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Research Article

Heterosis for grain yield and its attributing traits in bread wheat (*Triticum aestivum* L.)

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Abstract

The present investigation was undertaken in order to estimate the heterosis for grain yield and its components in bread wheat (*Triticum aestivum* L.) for 13 characters. The crosses were attempted by using line × tester mating design among 8 lines and 4 testers during *rabi* 2019. The resultant 32 hybrids together with 12 parents and 1 standard check (GW 451) were tested using randomized block design with three replications at Wheat Research Station, Junagadh Agricultural University, Junagadh during *rabi* 2020-21. The prominent heterotic effects were observed for grain yield per plant and its components. A total of 3 and 3 hybrids exhibited significant desirable heterobeltiosis and standard heterosis, respectively for grain yield per plant. The heterobeltiosis for grain yield ranged from -47.58 % to 62.72 %, while standard heterosis ranged from -35.06 % to 36.92 %. The cross J 16-08 × GW 366 (62.72%) exhibited the highest desirable heterosis over better parent followed by J 16-08 × GW 11 (28.98%) and J 17-08 × GW 366 (19.39%). The cross J 16-08 × GW 366 (36.92%) exhibited highest significant heterosis towards positive direction over standard check, followed by J 16-08 × GW 11 (17.36%) and GW 513 × GW 11 (11.58%). These hybrids also exhibited desirable heterosis for important yield attributes suggesting that the heterosis for grain yield was associated with heterosis for component characters.

Keywords: Bread wheat, line × tester analysis, heterosis

1. Introduction

Among the world's crops, wheat is pre-eminent both in regard to its antiquity and its importance as a food for mankind. Bread wheat is known to have been grown in the Nile valley by 5000 B.C., and its apparently later cultivation in other regions (e.g., the Indus and Euphrates valleys by 4000 B.C., China by 2500 B.C. and England by 2000 B.C.) indicate that it spread from Mediterranean centers of domestication. The civilizations of West Asia and of the European peoples have been largely based on wheat, while rice has been more important in East Asia. Due to its wide adaptability to diverse climatic conditions and multiple end-uses along with dynamic nature of genomes and polyploidy character, it has become a crop of financial and nutritional importance especially after the emergence of hexaploid wheat (Dubcovsky and Dvorak, 2007).

Wheat belongs to the genus *Triticum* of Poaceae family and believed to be originated from South West Asia

(Lupton, 1987). In fact, there are three natural group of wheat from polyploid series of *Triticum* species viz. *Triticum aestivum* a hexaploid wheat (bread wheat) which is having chromosome number 2n = 42, *Triticum durum*, a tetraploid wheat (macaroni wheat) with chromosome number 2n = 28 and *Triticum dicoccum*, also a tetraploid wheat (emmer wheat) with chromosome number 2n = 28 are presently grown as commercial crop in India, covering about 95, 4 and 1 per cent area, respectively.

The substantial improvement in production is utmost necessary not only to meet ever increasing food requirement for domestic consumption, but also for export to earn foreign exchange. To feed the growing population, the country's wheat requirement by 2050 has been estimated at 140 million metric tonnes and to achieve this target, wheat production has to be increased at the rate of >1per cent annually and this can be achieved through horizontal approach i.e. by increasing area under cultivation or through vertical approach i.e. varietal improvement, which is one of the strongest tools to take a quantum jump in production and productivity under various agro- climatic conditions.

Heterosis breeding is proved to be the potential method of increasing yield in most of the cross pollinated crops but the commercial exploitation of heterosis in self-pollinated crops like wheat is not appreciable owing to technical difficulties involved in sufficient hybrid seed production. For enhancing the genetic yield potential of the varieties and hybrids, the choice of suitable parents for evolving better varieties/hybrids is a matter of great concern to the plant breeders. The nature and magnitude of heterosis help in identifying superior cross combinations that may produce desirable segregants in the advanced generations. The crosses exhibiting high heterosis could be exploited for obtaining transgressive segregants for improvement of yield and yield components.

