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Estimation of heterosis in different crosses of bread wheat (*Triticum aestivum* L.)

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Abstract
An experiment was conducted to estimate the nature and magnitude of heterosis for grain yield and its component traits using line × tester mating design (8 lines and 4 testers). The conspicuous heterotic effects were observed for grain yield per plant and its components. A total of 7 and 6 hybrids manifested significant desirable heterobeltiosis and standard heterosis, respectively for grain yield per plant. The heterobeltiosis for grain yield ranged from -46.25 to 51.74%, while standard heterosis ranged from -30.03 to 47.95%. The cross GW 11 × GW 451 (51.74%) exhibited the highest desirable heterosis over better parent followed by HD 2932 × GW 451 (33.24%) and HD 2932 × GW 496 (33.16%). The cross MP 3288 × GW 366 (47.95%) exhibited highest significant heterosis towards positive direction over standard check, followed by GW 11 × GW 451 (46.35%) and MP 3288 × HI 1544 (40.58%). Such crosses can be exploited for development of high yielding varieties.

Keywords: *Triticum aestivum* L., heterosis, grain yield

Introduction
Since the dawn of civilization, wheat has been a major crop to feed the human society in every part of the world. Wheat was used not only for local feeding but also in trade for exchange of goods. It is believed that wheat developed from a type of wild grass native to the arid lands of Asia Minor. Cultivation of wheat is thought to have originated in Euphrates Valley as early as 10,000 B.C., making it one of the world's oldest cereal crops. In the Mediterranean region, centuries before recorded history, wheat was an important food. Wheat played such a dominant role in the Roman Empire that at the time it often was referred to as a "Wheat Empire". Wheat is a unique gift of nature to the mankind as it contains starch (60-68%), protein (6-21%), fat (1.5-2.0%), cellulose (2.0-2.5%), minerals (1.8%) and vitamins (Das, 2008) [5]. Bread wheat is consumed in India mainly as chapatti. Its other preparations include bread, biscuits, noodles, cakes, pizzas, doughnuts, etc. It is also milled as semolina, locally known as rava or sooji, to prepare different food products like upma, halwa etc.
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. The knowledge of heterosis would help in determination of parents which produce the best cross combinations having maximum expression of heterosis. For improving 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 breeder. The nature and magnitude of heterosis help in identifying superior cross combinations that may produce desirable segregants from the advanced generations. Heterosis breeding provides the ways to overcome yield barriers. The crosses exhibiting high heterosis could be exploited for obtaining transgressive segregants for improvement of yield and yield components.

Materials and Methods
The present study was conducted at Wheat Research Station, Junagadh Agricultural University, Junagadh (Gujarat), during *Rabi* 2017-18. The experimental material of the study consisted of eight lines i.e., GW 11, GW 173, GJW 463, HD 2932, J 11-04, Lok 1, MP 3288, Raj 4238 and four testers i.e. GW 366, GW 451, GW 496, HI 1544 one standard check (GW 366) and their 32 F_1s. The F_1s were made by crossing eight lines with four testers in line × tester mating design during *Rabi* 2016-17. These crosses were then evaluated along with the parents and check, GW 366 during *Rabi* 2017-18.

The experimental material consisting of 45 entries, including 12 parents, 32 crosses and 1 standard check was tested in randomized block design with three replications during *Rabi* 2017-18. 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. Twelve morphological characters namely, days to heading, days to maturity, 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 (%).

Estimation of Heterosis

The estimation of heterosis over better parent and over standard check is more realistic. Hence, in present investigation, heterosis was estimated over better parent (BP) and standard check (GW 366), referred to as heterobeltiosis and standard heterosis, respectively.

Heterobeltiosis is calculated as the deviation of F_1 from the better parent (Fonseca and Patterson, 1968) [7] and was expressed in percentage by following formula:

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

Where,

$\overline{F_1}$ = Mean performance of F_1

$\overline{BP}$ = Mean value of better parent of respective cross

Combination

The formula used to estimate heterosis over standard check value is given as under.

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

Where,

$\overline{F_1}$ = Mean performance of F_1

$\overline{SC}$ = Mean performance of standard check

Results and Discussion

The long term objective of most plant breeding programmes is to increase yield potential of a crop with high quality, which may be achieved by manipulating genes for yield components. Wheat is a major cereal crop of India. It has received considerable attention from the plant breeders which resulted into significant breakthrough by development of semi-dwarf, disease resistant and fertilizer responsive varieties (Lupton, 1987) [16]. Despite this huge increase, wheat workers feel that the yield has now attained a plateau, especially in high productivity zones. Development of commercial hybrid wheat may be one way that may overcome the existing problems of plateauing yield and further enhancement in wheat yields (Kant *et al.*, 2001) [12]. Another way to achieve breakthrough in yield improvement is to know genetic structure of grain yield and its components along with efficient use of available polygenic variability.

The analysis of variance (Table 1) showed significant differences for all 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 also found significant for all the characters except biological yield per plant indicating that the performance of hybrids as a group was different than that of the parents for most of the characters. The mean squares due to parents *vs.* hybrid were of higher order as against parents and hybrids for days to heading, days to maturity, plant height, number of effective tillers per plant, grain filling period, 100-grain weight and grain yield per plant. 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.

