Journal of Cereal Research

Volume 14 (2): 139-149

Homepage: http://epubs.icar.org.in/ejournal/index.php/JWR

Research Article

Heterotic capability of five crosses for quantitative traits in bread wheat (*Triticum aestivum* L.) with inbreeding depression studies using generation mean analysis

Darshika Busa[2], Ashwin Pansuriya[1*], Deep Vekaria[1], Chandrakant Singh[1], G. U. Kulkarni[2] and Jagdish Patel[3]

[1] *Wheat Research Station, Junagadh Agricultural University, Junagadh -362001*
[2] *Department of Genetics and Plant Breeding, Junagadh Agricultural University, Junagadh -362001*
[3] *Department of Seed Science and Technology, Junagadh Agricultural University, Junagadh -362001*

Article history:
Received: 04 June, 2022
Revised: 07 Aug., 2022
Accepted: 23 Aug., 2022

Citation:
Busa D, A Pansuriya, DM Vekaria, C Singh, GU Kulkarni and JB Patel. 2022. Heterotic capability of five crosses for quantitative traits in bread wheat (*Triticum aestivum* L.) with inbreeding depression studies using generation mean analysis. *Journal of Cereal Research* ***14 (2):*** *139-149. http://doi.org/10.25174/2582-2675/2022/124049*

****Corresponding author:***
E-mail: agpansuriya@jau.in

Abstract

Six generations, namely P_1, P_2, F_1, F_2, BC_1 and BC_2 of five crosses of bread wheat *viz.*, AKAW 4842 x Raj 4238, AKAW 4924 x RW 5, DBW 39 x MP 3353, GW 11 x DWAP 1540 and GW 455 x UP 2968 were developed to estimate the extent of heterosis and inbreeding depression and underlying genetic causes for different characters in bread wheat. The analysis of variance between families (crosses) revealed that the mean square due to crosses were highly significant for all the characters. The analysis of variance among progenies (generations) within each family (cross) indicated significant differences among six basic generation means for all the characters studied in all the five crosses. In the present study all the crosses depicted significant and positive mid parent heterosis and heterobeltiosis for grain yield per plant and almost all the component traits. Among which crosses AKAW 4842 x Raj 4238, AKAW 4924 x RW 5, GW 11 x DWAP 1540 and GW 455 x UP 2968 depicted negative inbreeding as well as significant and positive mid parent heterosis and heterobeltiosis for grain yield per plant therefore, intermating in F_2 generation may be advantageous for improving particular character for above mentioned crosses. Generally, the character like grain yield per plant governed by fixable additive gene effect can be improved through pedigree selection method.

Keywords: Bread wheat, heterosis, inbreeding depression, generation mean analysis

1. Introduction

Wheat (*Triticum sp.*) is usually accorded a premier place among 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 civilizations of the world. *Triticum aestivum* is most extensively grown crop among cereals in the world, grown on more than 17% of the cultivable land and consumed by nearly 40% of the global population. Wheat fulfils 20% of the total food calories and 21% protein in human diet (Bhutto *et al.*, 2016). India, a major contributor to the world wheat production after China witnessed a tremendous increase in production during the last four decades.

Wheat is a unique gift from nature to main kind as it can be moulded into innumerable products like chapattis, breads, cakes, biscuits, pasta and many hot and ready-to-eat breakfast foods. Wheat grain contains crude protein (13.3 %), fat (2.0 %), minerals (1.7 %), fibre (2.3%), other carbohydrates (68.7 %) and water (12 %) (Das, 2008). The uniqueness of wheat in contrast to other cereals is that wheat contains gluten protein, which enables leavened dough to rise by forming minute gas cells and this property enables bakers to produce light breads.

Nature and magnitude of heterosis is one of the important aspects for selection of the right parents for crosses and also helps in identification of superior cross combinations that may produce desirable transgressive segregants in advanced generations especially in self- pollinated crops like wheat. The superiority of hybrids depends on their yield potential over the better released varieties and the extent of heterosis for seed yield. The aim of heterosis analysis is to find out the best combination of crosses giving high degree of useful heterosis and characterization of hybrids for commercial exploitation. Singh and Singh (1984) appears to be most acceptable, both in concept and utilization of heterosis in self-pollinated crops. According to them, one can select a pure breeding line equally good or even better than F_1 hybrid. Therefore, the knowledge of heterosis together with inbreeding depression would help in determination of the parents which produce the best cross combinations having maximum heterosis and minimum inbreeding depression. Inbreeding depression points out whether the vigour observed in the F_1 generation can be fixed or not in later generations through selfing. The information of such estimates is essential to plan efficient breeding programmes as well as selection of parents so as to obtain good segregants for improvement of the crop yield.