2. Materials and Methods

Eight lines (females) namely, J 16 - 08, J 18 - 16, J 17 - 08, GW 513, AKAW 4901, HS 626, WH 1216, HD 3086 and four testers (males) i.e. GW 366, GW 11, HI 1544, GW 499 of bread wheat (*Triticum aestivum* L.) were selected on the basis of their phenotypic variability. The crossing programme was carried out during *Rabi* 2019-20 using line × tester mating design. The experimental material consisting of 45 entries, including 12 parents, 32 crosses and 1 standard check were tested in randomized block design with three replications during *Rabi* 2020-21. 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 per genotype in each replication were randomly selected for the purpose of recording observations on for 13 characters, *viz.,* days to heading, days to maturity, plant height, flag leaf area, 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, grain yield per plant, biological yield per plant and harvest index. 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: and Standard heterosis is per cent increase or decrease over standard check (GW-451) and was calculated by the following formula: where, = Mean performance of F_1 , = Mean value of batter parent of respective cross combination and Mean performance of standard check.

3. Results and Discussion

The analysis of variance (Table 1) depicted significant differences among the genotypes indicating that experimental materials had sufficient genetic variability for all the characters studied. The variance due to genotypes was further partitioned into variance due to parents, hybrids and parents vs. hybrids. The differences among the parents and hybrids were also found highly significant for all the characters studied. The mean squares due to parents *vs.* hybrids were found significant for plant height, number of effective tillers per plant, grain filling period, number of grains per main spike, grain yield per plant and harvest index. Suggesting that the performance of hybrids as a group was different than that of the parents for those characters. The mean squares due to parents *vs.* hybrid were of higher order as against parents and hybrids for number of spikelets per main spike, number of grains per main spike and grain yield per plant. The higher value of parent *vs.* hybrids indicates the presence of heterosis in material under study. This revealed the presence of substantial amount of heterosis in various cross combinations due to effect of directional dominance.

The heterotic effect in negative direction is desirable for days to heading in wheat. The earliest hybrid was HD 3086 × GW 499 (-12.07%) followed by J 17-08 × GW 11 (-11.98%) and AKAW 4901 × GW 499 (-11.41%). Out of 32 hybrids, 14 hybrids manifested significant and desirable (negative) estimate of heterobeltiosis (Table 2). Out of 32 hybrids, none exhibited significant and negative heterosis over standard check (Table 2). Significant negative heterosis for days to heading have also been reported by Dhoot *et al.* (2020). The negative heterosis for days to maturity is considered desirable for earliness in wheat crop. The earliest hybrid was J 16-08 × GW 499 (-6.02%) followed by WH 1216 × GW 366 (-4.62%), J 16-08 × HI 1544 (-3.68%) and AKAW 4901 × GW 499 (-3.68%). Out of 32 hybrids, 5 hybrid recorded significant negative heterosis over better parent (Table 2). None of the hybrids found earlier to standard check variety GW 451 (Table 2). Significant negative heterosis for days to maturity have also been reported by Saren *et al.* (2018).

In wheat, short plant height is desirable trait. The highest desirable heterobeltiosis was recorded by the cross AKAW 4901 × GW 11 (-17.49%) followed by AKAW 4901 × GW 366 (-17.24%) and AKAW 4901 × HI 1544 (-13.66%). Out of 32 hybrids, 12 hybrids manifested significant and desirable (negative) heterosis over better parent for this trait (Table 2). Out of 32 hybrids, none exhibited significant and desirable (negative) heterosis over standard check (Table 2). These results are in conformity with the results obtained by Khokhar *et al.* (2019).

Table 1. Analysis of variance (mean squares) for parents and hybrids for grain yield and its contributing characters in bread wheat

Source	df	Days to heading	Days to maturity	Plant height	Flag leaf area	Number of effective tillers per plant	Length of main spike	Number of spikelets per main spike
Replications	2	8.32	7.50	19.27	5.95	0.40	0.78	1.47
Genotypes	43	42.26**	18.08**	77.80**	17.77**	9.45**	2.26**	2.53**
Parents	11	80.12**	16.29**	117.11**	13.38**	8.06**	4.08**	3.17**
Hybrids	31	29.68**	18.97**	64.49**	19.90**	10.18**	1.69**	2.28**
Parents vs Hybrid	1	15.55	10.11	57.70*	0.04	2.37*	0.06	3.44
Error	86	4.05	4.70	13.88	1.93	0.59	0.31	1.07

Contd...