Heterobeltiosis and standard heterosis were estimated with the check GW 366 and results are presented in Table 2 to 4 and Graph 1. In wheat, earliness in heading is desirable trait. For days to heading, heterosis over better parent ranged from -8.20 per cent (GJW 463 × GW 451) to 18.30 per cent (Raj 4238 × GW 496). The earliest hybrid over better parent was GJW 463 × GW 451 (-8.20%) followed by GJW 463 × GW 366 (-7.10%) and GJW 463 × HI 1544 (-6.56%). Heterosis over standard check ranged from -5.96 per cent (GW 173 × HI 1544, HD 2932 × GW 366 and HD 2932 × HI 1544) to 19.87 per cent (MP 3288 × GW 366 and Raj 4238 × GW 496). Significant negative heterosis for days to heading have also been reported by Lal *et al*. (2013) [14], Lamala kshmin devi *et al*. (2013) [15] and Singh *et al.* (2013) [15].

Early maturing parent is considered as better parent in wheat crop. For days to maturity, the range of heterosis over better parent recorded from -2.42 per cent (GW 11 × HI 1544) to 13.62 per cent (Raj 4238 × GW 496). The hybrid GW 11 × HI 1544 (-2.42) expressed significant negative heterosis over better parent. The heterosis over standard check ranged from 1.44 per cent (GW 11 × HI 1544) to 14.03 per cent (MP 3288 × GW 366 and Raj 4238 × GW 496). Significant negative heterosis for days to maturity have also been reported by Lal *et al.* (2013) [14], Lamalakshmi devi *et al.* (2013) [15] and Singh *et al.* (2013) [15].

For plant height, heterosis over better parent ranged from -24.91 per cent (MP 3288 × GW 451) to 1.95 per cent (HD 2932 × GW 451). The highest desirable heterobeltiosis was recorded by the cross MP 3288 × GW 451 (-24.91%) followed by GW 173 × GW 366 (-19.91%) and MP 3288 × GW 366 (-17.75%). Heterosis over standard check ranged from -18.33 per cent (GW 173 × GW 366) to 6.47 per cent (J 11-04 × HI 1544). The highest desirable standard heterosis was recorded by the cross GW 173 × GW 366 (-18.33%) followed by GW 173 × GW 451 (-17.61%) and MP 3288 × GW 451 (-15.80%). These results are in confirmation with the results of Rathod (2003) [20], Vanpariya *et al*. (2006) [24] and Singh *et al*. (2007) [21].

For number of effective tillers per plant, heterosis over better parent ranged from -46.15 per cent (GJW 463 × HI 1544) to 39.13 per cent (MP 3288 × HI 1544). The highest significant positive heterosis over better parent was expressed by the hybrid MP 3288 × HI 1544 (39.13%) followed by GW 11 × GW 451 (37.85%) and GW 11 × GW 496 (26.23%). Heterosis over standard check ranged from -42.95 per cent (J 11-04 × HI 1544) to 26.18 per cent (MP 3288 × GW 366). The cross MP 3288 × GW 366 (26.18%) exhibited highest significant and positive heterosis over standard check followed by the cross GW 11 × GW 451 (16.11%). Similar findings were reported by earlier workers *viz.*, Kalimullah

(2011) [10], Kumar *et al*. (2011) [13], Singh *et al.* (2013) [13] and Ahmad *et al.* (2016) [1].

For length of main spike, the range of heterosis over better parent was recorded from -17.89 per cent (Raj 4238 × GW 496) to 15.37 per cent (Lok 1 × HI 1544). The highest desirable heterosis was recorded by the hybrid Lok 1 × HI 1544 (15.37%) followed by GW 173 × HI 1544 (13.35%) and GW 11 × GW 451 (10.17%). Heterosis over standard check ranged from -4.41 per cent (Raj 4238 × GW 496) to 30.56 per cent (GJW 463 × GW 496). The cross GJW 463 × GW 496 (30.56%) expressed the highest significant positive heterosis over standard check followed by MP 3288 × GW 496 (28.15%) and MP 3288 × HI 1544 (26.74%). Kalimullah (2011) [10], Lamalakshmi devi *et al.* (2013) [15], Singh *et al.* (2013) [15] and Gul *et al.* (2015) [8] also reported significant positive heterosis for spike length in wheat.

For number of spikelets per spike, the magnitude of heterosis over better parent ranged from -15.75 per cent (J 11-04 × GW 451) to 15.57 per cent (Lok 1 × HI 1544). The highest heterobeltiosis was exhibited by the cross Lok 1 × HI 1544 (15.57%) followed by Lok 1 × GW 496 (14.15%) and GW 11 × GW 451 (12.56%). Heterosis over standard check ranged from -1.40 per cent (Lok 1 × GW 366 and Raj 4238 × GW 496) to 30.84 (MP 3288 × GW 496). The cross MP 3288 × GW 496 (30.84%) exhibited the highest significant positive heterosis over standard check followed by J 11-04 × HI 1544 (28.04%) and MP 3288 × HI 1544 (25.70%). Significant positive heterosis for this character has been reported by Kumar *et al.* (2011) [13], Lamalakshmi Devi *et al.* (2013) [15], Singh *et al*. (2013) [15] and Ahmad *et al.* (2016) [1].

