# HETEROSIS STUDIES FOR YIELD AND ITS COMPONENTS IN BREAD WHEAT (*Triticum aestivum* L.) OVER ENVIRONMENTS

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***ABSTRACT***

***A set of diallel crosses involving 9 parents was made to measure the extent of heterosis over better parent and standard heterosis for yield and yield contributing characters under three different environments. The analysis of variance for genotypes, parents and hybrids indicated the existence of considerable amount of genetic variability amongst genotypes, parents and hybrids for seed yield per plant and most of the characters under study. The comparison of parents vs. hybrids across the environments, in general, revealed the existence of heterosis. The interaction of genotypes with the environments indicates the non-linear response of the genotypes to the change in the environment. No specific consistency was observed with regards to heterosis for grain yield and yield component in different crosses. On pooled basis, four hybrids over better parent and one hybrid over standard check variety exhibited significant and positive heterosis. NW 5013 × BW 5872 in $E_1$, PHSC 5 × GW 2010-287, DBW 90 × BW 5872 and NW 5013 × QLD 65 in $E_2$, NW 5013 × QLD 65, DBW 90 × GW 2010-287, PHSC 5 × GW 2010-287 and DBW 90 × BW 5872 in $E_3$ and PHSC 5 × GW 2010-287 in pooled results were the best significant and positive cross combinations with respect to standard heterosis for grain yield per plant.***

***KEY WORDS: Bread wheat, Hetreobeltiosis, Standard heterosis***

## INTRODUCTION

Wheat (*Triticum spp.*) is usually accorded a premier place among the cereals because of the vast acreage devoted to its cultivation, its high nutritive value and its association with some of the earliest and most important civilization of the world. Wheat is one of the most important staple food crops of the world, feeding about 40 per cent of the world population and providing 20 per cent of total food calories and protein in human nutrition (Gupta *et al*., 2008). Wheat is a major contribute to the food security system in India as well, occupying nearly area 30.23 million hectare during 2015-16, producing 93.50 million tonnes of wheat with the productivity of 3093 kg/ha (Anon., 2016a). State wise analysis indicated that Uttar Pradesh has maximum area and production under wheat followed by Punjab and Madhya Pradesh. In Gujarat, during 2015-16, wheat is grown in about 0.85 million ha with total production of 2.48 million tonnes and a productivity of 2919 kg/ha (Anon., 2016b).

The magnitude of heterosis is associated with heterozygosity, because the dominance variance is associated with heterozygosity. The commercial exploitation of heterosis in wheat has limited application because of practical difficulties of hybrid seed production in sufficient quantity. However, the discovery of male sterility and genes which restore fertility (Wilson and Ross, 1962; Schmidt *et al.,* 1970) and the use of chemical hybridizing agents (CHAS) which act as gametocides (Borghi *et al.,* 1988; Morgan *et al.,* 1989) have encouraged many workers to examine first generation progeny yield in wheat. A good progress have been archived in the development of hybrid wheat varieties and several varieties are under testing hence, the knowledge of heterosis would help in determination of parents which produce the best cross combinations. The nature and magnitude of heterosis will also help in identifying superior cross combinations that may produce desirable transgressive segregants in the advanced generations.

## MATERIALS AND METHODS

The experimental materials comprised of nine parents (NW 5013, DBW 90, PHSC 5, GW 2010-287, BW 5872, QLD 65, QLD 46, RAJ 4238 and GW 496), their thirty-six $F_1$ hybrids and one standard check variety GW 366 were evaluated in three different environments [Early ($25^{th}$ October), timely ($15^{th}$ November) and late sowing ($5^{th}$ December)] designated as environment I ($E_1$), environment II ($E_2$) and environment III ($E_3$), respectively, in randomized block design with three replications during *rabi* 2016-17 at Sagadividi Farm, Department of Seed Science and Technology, College of Agriculture, Junagadh Agricultural University, Junagadh. Five competitive plants per genotype in each replication in each environment were selected randomly for recording observations on different characters *viz.,* plant height (cm), number of effective tillers per plant, length of main spike (cm), peduncle length of main spike (cm), number of spikelets per main spike, number of grains per main spike, grain weight per main spike (g), 1000 grain weight (g), grain yield per plant (g), biological yield per plant (g) and harvest index (%), while observations on days to heading, grain filling period and days to maturity were recorded on plot basis. The mean of each plot was used for statistical analysis. Analysis of variance for all the characters in each environment was done as suggested by Panse and Sukhatme (1985). The standard heterosis (SH%) and heterobeltiosis (HB%) were estimated as deviation of $F_1$ value from the better-parent and standard heterosis values as suggested by Fonseca and Patterson (1968) and Meredith and Bridge (1972), respectively.

