH	-0.23^{NS}	-0.18^{NS}	0.06^{NS}	-0.016^{NS}	0.10^{NS}	0.55**	0.28^{NS}										
GYP	0.39*	0.30^{NS}	0.71**	0.254^{NS}	0.33^{NS}	-0.10^{NS}	-0.07^{NS}	0.11^{NS}									
BYPP	0.44**	0.34*	0.70**	0.301^{NS}	0.35*	-0.21^{NS}	-0.08^{NS}	0.06^{NS}	0.96**								
HI	0.15^{NS}	0.05^{NS}	0.47**	0.005^{NS}	0.14^{NS}	0.17^{NS}	-0.05^{NS}	0.17^{NS}	0.71**	0.50**							
NGPS	0.25^{NS}	0.04^{NS}	0.58**	0.226^{NS}	0.24^{NS}	-0.01^{NS}	-0.21^{NS}	0.06^{NS}	0.56**	0.50**	0.50**						
TGW	-0.10^{NS}	-0.11^{NS}	0.43**	-0.100^{NS}	0.21^{NS}	0.34*	-0.00^{NS}	0.20^{NS}	0.39*	0.21^{NS}	0.67**	0.58**					
SL	0.23^{NS}	0.15^{NS}	0.35*	0.213^{NS}	0.40*	0.13^{NS}	0.00^{NS}	0.30^{NS}	0.49**	0.45**	0.39*	0.34*	0.30^{NS}				
LAI	-0.07^{NS}	0.03^{NS}	0.52**	0.067^{NS}	0.06^{NS}	0.07^{NS}	-0.05^{NS}	0.10^{NS}	0.64**	0.51**	0.70**	0.36*	0.54**	0.32^{NS}			
CF	0.06^{NS}	-0.07^{NS}	0.15^{NS}	-0.153^{NS}	0.18^{NS}	0.01^{NS}	-0.16^{NS}	0.00^{NS}	0.40*	0.28^{NS}	0.60**	0.25^{NS}	0.41*	0.19^{NS}	0.44**		
CC	0.30^{NS}	0.12^{NS}	0.28^{NS}	0.078^{NS}	0.28^{NS}	-0.37*	-0.38*	-0.19^{NS}	0.55**	0.56**	0.34*	0.37*	0.09^{NS}	0.26^{NS}	0.19^{NS}	0.56**	

**Significant at 1 per cent, *significant at 5 per cent level.

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Conclusions

The best heterotic cross for grain yield per plant and its component traits was identified as HI 544 x NIAW 34 (18.41%), followed by HI 1544 x GW 322 (15.36%), PBW 723 x NIAW 34 (13.97%), NW 5054 x PBW 723 (13.04%) and HD 3086 x DBW 110 (12.20%), respectively. The HI 1544 x NIAW 34 hybrid was also found to be superior heterotic in terms of biological yield per plant and harvest index. Based on better parent heterosis, the cross HD 3086 x DBW 110 and HD 3086 x HI 1544 were the top identified hybrids for LAI. The top two identified heterotic crosses for chlorophyll fluorescence were NW 5054 x PBW 723 and HD 3086 x NIAW 34. The highest level of significant heterosis for chlorophyll content was observed in the cross HD 3086 x K 1006 and NW 5054 x PBW 723.

The hybrids HI 1544 x NIAW 34, HI 1544 x GW 322, and HD 3086 x DBW 110 were found to be the best hybrids due to their excellent *per se* performance, GCA effects with significant SCA effects for grain yield per plant and attributes. The parents HD 3086 and NW 5054 were also identified as the best parents in terms of GCA/SCA values, *per se* performance for grain yield per plant, and physiological traits. More chlorophyll content, LAI and chlorophyll fluorescence help to identify superior cross combination for water-limited conditions.

Days to heading, flag leaf length, biological yield per plant, harvest index, number of grains per spike thousand-grain weight, spike length, leaf area index, chlorophyll fluorescence, and chlorophyll content all correlated positively with grain yield per plant.

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