For grain filling period, the range of heterosis over better parent was recorded from -23.70 per cent (J 11-04 × HI 1544) to 15.57 per cent (MP 3288 × GW 451). The highest desirable (negative) heterosis was recorded by the hybrid J 11-04 × HI 1544 (-23.70%) followed by GJW 463 × HI 1544 (-17.78%) and MP 3288 × HI 1544 (-14.07%). Heterosis over standard check ranged from -17.60 per cent (J 11-04 × HI 1544) to 12.80 (MP 3288 × GW 451). The cross J 11-04 × HI 1544 (-17.60%) exhibited the highest significant negative heterosis over standard check followed by J 11-04 × GW 496 (-12.00%) and MP 3288 × GW 496 (-12.00%). Significant negative heterosis for this character has been reported by Bhatiya (2006) [3].

For number of grains per main spike, the range of heterosis over better parent recorded from -16.08 per cent (J 11-04 × GW 451) to 13.55 per cent (Lok 1 × HI 1544). The highest heterosis over better parent in desirable direction was recorded by the cross Lok 1 × HI 1544 (13.55%) followed by GJW 463 × GW 366 (12.17%) and GJW 463 × HI 1544 (9.20%). The range of standard heterosis for this trait varied from -1.33 per cent (Lok 1 × GW 366 and Raj 4238 × GW 496) to 30.94 per cent (MP 3288 × GW 496). The cross MP 3288 × GW 496 (30.94%) exhibited the highest heterosis over standard check in desired direction followed by J 11-04 × HI 1544 (28.14%) and MP 3288 × HI 1544 (25.57%). Significant positive heterosis for number of grain per main spike in wheat has been reported by Kamani (2009) [11], Bilgin *et al.* (2011) [4], Kalimullah (2011) [10] and Kumar *et al.* (2011) [13].

For 100-grain weight, the range of heterosis over better parent recorded from -14.55 per cent (J 11-04 × HI 1544) to 13.24 per cent (Lok 1 × GW 366). The highest heterosis over better parent in desirable direction was recorded by the cross Lok 1 × GW 366 (13.24%) followed by HD 2932 × GW 496 (12.13%). Heterosis over standard check ranged from -19.28 per cent (MP 3288 × GW 496) to 15.98 per cent (Lok 1 × GW 366). The cross Lok 1 × GW 366 (15.98%) exhibited the highest significant and positive heterosis over standard check. Significant positive heterosis for 100-grain weight (g) in wheat has been also reported by Akbar *et al.* (2005) [2], Hassan *et al*. (2005) [9] and Vanpariya *et al.* (2006) [24].

For grain yield per plant, the range of heterosis over better parent was recorded from -46.25 per cent (GJW 463 × HI 1544) to 51.74 per cent (GW 11 × GW 451). The cross GW 11 × GW 451 (51.74%) exhibited the highest desirable heterosis over better parent followed by HD 2932 × GW 451 (33.24%) and HD 2932 × GW 496 (33.16%). Heterosis over standard check ranged from -30.03 per cent (HD 2932 × HI 1544) to 47.95 per cent (MP 3288 × GW 366). The cross MP 3288 × GW 366 (47.95%) exhibited highest significant heterosis towards positive direction over standard check, followed by GW 11 × GW 451 (46.35%) and MP 3288 × HI 1544 (40.58%). The present findings are in accordance with those of Patel *et al.* (2015) [17], Ahmad *et al.* (2016) [1], Rahul (2017) [19] and Thomas *et al.* (2017) [23] for grain yield per plant.

For biological yield per plant, the range of heterosis over better parent was recorded from -39.58 per cent (J 11-04 × GW 451) to 46.29 per cent (GW 11 × GW 451). The highest heterobeltiosis was recorded by the hybrid GW 11 × GW 451 (46.29%), followed by MP 3288 × GW 366 (40.07%) and MP 3288 × GW 451 (38.33%). Heterosis over standard check ranged from -36.14 per cent (HD 2932 × HI 1544) to 67.28 per cent (GW 11 × GW 451). The cross GW 11 × GW 451 (67.28%) heterosis over standard check followed by MP 3288 × GW 366 (58.43%) and MP 3288 × GW 451 (58.18%). Similar findings have also been reported by Prasad *et al.* (1998) [18], Akbar *et al.* (2005) [2] and Kamani (2009) [11] for biological yield per plant.

Heterobeltiosis for harvest index ranged from -33.82 per cent (MP 3288 × GW 451) to 23.65 per cent (GW 173 × GW 451). The highest significant and desirable heterosis over better parent was recorded by the cross GW 173 × GW 451 (23.65%) followed by HD 2932 × HI 1544 (14.83%) and HD 2932 × GW 451 (14.50%). Heterosis over standard check ranged from -32.76 per cent (MP 3288 × GW 451) to 9.56 per cent (HD 2932 × GW 366). Similar findings have also been observed by Bilgin *et al.* (2011) [4], Desale and Mehta (2013) [6, 24], and Singh *et al.* (2013) [15].