Source	df	Grain filling period	Number of grains per main spike	100 - grain weight	Grain yield per plant	Biological yield per plant	Harvest index
Replications	2	6.37	7.99	0.18	4.82*	12.76	39.37
Genotypes	43	23.61**	38.59**	0.33**	13.68**	143.02**	119.60**
Parents	11	36.27**	20.29*	0.22**	14.14**	105.47**	64.95**
Hybrids	31	19.21**	41.98**	0.38**	13.41**	160.86**	139.68**
Parents vs Hybrid	1	20.84**	134.82**	0.01	16.90**	3.00	98.22*
Error	86	2.72	8.38	0.07	1.28	7.40	19.83

Table 2. Per cent heterosis in F1s over better parent (H_1) and standard check GW 451 (H_2) for days to heading, days to maturity and plant height

Sr. No.	Hybrids	Days to heading		Days to maturity		Plant height	
		H_1	H_2	H_1	H_2	H_1	H_2
1	J 16-08 x GW366	-7.93**	-1.95	-2.68	3.56*	5.16	26.61**
2	J 16-08 x GW11	6.71*	13.64**	4.01*	10.68**	-1.13	25.94**
3	J 16-08 x HI1544	-4.27	1.95	-3.68*	2.49	4.05	25.28**
4	J 16-08 x GW499	-9.76**	-3.90	-6.02**	0.00	1.93	22.73**
5	J 18-16 x GW366	8.92**	11.04**	2.77	5.69**	9.13*	21.95**
6	J 18-16 x GW11	12.34**	12.34**	0.69	3.56*	-10.60**	13.87**
7	J 18-16 x HI1544	15.58**	15.58**	4.84**	7.83**	9.13*	21.84**
8	J 18-16 x GW499	6.49*	6.49*	0.00	2.85	7.84*	20.51**
9	J 17-08 x GW366	-4.19	3.90	0.00	2.85	23.09**	32.37**
10	J 17-08 x GW11	-11.98**	-4.55	-1.05	1.07	-3.10	23.43**
11	J 17-08 x HI1544	3.59	12.34**	1.74	3.91*	2.54	12.08**
12	J 17-08 x GW499	-8.38**	-0.65	1.05	3.20*	-1.55	7.21
13	GW513 x GW366	0.00	5.84*	1.02	5.34**	-10.54**	17.63**
14	GW513 x GW11	-2.45	3.25	-1.37	2.85	-10.46**	17.74**
15	GW513 x HI1544	-4.91	0.65	-2.39	1.78	-12.48**	15.08**
16	GW513 x GW499	-0.61	5.19*	-0.68	3.56*	-10.54**	17.63**
17	AKAW4901 x GW366	-3.26	15.58**	1.00	7.47**	-17.24**	10.20*
18	AKAW4901 x GW11	-1.09	18.18**	1.67	8.19**	-17.49**	9.87*
19	AKAW4901 x HI1544	-10.33**	7.14*	-2.34	3.91*	-13.66**	14.97**
20	AKAW4901 x GW499	-11.41**	5.84*	-3.68*	2.49	-7.91*	22.62**
21	HS626 x GW366	-2.19	16.23**	1.35	7.12**	3.03	31.93**
22	HS626 x GW11	-3.28	14.94**	2.02	7.83**	8.92*	39.47**
23	HS626 x HI1544	-3.83	14.29**	-1.01	4.63**	-4.16	22.73**
24	HS626 x GW499	-9.29**	7.79**	3.03*	8.90**	-8.57*	17.07**
25	WH1216 x GW366	-7.18**	9.09**	-4.62**	2.85	-1.19	19.40**
26	WH1216 x GW11	-7.18**	9.09**	-3.63*	3.91*	-6.53*	19.07**
27	WH1216 x HI1544	-6.63**	9.74**	-1.32	6.41**	15.23**	39.25**
28	WH1216 x GW499	-7.73**	8.44**	-1.32	6.41**	1.65	22.84**
29	HD3086 x GW366	-6.32*	5.84*	-0.69	2.14	4.51	20.62**
30	HD3086 x GW11	-8.05**	3.90	-2.08	0.71	-12.45**	11.53*
31	HD3086 x HI1544	-4.02	8.44**	0.00	2.85	-1.06	14.19**
32	HD3086 x GW499	-12.07**	-0.65	-2.77	0.00	1.92	17.63**
	SE±	1.62	1.62	1.75	1.75	3.01	3.01

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

For flag leaf area, the highest significant positive heterosis over better parent was registered by the hybrid WH 1216 × GW 11 (29.20%) followed by GW 513 × GW 499 (15.44%) and HS 626 × GW 499 (14.39%). Out of 32 hybrids, 6 hybrids depicted significant and positive heterosis over better parent (Table 3). The cross WH 1216 × GW 11 (12.63%) exhibited the highest significant and positive heterosis over standard check followed by the cross GW 513 × GW 499 (11.12%) and HS 626 × GW 499 (7.63%). Among 32 hybrids, 3 hybrids showed significant and positive heterosis over standard check (Table 3). Similar findings were reported for this trait by earlier worker Kalimullah (2011).