## RESULTS AND DISCUSSION

Analysis of variance for individual environment as well as pooled over environments was carried out to test the difference among parents and hybrids for 14 different quantitative characters. The data presented in Table 1 indicated that mean sum of squares due to genotypes were significant for all the traits in all the environments, except for days to maturity, peduncle length of main spike and number of spikelets per main spike in environment I ($E_1$); for number of effective tillers per plant, length of main spike, peduncle length of main spike, number of grains per main spike, grain weight per main spike and biological yield per plant in environment II ($E_2$); and for peduncle length of main spike and number of spikelets per main spike in environment III ($E_3$). Further, partitioning of the genotypic mean sum of squares into parents and hybrids evinced that mean sum of squares due to parents were significant for all the traits in all the environments, except for days to maturity, number of effective tillers per plant, peduncle length of main spike, number of spikelets per main spike and number of grains per main spike in $E_1$; for days to heading, grain filling period, plant height, number of effective tillers per plant, length of main spike, peduncle length of main spike, number of spikelets per main spike, number of grains per main spike, grain weight per main spike, biological yield per plant and harvest index in $E_2$; and for grain filling period, plant height, peduncle length of main spike and number of spikelets per main spike in $E_3$. Mean sum of squares due to hybrids were significant for all the traits in all the environments, except for days to maturity, peduncle length of main spike and number of spikelets per main spike in $E_1$; for days to heading, number of effective tillers per plant, length of main spike, peduncle length of main spike, number of grains per main spike, grain weight per main spike and biological yield per plant in $E_2$; and for number of spikelets per main spike in $E_3$. These results indicated the existence of considerable amount of genetic variability amongst genotypes, parents and hybrids for seed yield per plant and most of the characters under study. Similarly, mean sum of squares due to parents *vs*. hybrids were significant for days to heading and 1000 grain weight in all the three environments, while days to maturity, grain yield per plant, biological yield per plant and harvest index in $E_3$; for plant height and length of main spike in $E_2$ and $E_3$; and for number of effective tillers per plant and grain weight per main spike in $E_1$ and $E_2$ were found significant, indicated that the performance of parents was different from that of crosses, thereby, suggesting the presence of mean heterosis for all these characters.

Pooled analysis of variance over environments (Table 2) exhibited significant differences among genotypes, parents and hybrids for all the characters, except number of spikelets per main spike and number of grains per main spike for parents, which revealed the influence of environment on the expression of these characters and also the wide diversity among the parents. The comparison of parents vs. hybrids was found significant for all the characters, except for grain filling period, peduncle length of main spike, number of spikelets per main spike, number of grains per main spike and harvest index, which, in general, revealed the existence of heterosis. The interaction of genotypes with the environments was significant for all the characters, except peduncle length of main spike and number of spikelets per main spike, indicates the non-linear response of the genotypes to the change in the environment. This is in compliance with the general belief that the genotypes x environment interactions are common in crop plant species (Allard and Bradshaw, 1964). Sprague and Federer (1951) suggested that the biasness caused by genotype x environment interaction in the estimates of genetic parameters is of unknown magnitude and direction and it may not be same for each parameter. The parents x environments interaction was significant for days to heading, grain weight per main spike, 1000 grain weight, grain yield per plant, biological yield per plant and harvest index, which indicated that the performance of parents was not consistent over environments for these traits. The interactions of hybrids with the environments were significant for all the characters, except peduncle length of main spike and number of spikelets per main spike, suggesting that hybrids interacted significantly with different environments for all the traits, except for peduncle length of main spike and number of spikelets per main spike. Parents *vs*. hybrids x environments interaction were found significant for plant height, length of main spike, grain yield per plant and harvest index, indicates substantial amount of hybrid vigour in the crosses for these traits and the crosses performed differentially in different environments.

With respect to heterobeltiosis recorded for different cross combinations for grain yield per plant, it was observed that DBW 90 × GW 496 (24.30 %) in $E_1$ and DBW 90 × GW 2010-287 (35.96 %) and PHSC 5 × GW 2010-287 (17.61 %) in $E_2$ were the best significant and positive heterobeltiotic cross combinations for grain yield per plant, while total of 10 and 4 cross combinations exhibited significant and positive heterobeltiosis for grain yield per plant in $E_3$ and pooled over environments, respectively, of which the best three cross combinations were DBW 90 × BW 5872 (70.87 %), Raj 4238 × GW 496 (37.10 %) and BW 5872 × QLD 65 (35.76 %) in $E_3$; and DBW 90 × GW 2010-287 (25.48 %), DBW 90 × BW 5872 (24.41 %) and GW 2010-287 × BW 5872 (20.22 %) in pooled over environments (Table 4). The heterobeltiosis for grain yield per plant ranged in between -31.30 per cent (PHSC 5 × Raj 4238) to 24.30 per cent (DBW 90 × GW 496) in $E_1$, -36.03 per cent (NW 5013 × GW 496) to 35.96 per cent (DBW 90 × GW 2010-287) in $E_2$, -21.75 per cent (NW 5013 × GW 2010-287) to 70.87 per cent (DBW 90 × BW 5872) in $E_3$ and -23.72 per cent (PHSC 5 × Raj 4238) to 25.48 per cent (DBW 90 × GW 2010-287) in pooled over environments (Table 3).