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

Source	d.f.	Days to heading	Days to maturity	Plant height	Number of effective tillers per plant	Length of main spike	Number of spikelets per main spike
Replications	2	1.23	0.84	25.19	1.89	0.17	0.84
Genotypes	43	52.44**	52.09**	75.69**	7.73**	1.88**	6.45**
Parents	11	53.54**	22.09**	58.77**	6.65**	2.25**	11.27**
Hybrids	31	47.71**	32.77**	60.65**	7.68**	1.76**	4.73**
Parents vs Hybrid	1	187.15**	981.11**	728.15**	21.16**	1.40*	6.57*
Error	86	0.80	0.98	14.33	0.74	0.23	0.95

Source	d.f.	Grain filling period	Number of grains per main spike	100-grain weight	Grain yield per plant	Biological yield per plant	Harvest index
Replications	2	0.96	0.92	0.23	9.29*	86.74*	10.70
Genotypes	43	31.15**	52.59**	0.66**	22.80**	186.02**	37.52**
Parents	11	26.03**	82.87**	0.77**	16.58**	71.02**	60.46**
Hybrids	31	30.55**	42.50**	0.58**	24.86**	230.34**	28.97**
Parents vs Hybrid	1	106.19**	31.12*	1.64**	27.22**	77.41	50.06**
Error	86	1.37	6.91	0.16	2.75	25.37	6.61

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

Table 2: Percent heterosis over better parent (H_1) and standard check GW 366 (H_2) for days to heading, days to maturity, plant height and number of effective tillers per plan**t**

Sr No.	Hybrids	Days to heading		Days to maturity		Plant height (cm)		Number of effective tillers per plant	
		H_1	H_2	H_1	H_2	H_1	H_2	H_1	H_2
1	GW 11 × GW 366	3.31*	3.31*	7.45**	8.99**	-9.96*	-8.18*	-4.79	-6.71
2	GW 11 × GW 451	2.53	7.28**	5.96**	8.63**	-6.57	-5.48	37.85**	16.11*
3	GW 11 × GW 496	1.96	3.31*	7.45**	8.99**	-3.69	-2.56	26.23**	3.36
4	GW 11 × HI 1544	-3.36*	-4.64**	-2.42**	1.44	-5.34	-2.88	25.23**	-10.07
5	GW 173 × GW 366	-4.64**	-4.64**	2.14*	3.24**	-19.91**	-18.33**	-21.58**	-23.15**
6	GW 173 × GW 451	3.80**	8.61**	8.42**	11.15**	-13.82**	-17.61**	19.12*	0.34
7	GW 173 × GW 496	-3.92**	-2.65	7.53**	7.91**	-13.04**	-14.29**	17.21*	-4.03
8	GW 173 × HI 1544	-0.70	-5.96**	-0.35	3.60**	-13.49**	-11.23**	22.28*	-20.81**
9	GJW 463 × GW 366	-7.10**	12.58**	-0.33	8.63**	-4.32	-2.43	-40.24**	-32.21**
10	GJW 463 × GW 451	-8.20**	11.26**	1.98*	11.15**	-9.61*	-7.91*	-8.88	3.36
11	GJW 463 × GW 496	-4.92**	15.23**	0.00	8.99**	-7.85*	-6.11	-23.96**	-13.76
12	GJW 463 × HI 1544	-6.56**	13.25**	-0.99	7.91**	-4.38	-1.89	-46.15**	-38.93**
13	HD 2932 × GW 366	-5.96**	-5.96**	2.49**	3.60**	-12.25**	-10.51**	-18.15*	-19.80**
14	HD 2932 × GW 451	5.06**	9.93**	8.42**	11.15**	1.95	3.32	23.41**	4.03
15	HD 2932 × GW 496	3.92**	5.30**	10.75**	11.15**	-14.80**	-13.66**	22.63*	7.45
16	HD 2932 × HI 1544	-3.40*	-5.96**	-1.38	2.52**	-11.38**	-9.07*	-0.48	-30.20**
17	J 11-04 × GW 366	3.23*	5.96**	6.41**	7.55**	-10.05**	-1.89	-34.93**	-36.24**
18	J 11-04 × GW 451	2.53	7.28**	3.16**	5.76**	-13.84**	-6.02	-19.52*	-32.21**
19	J 11-04 × GW 496	10.97**	13.91**	6.76**	7.91**	-8.81*	-0.54	10.48	-8.05
20	J 11-04 × HI 1544	11.61**	14.57**	1.73*	5.76**	-2.39	6.47	-31.45**	-42.95**
21	Lok 1 × GW 366	-4.64**	-4.64**	1.42	2.52**	-6.61	-4.76	-8.22	-10.07
22	Lok 1 × GW 451	2.53	7.28**	9.47**	12.23**	-10.55**	-10.47**	5.98	-10.74
23	Lok 1 × GW 496	4.58**	5.96**	8.24**	8.63**	-6.37	-6.29	20.08*	-1.68
24	Lok 1 × HI 1544	2.8	-2.65	-1.04	2.88**	-4.73	-2.25	13.57	-15.77**
25	MP 3288 × GW 366	7.74**	19.87**	10.45**	14.03**	-17.75**	-7.77*	28.78**	26.18**
26	MP 3288 × GW 451	-4.76**	5.96**	10.10**	13.67**	-24.91**	-15.80**	2.39	-13.69
27	MP 3288 × GW 496	2.98*	14.57**	4.88**	8.27**	-11.30**	-0.54	15.16	-5.70
28	MP 3288 × HI 1544	3.57**	15.23**	6.57**	10.79**	-7.69*	3.50	39.13**	7.38
29	Raj 4238 × GW 366	4.64**	4.64**	8.19**	9.35**	-9.82*	-8.04*	-32.88**	-34.23**
30	Raj 4238 × GW 451	10.13**	15.23**	9.47**	12.23**	-9.01*	-10.15*	3.59	-12.75
31	Raj 4238 × GW 496	18.30**	19.87**	13.62**	14.03**	0.68	-0.58	22.54*	0.34
32	Raj 4238 × HI 1544	4.05**	1.99	3.46**	7.55**	-4.90	-2.43	25.26**	-17.11*
SE±		0.73	0.73	0.80	0.80	2.85	2.85	0.69	0.69
CD at 5%		1.46	1.46	1.60	1.60	5.69	5.69	1.39	1.39