For number of effective tillers per plant, the highest significant positive heterosis over better parent was recorded by the hybrid J 18-16 × HI 1544 (43.18%) followed by HS 626 × GW 11 (37.67%) and WH 1216 × GW 499 (28.57%). Out of 32 hybrids, 9 hybrids showed significant and positive heterosis over better parent (Table 3). The cross J 16-08 × GW 11 (39.40%) exhibited the highest significant and positive heterosis over standard check followed by the cross HD 3086 × GW 366 (38.83%) and J 16-08 × GW 499 (34.83%). Out of 32, 11 hybrids registered significant and positive heterosis over standard check (Table 3). Similar findings were also reported by earlier worker Motawea (2017).

For length of main spike, the highest desirable heterosis was recorded by the hybrid J 17-08 × GW 11 (11.74%). Out of 32 hybrids, only one hybrid showed significant and positive heterosis over better parent (Table 3).The cross HS 626 × HI 1544 (19.20%) expressed the highest significant positive heterosis over standard check followed by J 16-08 × GW 11 (17.03%) and HD 3086 × GW 499 (17.03%). Out of 32 hybrids, 18 hybrids exhibited significant positive desirable heterosis over standard check (Table 3). The results are in corroboration with those reported earlier by Shahzadi *et al.* (2015).

Table 3. Per cent heterosis in F1s over better parent (H_1) and standard check GW 451 (H_2) for flag leaf area, number of effective tillers per plant and length of main spike

Sr. No.	Hybrids	Flag leaf area		Number of effective tillers per plant		Length of main spike	
		H_1	H_2	H_1	H_2	H_1	H_2
1	J 16-08 x GW366	-2.71	-11.23**	13.31*	25.12**	-1.83	16.67**
2	J 16-08 x GW11	-8.19	-20.99**	26.25**	39.40**	-1.52	17.03**
3	J 16-08 x HI1544	7.19	-7.60*	-29.30**	-21.94**	-3.66	14.49**
4	J 16-08 x GW499	-1.66	-7.48*	22.10**	34.83**	-3.35	14.86**
5	J 18-16 x GW366	-11.96**	-15.15**	-1.47	5.41	1.96	-5.80
6	J 18-16 x GW11	-11.05**	-14.27**	20.18**	12.36*	-14.95**	-13.41**
7	J 18-16 x HI1544	-1.66	-5.17	43.18**	33.86**	-15.84**	-1.81
8	J 18-16 x GW499	6.12	2.28	-4.33	-7.06	4.65	-2.17
9	J 17-08 x GW366	-9.95**	-1.36	18.10**	34.77**	1.81	2.17
10	J 17-08 x GW11	-23.21**	-15.89**	-5.61	7.71	11.74**	13.77**
11	J 17-08 x HI1544	-23.35**	-16.05**	-36.27**	-27.28**	-14.91**	-0.72
12	J 17-08 x GW499	-15.96**	-7.95*	-6.98	6.14	-3.25	-2.90
13	GW513 x GW366	-16.22**	-19.36**	-21.02**	6.73	1.33	10.51*
14	GW513 x GW11	-21.05**	-24.00**	-8.52*	23.62**	-7.97*	0.36
15	GW513 x HI1544	9.87*	5.76	-12.39**	18.39**	-3.42	12.68**
16	GW513 x GW499	15.44**	11.12**	-24.49**	2.05	-1.33	7.61
17	AKAW4901 x GW366	7.71*	3.91	-8.79	6.22	-6.12*	11.23*
18	AKAW4901 x GW11	-18.26**	-21.14**	-29.98**	-18.46**	-9.17*	7.61*