The overall performance of hybrids over three environments for grain yield per plant indicated that four cross combinations showed significant positive heterosis over better parent. The top ranked cross combination across the environments with respect to *per se* performance PHSC 5 × GW 2010-287 noted the significant and desirable heterobeltiosis in $E_2$ and $E_3$, but it had non-significant but desirable heterobeltiosis in pooled over environments. The highest and significant heterobeltosis of 25.48 per cent across the environments for grain yield per plant was recorded by the hybrid DBW 90 × GW 2010-287. This hybrid also exhibited significant heterosis over better parent in $E_2$ and $E_3$ environment and non-significant, but desirable heterobeltiosis in $E_1$. The second most heterotic hybrid for hrain yield per plant over better parent [DBW 90 × BW 5872 (24.41 %)] also noted significant heterosis over better parent in $E_3$ environment and non-significant, but desirable heterobeltiosis in $E_1$ and $E_2$. The third ranked hybrid GW 2010-287 × BW 5872 manifested significant and positive heterobeltiosis (20.22 %) noted non-significant, but positive heterobeltiosis in all three individual environments. On pooled basis, one hybrid each for days to maturity and length of main spike registered significant heterobeltosis in desired direction, while for rest of the traits studied, none of the hybrid manifested significant desirable heterobeltiosis. In individual environment as well as on pooled basis, it was observed that majority of hybrids exhibited low heterobeltosis for grain yield per plant as well as for important yield contributing characters. The results are in accordance with the results reported by Bilgin *et al*. (2011), Yao *et al.* (2011), Lal *et al.* (2013), Kalhoro *et al.* (2015) and Baloch *et al.* (2016) in wheat.

With respect to standard heterosis, NW 5013 × BW 5872 (22.14 %) in $E_1$, PHSC 5 × GW 2010-287 (24.31 %), DBW 90 × BW 5872 (19.38 %) and NW 5013 × QLD 65 (16.27 %) in $E_2$, NW 5013 × QLD 65 (20.18 %), DBW 90 × GW 2010-287 (20.18 %), PHSC 5 × GW 2010-287 (17.96 %) and DBW 90 × BW 5872 (16.95 %) in $E_3$ and PHSC 5 × GW 2010-287 (18.00 %) in pooled results were the best significant and positive cross combinations for grain yield per plant (Table 4). The standard heterosis for grain yield per plant ranged in between -18.22 per cent (QLD 46 × Raj

4238) to 22.14 per cent (NW 5013 × BW 5872) in $E_1$, -34.64 per cent (NW 5013 × GW 496) to 24.31 per cent (PHSC 5 × GW 2010-287) in $E_2$ , -27.13 per cent (PHSC 5 × GW 496) to 20.18 per cent (DBW 90 × GW 2010-287) in $E_3$ and -20.19 per cent (PHSC 5 × Raj 4238) to 18.00 per cent (PHSC 5 × GW 2010-287) in pooled over environments (Table 3).

The top ranked cross combination across the environments with respect to *per se* performance PHSC 5 × GW 2010-287 noted the significant and desirable standard heterosis in $E_2$, $E_3$ and pooled over environments, but it manifested non-significant and desirable standard heterosis in $E_1$. On pooled basis, two cross combinations each for days to heading and days to maturity and one cross combination for 1000 grain weight registered significant standard heterosis in desired direction, while for rest of the traits studied, none of the cross combination manifested significant desirable standard heterosis. In individual environment as well as on pooled basis, it was observed that majority of hybrids exhibited low to moderate standard heterosis for grain yield per plant as well as for important yield contributing characters. As observed in the present study, Bilgin *et al*. (2011), Patil *et al.* (2011), Singh *et al.* (2012), Desale and Mehta (2013), Barot *et al.* (2014), Kalhoro *et al.* (2015) and Baloch *et al.* (2016) also reported the presence of considerable heterosis for grain yield per plant and some of the important yield components in bread wheat.

From commercial cultivation point of view, the superiority of new hybrid should be judged by comparing their performance with the best cultivated variety/hybrid. Variety GW 366 released for general cultivation in Gujarat was, therefore, used as the standard check in order to obtain information regarding superiority of new hybrids. The top ten cross combinations across the environments with respect to *per se* performance for grain yield per plant are listed in Table 5 along with their values of heterobeltosis, standard heterosis, sca effects as well as component traits showing significant as well as non-significant, but desirable heterosis over better parent and standard check variety GW 366. Out of 36 cross combinations tested, only 1 cross combination PHSC 5 × GW 2010-287 found superior then GW 366 in respect of grain yield per plant, as it manifested significant standard heterosis across the environments for grain yield per plant along with significant sca effect. However, this cross combination does not manifested significant standard heterosis in desired direction for any of the yield components, but noted the desirable heterosis for days to heading, days to maturity, length of main spike, peduncle length of main spike, number of spikelets per main spike, number of gains per main spike, grain weight per main spike, 1000 grain weight, biological yield per plant and harvest index. As discussed earlier, this cross combination also noted the significant and desirable standard heterosis in $E_2$ and $E_3$ environments and non-significant but desirable standard heterosis in $E_1$ for grain yield per plant. This cross combination also exhibited significant and desirable standard heterosis for number of effective tillers per plant, length of main spike and grain weight per main spike in $E_1$, for days to heading in $E_2$ and for days to maturity and harvest index in $E_3$. The data given in Table 5 also revealed that cross combinations GW 2010-287 × QLD 65 and GW 2010-287 × BW 5872 manifested the significant and desirable heterosis over standard check GW 366 for days to maturity and 1000 grain weight, respectively. However, all the ten hybrids manifested desirable but non-significant standard heterosis for many of the yield components.