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

Table 3: Percent heterosis over better parent (H_1) and standard check GW 366 (H_2) for length of main spike, number of spikelets per main spike, grain filling period and number of grains per main spike

Sr No.	Hybrids	Length of main spike		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	H_1	H_2
1	GW 11 × GW 366	2.75	2.54	3.72	4.21	5.60*	5.60*	2.72	3.20
2	GW 11 × GW 451	10.17*	10.77*	12.56*	13.03*	-0.80	-0.80	8.52*	11.05*
3	GW 11 × GW 496	-5.29	10.27*	0.93	1.40	5.60*	5.60*	-3.63	1.48
4	GW 11 × HI 1544	5.01	6.28	7.44	7.94	-6.67**	0.80	7.29	7.79
5	GW 173 × GW 366	3.50	3.28	8.21	4.67	4.80*	4.80*	6.19	5.69
6	GW 173 × GW 451	7.78	8.36	8.61	4.67	4.00	4.00	2.21	4.68
7	GW 173 × GW 496	-7.29	7.94	2.86	0.93	12.00**	12.00**	-3.40	1.71
8	GW 173 × HI 1544	13.35**	14.72**	11.66*	8.53	-0.74	7.20**	9.08*	8.57
9	GJW 463 × GW 366	-5.74	17.82**	0.68	20.68**	-6.56**	-8.80**	12.17*	20.73**
10	GJW 463 × GW 451	-8.78*	14.01**	-5.65	13.08*	0.82	-1.60	2.39	10.21
11	GJW 463 × GW 496	4.46	30.56**	-2.63	16.71**	-6.72**	-11.20**	8.47*	16.76**
12	GJW 463 × HI 1544	0.13	25.16**	-0.19	19.63**	-17.78**	-11.20**	9.20*	17.54**

13	HD 2932 × GW 366	-11.25*	-3.04	-8.16	5.14	9.84**	7.20**	-8.10*	5.22
14	HD 2932 × GW 451	-2.87	6.11	-2.86	11.21*	4.10	1.60	-5.24	8.50
15	HD 2932 × GW 496	-4.21	11.52*	-9.80*	3.27	13.45**	8.00**	-7.62	5.77
16	HD 2932 × HI 1544	-5.23	3.53	-8.27	5.02	-2.96	4.80*	-8.17	5.14
17	J 11-04 × GW 366	-10.89*	4.78	-8.06	17.29**	1.64	-0.80	-8.10*	19.41**
18	J 11-04 × GW 451	-8.35	7.78	-15.75**	7.48	-4.10	-6.40**	-16.08**	9.04
19	J 11-04 × GW 496	5.23	23.74**	-3.30	23.36**	-7.56**	-12.00**	-5.58	22.68**
20	J 11-04 × HI 1544	4.38	22.74**	0.37	28.04**	-23.70**	-17.60**	-1.38	28.14**
21	Lok 1 × GW 366	1.91	2.04	-0.47	-1.40	5.74*	3.20	-0.47	-1.33
22	Lok 1 × GW 451	-1.47	-0.94	0.24	-0.70	10.66**	8.00**	-3.04	-0.70
23	Lok 1 × GW 496	-2.79	13.18*	14.15*	13.08*	4.10	1.60	2.96	8.42
24	Lok 1 × HI 1544	15.37*	16.76**	15.57**	14.49*	-8.15**	-0.80	13.55**	13.02*
25	MP 3288 × GW 366	-7.06	17.71**	-12.97**	16.82**	-3.28	-5.60*	-10.21*	20.65**
26	MP 3288 × GW 451	-8.03*	16.49**	-12.67**	17.22**	15.57**	12.80**	-11.66*	18.71**
27	MP 3288 × GW 496	1.18	28.15**	-2.52	30.84**	-7.56**	-12.00**	-2.55	30.94**
28	MP 3288 × HI 1544	0.07	26.74**	-6.35	25.70**	-14.07**	-7.20**	-6.55	25.57**
29	Raj 4238 × GW 366	-5.82	-0.06	-2.39	4.91	7.38**	4.80*	-2.32	4.99
30	Raj 4238 × GW 451	-3.61	2.29	0.00	7.48	-1.64	-4.00	0.07	7.56
31	Raj 4238 × GW 496	-17.89**	-4.41	-8.26	-1.40	-0.84	-5.60*	-8.19*	-1.33
32	Raj 4238 × HI 1544	-3.13	2.79	-2.17	5.14	-3.70	4.00	-2.10	5.22
SE±		0.40	0.40	0.79	0.79	0.94	0.94	2.19	2.19
CD at 5%		0.81	0.81	1.57	1.57	1.89	1.89	4.38	4.38