19	AKAW4901 x HI1544	-10.49*	-13.65**	-12.31*	2.12	-14.98**	0.72
20	AKAW4901 x GW499	-1.11	-4.59	-16.42**	-2.67	-1.53	16.67**
21	HS626 x GW366	-8.43*	-16.46**	-4.37	2.30	-7.60*	10.14*
22	HS626 x GW11	11.67*	-7.37*	37.67**	13.86*	-2.43	16.30**
23	HS626 x HI1544	-7.39	-20.17**	-12.69	-27.79**	0.00	19.20**
24	HS626 x GW499	14.39**	7.63*	-25.37**	-27.50**	-12.16**	4.71
25	WH1216 x GW366	2.87	-6.14	0.21	7.20	-3.70	13.04**
26	WH1216 x GW11	29.20**	12.63**	-11.71	-16.71**	-9.57*	6.16
27	WH1216 x HI1544	-16.31**	-27.04**	11.01	4.72	-4.32	12.32**
28	WH1216 x GW499	5.39	-0.84	28.57**	24.90**	-1.23	15.94**
29	HD3086 x GW366	5.38	-0.78	17.77**	38.83**	-8.67*	6.88
30	HD3086 x GW11	-16.40**	-21.29**	-20.25**	-6.00	-15.17**	-0.72
31	HD3086 x HI1544	-3.34	-8.99*	-16.72**	-1.83	-5.26	10.87*
32	HD3086 x GW499	-4.44	-10.03*	-36.79**	-25.48**	0.00	17.03**
	SE±	1.13	1.13	0.62	0.62	0.46	0.46

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

For number of spikelets per main spike, the highest heterobeltiosis was exhibited by the cross J 16-08 × GW 366 (7.91%). Out of 32 hybrids, only one hybrid registered significant and positive heterosis over better parent (Table 4). The cross J 16-08 × GW 366 (22.42%) exhibited the highest significant positive heterosis over standard check followed by J 16-08 × GW 11 (21.52%) and HS 626 × GW 11 (14.35%). Out of 32 hybrids, 12 hybrids showed significant and positive heterosis over standard check (Table 4). Significant positive heterosis for this character has also been reported by Ahmad *et al.* (2016).

In case of grain filling period, the highest desirable (positive) heterosis was recorded by the hybrid J 16-08 × GW 366 (8.20%). Out of 32 hybrids, only one hybrid manifested significant and desirable heterosis over better parent for this trait (Table 4).The cross J-16-08 × GW 366 (10.92%) exhibited the highest significant positive heterosis over standard check followed by J 16-08 × GW 499 (8.40%) and GW 513 × GW 499 (6.72%). Out of 32 hybrids, 3 hybrids registered significant and desirable heterosis over standard check (Table 4). Significant desirable heterosis for this character has been reported by Thomas *et al.* (2017).

Regarding number of grains per main spike, the highest heterosis over better parent in desirable direction was recorded by the cross GW 513 × GW 366 (24.00%) followed by HS 626 × GW 366 (22.91%) and J 16-08 × GW 366 (22.48%). Nine hybrids expressed significant positive heterosis over better parent (Table 4). The cross HS 626 × GW 366 (29.98%) exhibited the highest heterosis over standard check in desired direction followed by GW 513 × GW 366 (25.30%) and HD 3086 × GW 366 (21.84%). Out of 32 hybrids, 11 exerted significant positive heterosis over standard check (Table 4). These results are in agreement with the earlier studies carried out by Kumar *et al.* (2019).

Table 4. Per cent heterosis in F1s over better parent (H_1) and standard check GW 451 (H_2) for number of spikelets per main spike, grain filling period and number of grains per main spike

Sr. No.	**Hybrids**	**Number of spikelets per main spike**		**Grain filling period**		**Number of grains per main spike**	
		H_1	**H_2**	**H_1**	**H_2**	**H_1**	**H_2**
1	J 16-08 x GW366	7.91*	22.42**	8.20**	10.92**	22.48**	20.98**
2	J 16-08 x GW11	7.11	21.52**	-11.28**	-0.84	5.94	5.76