2. Materials and methods

The present investigation was carried out on bread wheat (*Triticum aestivum* L.) at Wheat Research Station, Junagadh Agricultural University, Junagadh. The seeds of F_1 generations of five crosses were available from Wheat Research Station, Junagadh Agricultural University, Junagadh. The F_1 as well as 10 parents were sown in the field to generate F_2, BC_1 and BC_2 generations as well as fresh selfed seeds of P_1, P_2 and fresh F_1 during *Rabi* 2018-19 and materials which are developed were evaluated during *Rabi* 2019-20. Wheat Research Station, JAU, Junagadh is located in South Saurashtra Agro Climatic Zone of Gujarat state. Ten parents were used in this experiment *viz.,* AKAW 4842, AKAW 4924, DBW 39, GW 11, GW 455, Raj 4238, RW 5, MP 3353, DWAP 1540 and UP 2968. The experimental material was comprised of five crosses each with six basic generations, *viz.*, P_1, P_2, F_1 (P_1 x P_2), F_2 (F_1 selfed), BC_1 (F_1 x P_1) and BC_2 (F_1 x P_2). Ten diverse parents were selected on the basis of their phenotypic variability for different characters. The seeds of F_1 generations [AKAW 4842 x Raj 4238 (cross 1), AKAW 4924 x RW 5 (cross 2), DBW 39 x MP 3353 (cross 3), GW 11 x DWAP 1540 (cross 4) and GW 455 x UP 2968 (cross 5)] of five crosses were made during *Rabi* 2017-18. The F_1 as well as 10 parents were sown in the field to generate F_2, BC_1 and BC_2 generations as well as fresh selfed seeds of P_1, P_2 and fresh F_1 during *Rabi* 2018-19. The experiment was laid out in Compact Family Block Design with three replications having each row of 3 m length and 22.5 cm row to row distance. Each replication was divided into five compact blocks. The blocks were comprised of six basic generations of each cross. The crosses were assigned to each block and six generations of a cross were relegated to individual plot within the block. The single row plot for P_1, P_2 and F_1; two rows for each BC_1 and BC_2 generations and three rows of F_2 generation were accommodated. The observations were recorded on 10 competitive and randomly selected plants each from P_1, P_2 and F_1; 20 plants each from backcross (BC_1 and BC_2) and F_2 generations in each replication. Various observations taken were days to flowering (DF), days to maturity (DM), plant height (PH), number of effective tillers (TIL), length of main spike (SL; cm), number of spikelets per main spike, grain filling period, number of grains per main spike (NGPS), 100-grain weight (g), grain yield per plant (GY; g plant^{-1}), biological yield per plant (g plant $^{-1}$), and harvest index (HI; %).

The mean values obtained for each character were subjected to analysis of variance using Compact Family Block Design according to the following model as described by Panse and Sukhatme (1985). The standard statistical procedures were used to calculate means and variances of each generation for each character (Singh and Chaudhary, 2004). The crosses which showed significant differences among the different generations for various traits were subjected to generation mean analysis for the detection of digenic interactions and for the estimation of gene effects as suggested by Hayman (1958) and Cavalli (1952). The heterotic effects in term of superiority of F_1 over mid parent values (relative heterosis) as per Briggle (1963) and over better parent (heterobeltiosis) as per Fonseca and Patterson (1968). The inbreeding depression (ID) in F_2 generation was calculated as,

$$\text{Inbreeding depression (\%)} = \frac{\bar{F}_1 - \bar{F}_2}{\bar{F}_1} \times 100$$

Where,

$\bar{F}_1$ = Mean of F_1 generation

$\bar{F}_2$ = Mean of F_2 generation

3. Results and discussion

The analysis of variance for the experimental design for all the different characters studied in five crosses is presented in Table 1. The analysis of variance between families (crosses) revealed that the mean square due to crosses were highly significant for all the characters. The Bartlett's test for homogeneity of error variances of five crosses indicated that the error variances were heterogeneous for plant height, length of main spike, grain filling period, number of grains per main spike, 100 grain weight and biological yield per plants showed by significance of chi-square values and homogeneous for rest of characters *viz.* days to flowering, days to maturity, number of effective tillers per plant, number of spikelets per main spike, grain yield per plant and harvest index as showed by non-significance of chi-square values. The analysis of variance among progenies (generations) within each family (cross) indicated significant differences among six basic generation means for all the characters studied in all the five crosses. Hence, further genetic analysis of generation means and calculation of heterosis and inbreeding were carried out.