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

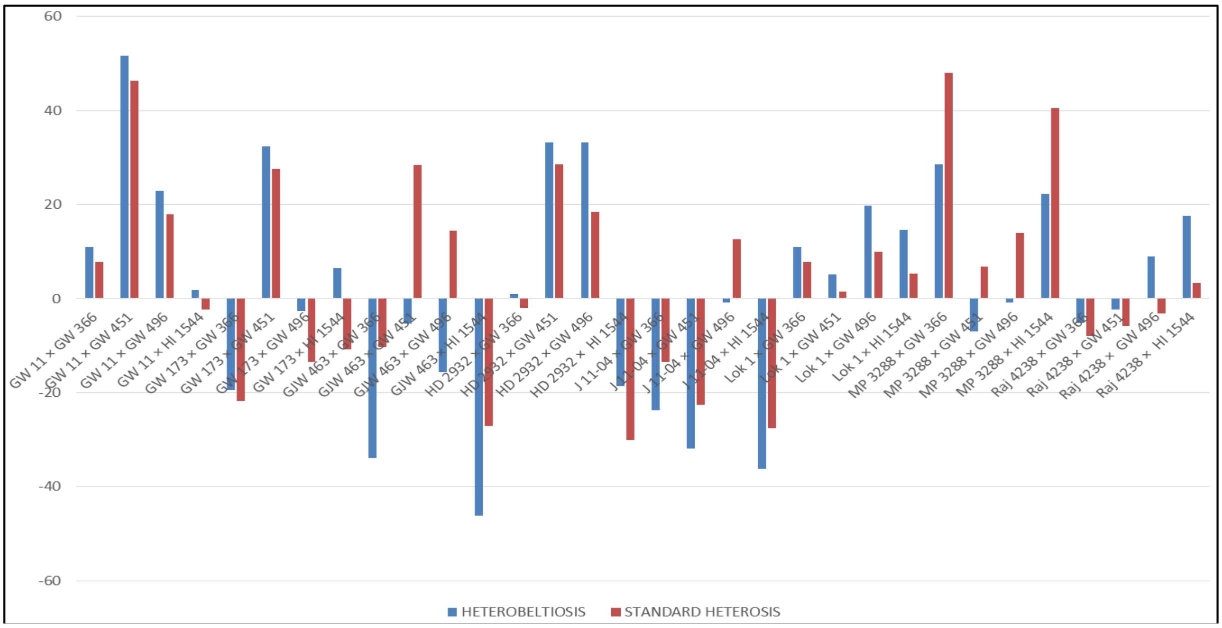
Table 4: Percent heterosis over better parent (H_1) and standard check GW 366 (H_2) for 100-grain weight, grain yield per plant, biological yield per plant and harvest index