3	J 16-08 x HI1544	-4.74	8.07	-4.84	-0.84	11.17*	9.80*
4	J 16-08 x GW499	-3.95	8.97*	4.03	8.40**	-1.14	3.51
5	J 18-16 x GW366	0.43	4.04	-11.72**	-5.04	7.58*	5.92
6	J 18-16 x GW11	-5.91	0.00	-21.05**	-11.76**	0.18	0.02
7	J 18-16 x HI1544	1.71	6.73	-10.94**	-4.20	4.53	2.91
8	J 18-16 x GW499	-7.79	-4.48	-14.84**	-8.40**	4.68	9.60*
9	J 17-08 x GW366	-5.71	3.59	-0.82	1.68	17.77**	20.57**
10	J 17-08 x GW11	-0.82	8.97*	-9.02**	1.68	-2.65	-0.33
11	J 17-08 x HI1544	-6.53	2.69	-14.52**	-10.92**	-0.30	2.06
12	J 17-08 x GW499	-8.16*	0.90	-2.42	1.68	2.54	7.35
13	GW513 x GW366	-7.00	7.17	-4.92	-2.52	24.00**	25.30**
14	GW513 x GW11	-12.45**	0.90	-12.78**	-2.52	6.76	7.87
15	GW513 x HI1544	-1.17	13.90**	-6.45*	-2.52	12.22*	13.40**
16	GW513 x GW499	-10.89**	2.69	2.42	6.72*	12.50**	17.78**
17	AKAW4901 x GW366	-7.49*	10.76*	-13.11**	-10.92**	4.33	7.53
18	AKAW4901 x GW11	-10.86**	6.73	-21.05**	-11.76**	0.52	3.60
19	AKAW4901 x HI1544	-11.61**	5.83	-12.10**	-8.40**	2.97	6.12
20	AKAW4901 x GW499	-7.12*	11.21*	-14.52**	-10.92**	0.17	4.87
21	HS626 x GW366	-8.00*	13.45**	-13.11**	-10.92**	22.91**	29.98**
22	HS626 x GW11	-7.27*	14.35**	-19.55**	-10.08**	-8.39*	-3.12
23	HS626 x HI1544	-8.00*	13.45**	-18.55**	-15.13**	6.21	12.31*
24	HS626 x GW499	-14.55**	5.38	-8.06**	-4.20	-6.23	-0.83
25	WH1216 x GW366	-3.66	6.28	-2.46	0.00	-15.81**	-0.36
26	WH1216 x GW11	-2.03	8.07	-17.29**	-7.56*	-7.55*	9.42*
27	WH1216 x HI1544	2.85	13.45**	-6.45*	-2.52	-11.12**	5.20
28	WH1216 x GW499	-2.03	8.07	-12.90**	-9.24**	-21.10**	-6.62
29	HD3086 x GW366	-6.48	3.59	-8.20**	-5.88*	13.40**	21.84**
30	HD3086 x GW11	-8.10*	1.79	-17.29**	-7.56*	-5.18	1.88
31	HD3086 x HI1544	-4.86	5.38	-10.48**	-6.72*	-1.89	5.42
32	HD3086 x GW499	-1.62	8.97*	-0.81	3.36	-0.54	6.86
	SE±	0.83	0.83	1.33	1.33	2.35	2.35

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

With respect to 100-grain weight, the highest heterosis over better parent in desirable direction was recorded by the cross WH 1216 × GW 499 (13.45%) followed by AKAW 4901 × GW 366 (8.26%) and J 18-16 × HI 1544 (8.24%). Six hybrids depicted significant desirable heterosis over better parent (Table 5). The cross HD 3086 × GW 499 (21.66%) exhibited the highest significant and positive heterosis over standard check followed by HS 626 × HI 1544 (19.53%) and AKAW 4901 × GW 366 (19.13%). Out of 32 hybrids, 12 hybrids showed significant desirable heterosis over standard check (Table 5). Significant desirable heterosis for this character has been reported by Gul *et al.* (2015).

In wheat, grain yield is one of the most important economic characters and the final product of the multiplicative interaction of contributing traits. Therefore, it is imperative to know the causes of heterosis for grain yield. The cross J 16-08 × GW 366 (62.72%) depicted the highest desirable heterosis over better parent followed by J 16-08 × GW 11 (28.98%) and J 17-08 × GW 366 (19.39%). Out of 32 hybrids, 3 hybrids expressed significant positive heterosis over better parent (Table 5). The cross J 16-08 × GW 366 (36.92%) recorded the highest significant heterosis towards positive direction over standard check, followed by J 16-08 × GW 11 (17.36%) and GW 513 × GW 11 (11.58%). Out of 32 hybrids, 3 hybrids showed significant positive desirable heterosis over standard check GW 366 (Table 5). These results were supported by those obtained by Khokhar *et al.* (2019).