## CONCLUSION

From the results and discussion, it can be concluded that no specific consistency was observed with regards to heterosis for grain yield and yield component in different crosses in bread wheat. DBW 90 × GW 496 (24.30 %) in $E_1$ and DBW 90 × GW 2010-287 (35.96 %) and PHSC 5 × GW 2010-287 (17.61 %) in $E_2$ were the best significant and positive heterobeltiotic cross combinations for grain yield per plant, while total of 10 and 4 cross combinations exhibited significant and positive heterobeltiosis for grain yield per plant in $E_3$ and pooled over environments, of which the best three cross combinations were DBW 90 × BW 5872 (70.87 %), Raj 4238 × GW 496 (37.10 %) and BW 5872 × QLD 65 (35.76 %) in $E_3$; and DBW 90 × GW 2010-287 (25.48 %), DBW 90 × BW 5872 (24.41 %) and GW 2010-287 × BW 5872 (20.22 %) in pooled over environments. With respect to standard heterosis, NW 5013 × BW 5872 (22.14 %) in $E_1$, PHSC 5 × GW 2010-287 (24.31 %), DBW 90 × BW 5872 (19.38 %) and NW 5013 × QLD 65 (16.27 %) in $E_2$, NW 5013 × QLD 65 (20.18 %), DBW 90 × GW 2010-287 (20.18 %), PHSC 5 × GW 2010-287 (17.96 %) and DBW 90 × BW 5872 (16.95 %) in $E_3$ and PHSC 5 × GW 2010-287 (18.00 %) in pooled results were the best significant and positive cross combinations for grain yield per plant. Overall, PHSC 5 × GW 2010-287 noted the significant and desirable standard heterosis in $E_2$, $E_3$ and pooled over environments, but it manifested non-significant and desirable standard heterosis in $E_1$. Therefore, this cross could be exploited further for yield advancement in bread wheat.

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**Table 1: Analysis of variance for different characters in individual environments in Wheat**

| Characters | Env. | Replications (2) | Genotypes (44) | Parents (8) | $F_1$s (35) | Parent *vs* $F_1$s (1) | Error (88) |
|---|---|---|---|---|---|---|---|
| Days to heading | $E_1$ | 8.49 | 58.88** | 55.14** | 59.93** | 52.26** | 3.79 |
| | $E_2$ | 32.81** | 19.48** | 10.62 | 22.02 | 1.45** | 5.8 |
| | $E_3$ | 33.21** | 59.61** | 74.58** | 57.18** | 24.92* | 5.65 |
| Days to maturity | $E_1$ | 84.69** | 14.63 | 17.83 | 14.3 | 0.27 | 12.07 |
| | $E_2$ | 27.34 | 45.34** | 59.81** | 42.98** | 12.15 | 17.46 |
| | $E_3$ | 4.59 | 28.16** | 21.17** | 28.47** | 73.34** | 5.43 |
| Grain filling | $E_1$ | 125.98** | 20.85** | 22.45* | 21.06** | 0.82 | 10.14 |
| | $E_2$ | 46.02 | 67.82** | 44.79 | 74.88** | 5.2 | 26.87 |
| | $E_3$ | 24.22 | 61.42** | 17.14 | 72.82** | 16.02 | 10.08 |
| Plant height (cm) | $E_1$ | 131.66** | 56.52** | 38.97** | 62.14** | 0.0002 | 13.92 |
| | $E_2$ | 2.24 | 126.95** | 23.89 | 120.25** | 1186.07** | 17.93 |
| | $E_3$ | 132.37** | 82.92** | 25.84 | 88.85** | 332.29** | 21.39 |
| Number of effective tiilers/plant | $E_1$ | 1.29 | 1.59** | 0.81 | 1.69** | 4.18** | 0.47 |
| | $E_2$ | 1.70 | 0.86 | 0.57 | 0.79 | 5.58* | 1.17 |
| | $E_3$ | 3.71** | 2.90** | 1.92** | 3.21** | 0.003 | 0.32 |
| Length of main spike (cm) | $E_1$ | 4.40** | 4.13** | 3.59** | 4.37** | 0.1 | 0.59 |
| | $E_2$ | 0.14 | 1.43 | 1.71 | 1.11 | 10.42* | 1.55 |
| | $E_3$ | 8.22** | 3.41** | 3.23** | 3.29** | 9.23** | 0.67 |
| Peduncle length of main spike | $E_1$ | 83.28** | 13.08 | 9.01 | 14.16 | 7.89 | 9.69 |
| | $E_2$ | 91.12** | 12.31 | 23.09 | 9.01 | 41.61 | 13.25 |
| | $E_3$ | 118.01** | 13.07 | 8.84 | 14.40* | 0.35 | 8.9 |
| Number of spikelets/ main spike | $E_1$ | 23.87** | 2.04 | 1.87 | 2.12 | 0.76 | 1.66 |
| | $E_2$ | 46.47** | 8.90** | 5.2 | 9.94** | 2.31 | 4.91 |
| | $E_3$ | 18.25** | 2.47 | 2.40 | 2.47 | 3.02 | 2.32 |
| Number of grains/main spike | $E_1$ | 42.99* | 29.39** | 13.16 | 32.87** | 37.76 | 13.1 |
| | $E_2$ | 52.27 | 17.33 | 7.89 | 19.95 | 1.49 | 21.29 |
| | $E_3$ | 50.84 | 58.49** | 58.38** | 58.99** | 42.00 | 16.76 |
| Grain weight/main spike (g) | $E_1$ | 0.03 | 0.09** | 0.10** | 0.08** | 0.36** | 0.02 |
| | $E_2$ | 0.16* | 0.18 | 0.09 | 0.2 | 0.17** | 0.05 |
| | $E_3$ | 0.06 | 0.13** | 0.11** | 0.13** | 0.02 | 0.04 |
| 1000-grain weight | $E_1$ | 8.19* | 38.72** | 40.24** | 35.21** | 149.31** | 2.46 |
| | $E_2$ | 52.37** | 48.72** | 31.81** | 51.25** | 95.31** | 2.84 |
| | $E_3$ | 5.38 | 32.41** | 17.42** | 33.75** | 105.58** | 2.72 |
| Grain yield/plant (g) | $E_1$ | 0.65 | 6.79** | 6.08* | 7.14** | 0.38 | 2.47 |
| | $E_2$ | 5.96 | 15.34** | 11.32** | 16.63** | 2.6 | 3.22 |
| | $E_3$ | 18.18** | 17.96** | 13.35** | 16.21** | 115.93** | 2.91 |
| Biological yield/plant (g) | $E_1$ | 115.88** | 81.86** | 68.55** | 87.23** | 0.39 | 10.71 |
| | $E_2$ | 12.96 | 16.18 | 16.19 | 15.77 | 30.35 | 25.44 |
| | $E_3$ | 401.94** | 64.07** | 88.60** | 56.80** | 122.30** | 16.58 |
| Harvest index (%) | $E_1$ | 131.53* | 193.60** | 159.39** | 206.91** | 1.28 | 36.19 |
| | $E_2$ | 9.15 | 62.47** | 46.35 | 66.07** | 65.49 | 34.43 |
| | $E_3$ | 128.91* | 161.46** | 286.09** | 131.85** | 200.60* | 33.78 |