Sr No.	Hybrids	100-grain weight		Grain yield per plant		Biological yield per plant		Harvest index	
		H_1	H_2	H_1	H_2	H_1	H_2	H_1	H_2
1	GW 11 × GW 366	8.93	11.57	10.94	7.73	3.68	18.34	-10.24*	-9.13
2	GW 11 × GW 451	-1.06	-6.21	51.74**	46.35**	46.29**	67.28**	4.71	-11.84*
3	GW 11 × GW 496	2.09	-7.20	22.94*	17.89	8.37	23.69	5.10	-4.86
4	GW 11 × HI 1544	-5.38	-8.10	1.76	-2.41	-14.91	-2.88	5.96	0.95
5	GW 173 × GW 366	-11.17	-9.01	-19.39	-21.73*	-18.56	-21.99	-1.20	0.02
6	GW 173 × GW 451	-1.08	-6.23	32.34**	27.64*	7.22	22.6	23.65**	4.02
7	GW 173 × GW 496	-6.09	-18.91**	-2.74	-13.54	-7.81	-9.76	6.20	-3.86
8	GW 173 × HI 1544	-12.38*	-14.90*	6.46	-10.86	-3.88	-15.06	10.12	4.92
9	GJW 463 × GW 366	-8.80	-6.58	-33.97**	-10.38	-21.64	-8.62	-15.42**	-1.64
10	GJW 463 × GW 451	-4.76	-9.72	-5.34	28.49**	9.19	27.32*	-12.29**	2.00
11	GJW 463 × GW 496	-1.66	-15.08*	-15.64*	14.51	1.98	18.91	-17.14**	-3.63
12	GJW 463 × HI 1544	-6.51	-9.21	-46.25**	-27.04*	-37.53**	-27.15*	-13.24**	0.90
13	HD 2932 × GW 366	-6.10	-3.82	0.99	-1.93	-7.68	-10.32	8.22	9.56
14	HD 2932 × GW 451	-7.96	-12.75*	33.24**	28.51**	11.69	27.71*	14.50*	1.25
15	HD 2932 × GW 496	12.13*	-3.17	33.16**	18.37	25.57	22.92	6.53	-3.56
16	HD 2932 × HI 1544	-6.54	-9.23	-18.66	-30.03**	-34.26**	-36.14**	14.83**	9.41
17	J 11-04 × GW 366	-1.48	0.92	-23.80*	-13.50	-29.17**	-7.66	-7.17	-6.02
18	J 11-04 × GW 451	-3.91	-8.91	-31.88**	-22.67*	-39.58**	-21.23	12.77*	-1.59
19	J 11-04 × GW 496	-5.18	-18.12**	-0.85	12.55	-4.40	24.65	-0.40	-9.84
20	J 11-04 × HI 1544	-14.55*	-17.01**	-36.15**	-27.52*	-38.26**	-19.51	-5.13	-9.61
21	Lok 1 × GW 366	13.24*	15.98**	10.96	7.75	18.97	13.95	-10.57*	-4.61
22	Lok 1 × GW 451	5.84	8.32	5.18	1.45	-7.04	6.30	-11.12*	-5.20
23	Lok 1 × GW 496	-3.71	-1.46	19.73	9.90	18.55	16.05	-11.33*	-5.42
24	Lok 1 × HI 1544	-9.65	-7.54	14.70	5.29	12.13	-0.96	-0.61	6.02
25	MP 3288 × GW 366	-6.85	-4.59	28.66**	47.95**	40.07**	58.43**	-7.83	-6.36
26	MP 3288 × GW 451	-10.31	-14.98*	-7.05	6.88	38.33**	58.18**	-33.82**	-32.76**
27	MP 3288 × GW 496	-6.52	-19.28**	-0.86	14.00	-4.50	8.03	3.70	5.36
28	MP 3288 × HI 1544	-1.95	-4.77	22.25*	40.58**	27.94*	44.72**	-4.77	-3.24
29	Raj 4238 × GW 366	4.20	6.73	-5.22	-7.97	-6.81	3.00	-11.72*	-10.63*
30	Raj 4238 × GW 451	-13.38*	-17.89**	-2.33	-5.79	-9.55	3.43	8.80	-8.47
31	Raj 4238 × GW 496	-1.49	-8.92	8.96	-3.14	-4.70	5.34	1.42	-8.19
32	Raj 4238 × HI 1544	-1.40	-4.24	17.61	3.38	-0.89	9.55	-0.36	-5.07
SE±		0.30	0.30	1.46	1.46	4.53	4.53	2.05	2.05
CD at 5%		0.59	0.59	2.91	2.91	9.06	9.06	4.09	4.09

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

Table 5: Range of heterobeltiosis (H_1) and standard heterosis (H_2) for various characters in bread wheat

Sr No.	Characters	Range of heterosis		Number of crosses with significant heterosis			
		H_1 (%)	H_2 (%)	H_1		H_2	
				+ve	-ve	+ve	-ve
1	Days to heading (days)	-8.20 to 18.30	-5.96 to 19.87	15	11	23	6
2	Days to maturity (days)	-2.42 to 13.62	1.44 to 14.03	24	1	31	0
3	Plant height (cm)	-24.91 to 1.95	-18.33 to 6.47	0	20	0	14
4	Number of effective tillers per plant	-46.15 to 39.13	-42.95 to 26.18	13	9	2	12
5	Length of main spike (cm)	-17.89 to 15.37	-4.41 to 30.56	3	5	16	0
6	Number of spikelets per main spike	-15.75 to 15.57	-1.40 to 30.84	4	4	15	0
7	Grain filling period (days)	-23.70 to 15.57	-17.60 to 12.80	10	9	11	10
8	Number of grains per main spike	-16.08 to 13.55	-1.33 to 30.94	6	6	12	0
9	100-grain weight(g)	-14.55 to 13.24	-19.28 to 15.98	2	3	1	9
10	Grain yield per plant (g)	-46.25 to 51.74	-30.03 to 47.95	7	6	6	5
11	Biological yield per plant (g)	-39.58 to 46.29	-36.14 to 67.28	4	5	6	2
12	Harvest index (%)	-33.82 to 23.65	-32.76 to 9.56	4	10	0	3



Conclusion

The highest, positive and significant heterobeltiosis for grain yield per plant and some of its component traits were recorded in the crosses, GW 11 × GW 451, HD 2932 × GW 451 and HD 2932 × GW 496. The cross combinations GW 11 × GW 451 (for days to maturity, number of effective tillers per plant, length of main spike, number of spikelets per main spike, number of grains per main spike, grain yield per plant and biological yield per plant), HD 2932 × GW 451 (number of effective tillers, grain yield per plant and harvest index) and HD 2932 × GW 496 (plant height, number of effective tillers per plant, 100-grain weight and grain yield per plant) exhibited good heterobeltiosis. The highest, positive and significant standard heterosis for grain yield per plant and some of its component traits were recorded in the crosses, MP 3288 × GW 366, GW 11 × GW 451 and MP 3288 × HI 1544. The cross combinations MP 3288 × GW 366 (for plant height, 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, grain yield per plant and biological yield per plant), GW 11 × GW 451 (for number of effective tillers per plant, length of main spike, number of spikelets per main spike, number of grains per main spike, grain yield per plant and biological yield per plant) and MP 3288 × HI 1544 (for length of main spike, number of spikelets per main spike, grain filling period, number of grains per main spike, grain yield per plant and biological yield per plant) exhibited good standard heterosis. Such crosses could be exploited for practical plant breeding programme for obtaining desirable transgressive segregants in F_2 and subsequent generations in bread wheat.