Table 5. Per cent heterosis in F1s over better parent (H_1) and standard check GW 451 (H_2) for 100-grain weight and grain yield per plant

Sr. No.	Hybrids	100-grain weight		Grain yield per plant	
		H_1	H_2	H_1	H_2
1	J 16-08 x GW366	-3.43	4.74	62.72**	36.92**
2	J 16-08 x GW11	-8.33*	-4.27	28.98**	17.36**
3	J 16-08 x HI1544	-3.90	1.42	1.42	0.67
4	J 16-08 x GW499	3.33	7.91*	2.71	10.95
5	J 18-16 x GW366	-13.19**	-5.85	-14.13*	-4.95
6	J 18-16 x GW11	-0.53	3.32	-37.85**	-31.21**
7	J 18-16 x HI1544	8.24*	14.23**	-41.33**	-35.06**
8	J 18-16 x GW499	1.45	5.38	-33.81**	-26.73**
9	J 17-08 x GW366	-14.29**	-7.04*	19.39**	10.65
10	J 17-08 x GW11	-14.83**	-13.28**	-11.07	-17.58**
11	J 17-08 x HI1544	-1.20	4.27	-9.73	-10.40
12	J 17-08 x GW499	8.23*	8.14*	-6.14	1.39
13	GW513 x GW366	-9.31*	2.37	-47.58**	-29.14**
14	GW513 x GW11	-7.28*	4.66	-17.45**	11.58*
15	GW513 x HI1544	-5.32*	6.88*	-28.46**	-3.29
16	GW513 x GW499	-7.35*	4.58	-35.81**	-13.23*
17	AKAW4901 x GW366	8.26*	19.13**	-4.66	5.70
18	AKAW4901 x GW11	-5.39*	4.11	-37.70**	-30.93**
19	AKAW4901 x HI1544	-9.34*	-0.24	-35.72**	-28.74**
20	AKAW4901 x GW499	7.61*	18.42**	-18.15**	-9.26
21	HS626 x GW366	-9.64**	0.00	-4.63	-2.49
22	HS626 x GW11	-18.71**	-10.04*	-9.99	-7.97
23	HS626 x HI1544	8.00*	19.53**	-15.58*	-13.68*
24	HS626 x GW499	1.00	11.78**	-7.06	0.40
25	WH1216 x GW366	-2.84	5.38	7.50	-9.54
26	WH1216 x GW11	-3.18	-1.42	-2.22	-11.03
27	WH1216 x HI1544	4.12	9.88*	-7.84	-8.52
28	WH1216 x GW499	13.45**	13.36**	-1.31	6.60
29	HD3086 x GW366	-11.75**	2.13	4.65	8.40
30	HD3086 x GW11	-7.72*	6.80*	-19.90**	-17.03**

31	HD3086 x HI1544	-16.53**	-3.40	-2.19	1.31
32	HD3086 x GW499	5.12	21.66**	-31.84**	-26.37**
	SE±	0.22	0.22	0.93	0.93

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

Regarding biological yield per plant, the highest heterobeltiosis was recorded by the cross J 17-08 × GW 366 (37.79%) followed by J 16-08 × GW 366 (34.17%) and J 16-08 × GW 11 (29.68%). Out of 32 hybrids, 13 hybrids expressed significant and positive heterosis over better parent (Table 6). The cross GW 513 × GW 11 (52.23%) exhibited the highest significant heterosis over standard check followed by J 16-08 × GW 11 (35.14%) and HS 626 × HI 1544 (34.84%). Twelve hybrids expressed significant positive desirable heterosis over standard check (Table 6). Similar findings have also been reported by Motawea (2017).

Table 6. Per cent heterosis in F1s over better parent (H_1) and standard check GW 451 (H_2) for biological yield per plant and harvest index