***Note: Figure in the parenthesis indicates the degree of freedom***

**Table 2: Analysis of variance for different characters pooled over environments in wheat**

| Source of variation | d.f. | CHARACTERS | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | **Days to heading** | **Grain filling period** | **Days to maturity** | **Plant height (cm)** | **Number of effective tillers per plant** | **Length of main spike (cm)** | **Peduncle length of main spike (cm)** |
| Replication within environments | 6 | 24.84** | 72.68** | 38.87** | 88.76** | 2.23** | 4.25** | 97.47** |
| Environments (E) | 2 | 5536.69** | 1725.67** | 2827.03** | 805.79** | 256.65** | 49.47** | 1639.48** |
| Genotypes (G) | 44 | 46.22** | 96.46** | 38.08** | 129.51** | 2.11** | 5.35** | 24.46** |
| Parents (P) | 8 | 54.61** | 76.37** | 60.75** | 42.89* | 1.43* | 6.09** | 28.59** |
| Hybrids (H) | 35 | 43.92** | 103.68** | 32.48** | 126.58** | 2.14** | 4.99** | 23.29** |
| P *vs*. H | 1 | 60.09** | 4.46 | 52.63* | 925.13** | 6.30** | 11.81** | 32.36 |
| G x E | 88 | 45.88** | 30.02* | 25.02** | 68.44** | 1.62** | 1.82** | 7.00 |
| P x E | 16 | 42.87** | 17.83 | 19.03 | 22.90 | 0.93 | 1.22 | 6.18 |
| H x E | 70 | 47.61** | 33.57** | 26.64** | 72.33** | 1.78** | 1.89** | 7.14 |
| P *vs*. H x E | 2 | 9.27 | 3.38 | 16.56 | 296.62** | 1.73 | 3.97* | 8.75 |
| Environments pooled error | 264 | 5.08 | 21.30 | 11.65 | 17.75 | 0.65 | 0.94 | 10.61 |