References

1. Ahmad E, Kumar A, Jaiswal JP. Identifying heterotic combinations for yield and quality traits in bread wheat (*Triticum aestivum* L.). Elec. J Pl. Br. 2016; 7(2):352-361.
2. Akbar M, Khan MA, Rehman A, Nadeem A. Heterosis and heterobeltiosis for improvement of wheat grain yield. J Agric. Res. 2005; 45(2):91-97.
3. Bhatiya VJ. Genetics for slow leaf-rusting and yield related traits in bread wheat (*Triticum aestivum* L.). Unpublished Ph.D. (Agri.) thesis submitted to Junagadh Agricultural University, Junagadh, 2006.
4. Bilgin O, Balkan A, Korkut KZ. Heterotic and heterobeltiotic potentials of bread wheat (*Triticum aestivum* L.) hybrids for yield and yield components. J Tekirdang Agril. Faculty. 2011; 8(2):133-142.
5. Das NR. Wheat crop management. Scientific Publication, Jodhpur, 2008.
6. Desale CS, Mehta DR. Heteosis and combining ability analysis for grain yield and quality traits in bread wheat (*Triticum aestivum* L.). Elec. J Pl. Br. 2013; 4(3):1205-1213.

7. Fonseca S, Patterson FL. Hybrid vigour in a seven parents diallel cross in common winter wheat (*Triticum aestivum* L.). Crop Sci. 1968; 8(1):85-88.
8. Gul S, Aziz MK, Ahmad RI, Liaqat S, Rafiq M, Hussain F. *et al*. Estimation of heterosis and heterobeltiosis in wheat (*Triticum aestivum* L.) crosses. Basic Res. J Agric. Sci. 2015; 4(5):151-157.
9. Hassan M, Saeidi G, Rezai A. Estimation of genetic parameters and combining ability for yield and yield components in bread wheat. J Sci. Technol. Agri. Natural Resources. 2005; 9(2):157-171.
10. Kalimullah. Heterosis of certain important yield components in the population of wheat (*Triticum aestivum* L.) crosses. Elec. J Pl. Br. 2011; 2(2):239-243.
11. Kamani JM. Heterosis, combining ability and stability over environments in bread wheat (*Triticum aestivum* L.). Unpublished Ph.D. (Agri.) thesis submitted to Junagadh Agricultural University, Junagadh, 2009.
12. Kant L, Mani VP, Gupta HS. Winter × spring wheat hybridization – a promising avenue for yield enhancement. Pl. Br. 2001; 120(3):255-258.
13. Kumar A, Mishra VK, Vyas RP, Singh V. Heterosis and combining ability analysis in bread wheat (*Triticum aestivum* L.). J Pl. Br. and Crop Sci. 2011; 3(10):209-217.
14. Lal C, Kumar V, Maloo SR. Heterosis and inbreeding depression for some quantitative and heat tolerant characters in bread wheat (*Triticum aestivum* L.). J Wheat Res. 2013; 5(2):52-55.
15. Lamalakshmi Devi E, Swati Goel P, Singh M, Jaiswal JP. Heterosis studies for yield and yield contributing traits in bread wheat (*Triticum aestivum* L.). The Bioscan: Int. J Life sci. 2013; 8(3):905-909.
16. Lupton FGH. Wheat Breeeding: Its Scientific Basis. Chapman and Hall Ltd. London. 1987.
17. Patel D, Moitra PK, Shukla RS, Singh SK. Heterosis and combining ability estimates in partial diallel crosses of bread wheat (*Triticum aestivum* L.). Trends in Biosci. 2015; 8(19):5321-5329.
18. Prasad KD, Haque MF, Ganguli DK. Heterosis studies for yield and its components in bread wheat (*Triticum aestivum* L.). Ind. J Genet. 1998; 58(1):97-100.
19. Rahul SR. Combining ability and heterosis for morpho-physiological characters on bread wheat (*Triticum aestivum* L.). Agril. Res. & Tech. 2017; 13(1):1-8.
20. Rathod SK. Genetic architecture of grain yield and its important components in bread wheat (*Triticum aestivum* L.). Unpublished M.Sc. (Agri.) thesis submitted to Gujarat Agricultural University, Sardar krushinagar, 2003.
21. Singh J, Garg DK, Raje RS. Heterosis, combining ability and gene action for grain yield and its components under high temperature environment in bread wheat (*Triticum aestivum* L.). Ind. J Genet. 2007; 67(2):193-195.
22. Singh M, Lamalakshmi devi E, Aglawe S, Kousar N, Behera C. Estimation of heterosis in different crosses of bread wheat (*Triticum aestivum* L.). The Bioscan: Int. J Life Sci. 2013; 8(4):1393-1401.
23. Thomas N, Marker S, Lal GM, Dayal A. Study of heterosis for grain yield and its components in wheat (*Triticum aestivum* L.) over normal and heat stress condition. J. Pharma. and Phytochem. 2017; 6(4):824-830.
24. Vanpariya LG, Chovatia VP, Mehta DR. Heterosis for grain yield and its attributes in bread wheat (*Triticum aestivum* L.). National J. Pl. Improv. 2006; 8(2):100-102.