Sr. No.	Hybrids	Biological yield per plant		Harvest index	
		H_1	H_2	H_1	H_2
1	J 16-08 x GW366	34.17**	29.92**	0.73	5.53
2	J 16-08 x GW11	29.68**	35.14**	-0.27	-12.88
3	J 16-08 x HI1544	-15.88**	-6.78	19.58*	7.98
4	J 16-08 x GW499	13.58*	9.98	-14.97*	2.30
5	J 18-16 x GW366	-22.48**	-2.81	-6.42	-1.96
6	J 18-16 x GW11	-38.84**	-23.32**	2.49	-9.56
7	J 18-16 x HI1544	-28.74**	-10.65*	-19.02*	-26.87**
8	J 18-16 x GW499	-49.46**	-36.64**	-2.62	17.17*
9	J 17-08 x GW366	37.79**	11.01*	-15.74*	0.43
10	J 17-08 x GW11	-21.52**	-18.21**	-15.25*	1.02
11	J 17-08 x HI1544	-8.43	1.48	-25.65**	-11.38
12	J 17-08 x GW499	17.46**	6.04	-20.16**	-3.93
13	GW513 x GW366	-39.58**	-21.35**	-13.71	-9.60
14	GW513 x GW11	16.95**	52.23**	-29.52**	-26.56**
15	GW513 x HI1544	-20.50**	3.49	-10.31	-6.56
16	GW513 x GW499	-44.94**	-28.33**	1.01	21.54*
17	AKAW4901 x GW366	-21.93**	-9.63	12.18	17.52*
18	AKAW4901 x GW11	-3.54	11.66*	-36.20**	-38.17**
19	AKAW4901 x HI1544	-14.30**	-0.79	-25.61**	-27.90**
20	AKAW4901 x GW499	-1.54	13.98*	-33.47**	-19.96*
21	HS626 x GW366	13.85**	27.54**	-26.83**	-23.34**
22	HS626 x GW11	-14.70**	-4.44	5.65	-2.51
23	HS626 x HI1544	20.36**	34.84**	-30.48**	-35.85**
24	HS626 x GW499	-13.80**	-3.44	-12.70	5.04
25	WH1216 x GW366	14.99*	-2.04	-11.59	-7.39
26	WH1216 x GW11	-27.67**	-24.62**	37.16**	19.82*

27	WH1216 x HI1544	13.96**	26.29**	-19.71*	-27.49**
28	WH1216 x GW499	27.10**	14.74*	-22.39**	-6.62
29	HD3086 x GW366	-14.93**	-13.01*	19.41*	25.10**
30	HD3086 x GW11	25.07**	30.34**	-37.12**	-36.09**
31	HD3086 x HI1544	-16.19**	-7.12	9.03	10.82
32	HD3086 x GW499	15.99**	18.62**	-47.68**	-37.05**
	SE±	2.19	2.19	3.62	3.62

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

Table 7. Top five standard heterotic hybrids for grain yield per plant along with desirable heterosis for other traits

Heterotic crosses	Grain yield per plant (g)	Per cent heterosis of grain yield per plant over		Desirable heterosis for other traits over	
		Better parent	Check (GW 451)	Better parent	Check (GW 451)
J 16-08 × GW 366	17.60	62.72**	36.92**	DH, NET, NSMS, GFP, NGMS, BYP	NET, LMS, NSMS, GFP, NGMS, BYP
J 16-08 ×GW 11	15.09	28.98**	17.36**	NET,BYP	NET, LMS, NSMS, BYP
GW 513 × GW 11	14.34	-17.45**	11.58*	PH, BYP	NET, BYP
J 16-08 × GW 499	14.26	2.71	10.95	DH, DM, NET, BYP	NET, LMS, NSMS, GFP, 100-GW
J 17-08 × GW 366	14.22	19.39**	10.65	NET, NGMS, BYP	NET, NGMS, BYP

Where, *, ** were significant at 5 % and 1 % levels of probability, respectively.

DH = Days to heading; NET= Number of effective tillers per plant; NGMS= Number of grains per main spike; DM = Days to maturity; LMS= Length of main spike; 100-GW= 100-grain weight; PH = Plant height (cm); NSMS= Number of spikelets per main spike; BYP= Biological yield per plant; FLA= Flag leaf area (cm^2); GFP= Grain filling period; HI = Harvest Index

For harvest index, the highest significant and desirable heterosis over better parent was recorded by the cross WH 1216 × GW 11 (37.16%) followed by J 16-08 × HI 1544 (19.58%) and HD 3086 × GW 366 (19.41%). Out of 32 hybrids, 3 hybrids demonstrated significant and positive heterosis over better parent (Table 7). The cross HD 3086 × GW 366 (25.10%) exhibited the highest significant standard heterosis followed by GW 513 × GW 499 (21.54%) and WH 1216 × GW 11 (19.82%). Out of 32 hybrids, 5 manifested significant and positive heterosis over standard check (Table 7). Similar findings have also been observed by Barot and Patel (2013).

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Author's contribution

Conceptualization of research (HD and AGP); Designing of the experiments (HD, AGP and IBK); Contribution of experimental materials (AGP, JBP and CS); Execution of field/lab experiments and data collection (DH, AGP and DMV); Analysis of data and interpretation (AGP and HD); Preparation of the manuscript (HD, AGP and IBK).

Declaration

The authors declare no conflict of interest.

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