*Table 2: Contd…*

| Source of variation | d.f. | Characters | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Number of spikelets per main spike | Number of grains per main spike | Grain weight per main spike (g) | 1000 grain weight (g) | Grain yield per plant (g) | Biological yield per plant (g) | Harvest index (%) |
| Replication within environments | 6 | 29.52** | 48.70* | 8.31* | 21.98** | 8.26** | 176.93** | 89.87* |
| Environments (E) | 2 | 224.82** | 11551.29** | 2944.34** | 482.76** | 227.33** | 3537.25** | 616.76** |
| Genotypes (G) | 44 | 7.97** | 52.57** | 21.63** | 66.55** | 20.46** | 41.23** | 130.80** |
| Parents (P) | 8 | 4.62 | 31.93 | 15.62** | 36.92** | 14.41** | 39.14* | 139.89** |
| Hybrids (H) | 35 | 8.80** | 58.76** | 22.38** | 65.32** | 21.73** | 40.07** | 132.23** |
| P *vs*. H | 1 | 5.68 | 0.81 | 43.41** | 346.84** | 24.31** | 98.49* | 8.14 |
| G x E | 88 | 2.73 | 26.33** | 8.73** | 26.65** | 9.82** | 60.44** | 143.36** |
| P x E | 16 | 2.42 | 23.75 | 7.27** | 26.27** | 8.17** | 67.10** | 175.97** |
| H x E | 70 | 2.87 | 26.52** | 9.15** | 27.44** | 9.12** | 59.87** | 136.30** |
| P *vs*. H x E | 2 | 0.20 | 40.22 | 5.61 | 1.68 | 47.29** | 27.28 | 129.62* |
| Environments pooled error | 264 | 2.96 | 17.05 | 3.49 | 2.67 | 2.86 | 17.57 | 34.80 |

**** and ** significant at 5 and 1 per cent levels of significance, respectively***

**Table 3: Range of heterosis for 14 quantitative traits in three different environments in bread wheat**

| Characters | Range of heterosis (%) | | | | | |
|---|---|---|---|---|---|---|
| | Heterobeltosis (BP) | | | Standard check (SC) | | |
| | $E_1$ | $E_2$ | $E_3$ | $E_1$ | $E_2$ | $E_3$ |
| **Days to heading** | -24.99 to 32.37 | -8.39 to 11.32 | -17.34 to 28.19 | -27.35to 18.75 | -12.73 to 9.09 | -16.79 to 22.15 |
| **Days to maturity** | -4.33 to 9.61 | -7.12 to 8.75 | -12.90 to 4.67 | -8.53 to 3.28 | -10.06 to 6.10 | -11.22 to 1.61 |
| **Grain filling period** | -21.86 to 15.23 | -37.66 o 24.39 | -34.53 to 13.11 | -16.96to 16.98 | -27.81 o 18.81 | -31.58 to 9.79 |
| **Plant height (cm)** | -14.11 to 33.78 | -9.94 to 34.83 | -10.38 to 40.10 | -16.69 o 19.85 | -23.91to 12.05 | -7.54 to 39.35 |
| **Number of effective tillers per plant** | -14.78 to 19.69 | -12.68 to 9.73 | -27.01 to 16.51 | -19.49 o 14.40 | -8.83 to 8.83 | -21.61 to 21.72 |
| **Length of main spike (cm)** | -28.76 to 30.27 | -12.16to 23.09 | -27.96 to 43.59 | -17.05to 20.45 | -12.4 to 12.83 | -22.84 to 21.37 |
| **Peduncle length of main spike (cm)** | -24.48 to 18.72 | -16.69to 17.11 | -24.55 to 13.92 | -17.01to 22.15 | -14.16to 14.59 | -20.57 to 14.91 |
| **Number of spikelts per spike** | -13.18 to 12.98 | -27.83to 22.17 | -16.12 to 14.25 | -13.18 to 9.94 | -26.09to 15.92 | -9.80 to 11.41 |
| **Number of grains per spike** | -21.92 to 12.08 | -9.55 to 9.15 | -30.16 to 29.38 | 0.00 to 43.69 | -11.25 to 8.19 | -22.88 to 19.17 |
| **Grain weight per spike** | -35.47 to 10.42 | -34.98to 12.97 | -29.53 to 29.93 | -13.93to 36.07 | -31.05to 10.89 | -23.81 to 22.02 |
| **1000-grain weight (g)** | -25.84 to 6.27 | -33.45to 12.56 | -33.74 to 13.96 | -16.58to 13.81 | -26.68 to 6.91 | -26.97 to 15.63 |
| **Biological yield per plant (g)** | -32.93 to 32.66 | -13.96to 16.42 | -21.90 to 48.96 | -21.88to 33.50 | -9.48 to 14.17 | -21.39 to 23.60 |
| **Grain yield per plant (g)** | -31.30 to 24.30 | -36.0 to 35.96 | -21.75 to 70.87 | -18.22to 22.14 | -34.64to 24.31 | -27.13 to 20.18 |
| **Harvest index (%)** | -48.43 to 35.78 | -35.50to 19.95 | -45.00 to 70.80 | -38.46to 53.00 | -30.9 to 19.42 | -37.94 to 38.26 |

**Table 4:Estimates of per cent heterosis over better parent and standard check in individual and pooled over environments for grain yield per plant (g) in bread wheat**

| Sr. No. | Hybrid | $E_1$ | | $E_2$ | | $E_3$ | | Pooled | |
|---|---|---|---|---|---|---|---|---|---|
| | | BP | SH | BP | SH | BP | SH | BP | SH |
| 1. | NW 5013 × DW 90 | 8.04 | 13.03 | 1.55 | 3.76 | 13.55 | 5.39 | 7.47 | 7.06 |
| 2. | NW 5013 × PHSC 5 | -23.49** | -8.69 | -5.94 | -0.59 | -18.71* | -24.55** | -15.23 | -11.31 |
| 3. | NW 5013×GW 2010-287 | -21.43** | -17.80 | -8.74 | -6.75 | **-21.75*** | -23.95** | -15.68 | -16.00 |
| 4. | NW 5013 × BW 5872 | 16.74 | **22.14*** | -2.96 | 2.17 | -11.42 | -17.78* | 1.57 | 1.19 |
| 5. | NW 5013 × QLD 65 | -13.80 | -9.81 | 6.05 | 16.27* | 29.48** | **20.18*** | 3.78 | 9.87 |
| 6. | NW 5013 × QLD 46 | -3.75 | 0.70 | 5.34 | 7.63 | -1.91 | -7.60 | 0.63 | 0.25 |
| 7. | NW 5013 × Raj 4238 | -16.85* | -12.19 | -15.27 | -7.81 | 9.87 | 1.98 | -5.33 | -5.69 |
| 8. | NW 5013 × GW 496 | -6.43 | -2.10 | **-36.03**** | **-34.64**** | -8.39 | -14.97 | -17.82* | -18.13* |
| 9. | DW 90 × PHSC 5 | -27.60** | -13.59 | -18.89* | -14.27 | -18.88* | -26.17** | -21.80* | -18.19* |
| 10. | DW 90 × GW 2010-287 | 9.14 | 6.31 | **35.96**** | 12.33 | 23.66** | **20.18*** | **25.48**** | 13.25 |
| 11. | DW 90 × BW 5872 | 0.22 | -3.29 | 13.39 | 19.38** | **70.87**** | 16.95* | 24.41* | 11.81 |
| 12. | DW 90 × QLD 65 | -2.81 | -10.30 | -9.32 | -0.59 | 13.91 | -5.39 | 1.81 | -5.13 |
| 13. | DW 90 × QLD 46 | -18.75** | -18.01 | -7.73 | -6.81 | -6.10 | -11.56 | -10.58 | -11.81 |
| 14. | DW 90 × Raj 4238 | -3.98 | 1.40 | -13.28 | -5.64 | 1.72 | -18.56* | -6.07 | -8.06 |
| 15. | DW 90 × GW 496 | **24.30**** | 14.72 | 1.98 | 2.58 | 30.40** | -1.38 | 17.77 | 4.81 |
| 16. | PHSC 5 × GW 2010-287 | -7.40 | 10.51 | 17.61* | **24.31**** | 21.38* | 17.96* | 12.78 | **18.00*** |
| 17. | PHSC 5 × BW 5872 | -26.60** | -12.40 | -12.22 | -7.22 | 19.28* | 8.56 | -7.53 | -3.25 |
| 18. | PHSC 5 × QLD 65 | -6.46 | 11.63 | -15.00 | -6.81 | -4.61 | -13.17 | -7.83 | -3.56 |
| 19. | PHSC 5 × QLD 46 | -26.19** | -11.91 | -7.06 | -1.76 | 13.99 | 7.37 | -5.97 | -1.63 |
| 20. | PHSC 5 × Raj 4238 | **-31.30**** | -18.01 | -22.99 | -16.21* | -18.88* | -26.17** | **-23.72**** | **-20.19*** |
| 21. | PHSC 5 × GW 496 | -7.40 | 10.51 | -6.28 | -0.94 | -19.93* | **-27.13**** | -10.81 | -6.69 |
| 22. | GW 2010-287× BW 5872 | 6.26 | 3.50 | 8.92 | 14.68 | 9.49 | 6.41 | 20.22* | 8.50 |
| 23. | GW 2010-287×QLD 65 | 8.13 | 5.33 | 4.98 | 15.09 | 13.56 | 10.36 | 18.65* | 10.56 |
| 24. | GW 2010-287×QLD 46 | 6.25 | 7.22 | -16.28 | -15.44 | 11.09 | 7.96 | 0.82 | -0.56 |
| 25. | GW 2010-287x Raj 4238 | -13.74 | -8.90 | -6.80 | 1.41 | 0.00 | -2.81 | -1.02 | -3.13 |
| 26. | GW 2010-287×GW 496 | 11.51 | 8.62 | -23.35** | -22.90** | -7.58 | -10.18 | 0.69 | -9.13 |
| 27. | BW 5872 × QLD 65 | 11.33 | 7.43 | -2.14 | 7.28 | 35.76** | 12.75 | 17.24 | 9.25 |
| 28. | BW 5872 × QLD 46 | -5.07 | -4.20 | -1.67 | 3.52 | 0.89 | -4.97 | -0.38 | -1.75 |
| 29. | BW 5872 × Raj 4238 | -0.46 | 5.12 | -12.57 | -4.87 | 17.20 | -6.17 | -0.26 | -2.38 |
| 30. | BW 5872 × GW 496 | -3.20 | -6.59 | -20.80** | -16.62* | 34.60** | 1.80 | 3.20 | -7.25 |
| 31. | QLD 65 × QLD 46 | -2.78 | -1.89 | -3.21 | 6.11 | 4.26 | -1.80 | 2.41 | 1.00 |
| 32. | QLD 65 × Raj 4238 | -13.74 | -8.90 | -14.30 | -6.05 | 15.36 | -4.19 | -4.21 | -6.25 |
| 33. | QLD 65× GW 496 | 13.11 | 2.80 | -22.50** | -15.03* | 8.15 | -10.18 | -1.34 | -8.06 |
| 34. | QLD 46 × Raj 4238 | -22.56** | **-18.22** | -33.78** | -27.95** | 1.72 | -4.19 | -14.39 | -15.56 |
| 35. | QLD 46 × GW 496 | 6.46 | 7.43 | -28.66** | -27.95** | -13.10 | -18.14* | -12.80 | -14.00 |
| 36. | Raj 4238 × GW 496 | -17.52* | -12.89 | 1.46 | 10.39 | 37.10** | 9.76 | 5.49 | 3.25 |
| No. of crosses showing significant desirable heterosis | | 1 | 1 | 2 | 3 | 10 | 4 | 4 | 1 |
| Range of heterosis | | -31.30 to 24.30 | -18.22 to 22.14 | -36.03 to 35.96 | -34.64 to 24.31 | -21.75 to 70.87 | -27.13 to 20.18 | -23.72 to 25.48 | -20.19 to 18.00 |
| S.E. ± | | 1.28 | | 1.46 | | 1.39 | | 1.38 | |

**Table 5: Performance of top ten high yielding hybrids for heterosis over better parent (BP), standard check (GW 366), their SCA effects and component traits showing significant and desirable heterosis over standard check and better parent**

| Sr. No. | Hybrids | Grain yield per plant (g) | Heterosis over | | SCA effects | Components showing significant and desirable heterosis over | | Components showing non-significant and desirable heterosis over | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BP | GW 366 | | BP | GW 366 | BP | GW 366 |
| 1. | PHSC 5 × GW 2010-287 | 18.88 | 12.78 | 18.00* | 2.93** | - | - | DH, GFP, ET, LS, NSS, NGP, GWS, HI | DH, DM, LS, PLS, NSS, NGP, GWS, TW, BY, HI |
| 2. | DW 90 × GW 2010-287 | 18.12 | 25.48** | 13.25 | 2.37** | - | - | ET, LS, PLS, NSS, NGP, BY, HI | DH, DM, ET, LS, PLS, NSS, NGP, GWS, BY, HI |
| 3. | DW 90 × BW 5872 | 17.89 | 24.41* | 11.81 | 2.22** | - | - | DH, PH, ET, LS, PLS, NSS, NGP, BY, HI | DH, DM, PH, ET, LS, PLS, NSS, NGP, GWS, BY, HI |
| 4. | GW 2010-287 × QLD 65 | 17.69 | 18.65* | 10.56 | 1.29* | LS | DM | DH, ET, PLS, NSS, NGP, BY, HI | DH, ET, LS, PLS, NSS, NGP, GWS, TW, BY, HI |
| 5. | NW 5013 × QLD 65 | 17.58 | 3.78 | 9.87 | 1.69** | - | - | DM, PH, ET, LS, NSS, NGP, GWS, BY, HI | GFP, DM, PH, ET, LS, PLS, NSS, NGP, GWS, TW, BY, HI |
| 6. | BW 5872 × QLD 65 | 17.48 | 17.24 | 9.25 | 1.17 | - | - | DH, ET, LS, PLS, NGP, TW, BY, HI | DH, DM, ET, LS, PLS, NSS, NGP, GWS, TW, BY, HI |
| 7. | GW 2010-287 × BW 5872 | 17.36 | 20.22* | 8.50 | 0.92 | - | TW | GFP, ET, LS, PLS, NSS, NGP, GWS, BY | GFP, ET, LS, PLS, NSS, NGP, GWS, BY, HI |
| 8. | NW 5013 × DW 90 | 17.13 | 7.47 | 7.06 | 1.89** | - | - | DH, DM, PH, ET, LS, PLS, NSS, NGP, BY, HI | DH, DM, PH, ET, LS, PLS, NSS, NGP, GWS, TW, BY, HI |
| 9. | DW 90 × GW 496 | 16.77 | 17.77 | 4.81 | 2.17** | - | - | PH, ET, LS, PLS, NSS, NGP, HI | GFP, PH, ET, LS, PLS, NSS, NGP, GWS, BY |
| 10. | Raj 4238 × GW 496 | 16.52 | 5.49 | 3.25 | 2.09** | - | - | DH, GFP, DM, ET, LS, PLS, NSS, NGP, GWS, BY | DH, DM, PH, ET, LS, PLS, NSS, NGP, GWS, BY |

** and ** indicates significant at 5 per cent and 1 per cent levels of significance, respectively*

*DH= Days to heading, GFP = Grain filling period, DM = Days to maturity, PH = Plant height, ET = Number of effective tillers per plant, LS = length of main spike, PLS = Peduncle length of main spike, NSP = Number of spikelets per main spike, NGP = number of grain per main spike, GWS = grain weight per main spike, TW = 1000 grain weight, BY = Biological yield per plant, HI = Harvest ind*

*[MS received : March 03, 2018]* *[MS accepted : March 16, 2018]*