3.1 Days to flowering

The results on heterosis and inbreeding depression are presented in table 2. The heterosis over mid parent ranged from -6.88 % (GW 11 x DWAP 1540) to 7.14% (AKAW 4842 x Raj 4238) and were significant and positive in crosses AKAW 4842 x Raj 4238, AKAW 4924 x RW 5, DBW 39 x MP 3353 and GW 455 x UP 2968, while it was significant in desirable direction in cross GW 11 x DWAP 1540. For the purpose of estimation of heterosis over better parent, the parent having less number of days to opening of first flowering was considered as better parent. Heterosis over better parent ranged from -6.09 % (GW 11 x DWAP 1540) to 9.01 % (AKAW 4842 x Raj 4238) and were significant and positive in crosses AKAW 4842 x Raj 4238, AKAW 4924 x RW 5, DBW 39 x MP 3353, and GW 455 x UP 2968, while it was significant negative in cross GW 11 x DWAP 1540. The heterosis over mid parent and better parent was significant and desirable for days to flowering in only GW11 x DWAP. Desirable heterosis for this trait has also been reported by Lal *et al.* (2013), Aware and Padukone (2018) and Khokhar *et al.* (2019). The estimates of inbreeding depression ranged from -3.69 % (GW 11 x DWAP 1540) to 4.98 % (GW 455 x UP 2968) and was significant and positive in crosses AKAW 4842 x Raj 4238, AKAW 4924 x RW 5, GW 11 x DWAP 1540 and GW 455 x UP 2968. Positive and significant inbreeding depression was observed in AKAW 4842 x Raj 4238, AKAW 4924 x RW 5, GW 11 x DWAP 1540 and GW 455 x UP 2968 and is supported by earlier report of Kumar *et al.* (2018).

3.2 Days to maturity

As early maturity is desirable in wheat crop, the early maturing parent was considered as better parent for the calculation of heterobeltiosis. Heterosis over better parent ranged from -0.96 % (GW 455 x UP 2968) to 4.99 % (AKAW 4842 x Raj 4238) and were significant and positive in crosses AKAW 4842 x Raj 4238, AKAW 4924 x RW 5, DBW 39 x MP 3353 and GW 11 x DWAP 1540, while it was negative direction in cross 5. The observed values of inbreeding depression ranged from 0.31 % (AKAW 4924 x RW 5) to 3.97 % (GW 11 x DWAP 1540) and were significant and positive in crosses DBW 39 x MP 3353, GW 11 x DWAP 1540 and GW 455 x UP 2968. Results of the experiment with respect to days to maturity were similar to the findings of Khokhar *et al.* (2019). The crosses DBW 39 x MP 3353, GW 11 x DWAP 1540 and GW 455 x UP 2968 showed significant and positive inbreeding depression and similar result was reported by Kumar *et al.* (2018).

3.3 Plant height

The estimates of heterosis over mid parent ranged from 3.17% (AKAW 4924 x RW 5) to 10.57% (AKAW 4842 x Raj 4238). All the five crosses exhibited significant and positive mid parent heterosis. The dwarf plant was considered as better parent for calculating heterobeltiosis. The estimates of heterosis over better parent varied from 3.33% (AKAW 4924 x RW 5) to 13.53% (AKAW 4842 x Raj 4238) and were significant and positive in all the crosses. The estimates of inbreeding depression ranged from -1.09 % (DBW 39 x MP 3353) to 7.70 % (GW 455 x UP 2968) and was significant and positive in crosses AKAW 4924 x RW 5, GW 11 x DWAP 1540 and GW 455 x UP 2968. None of the crosses depicted significant but negative heterosis for this trait. Similar trend was noticed by Vanpariya *et al.* (2006) and Lal *et al.* (2013). Inbreeding depression for plant height was significant and positive in AKAW 4924 x RW 5, GW 11 x DWAP 1540 and GW 455 x UP 2968 and is supported by earlier report of Aware and Potdukhe (2018) and Kumar *et al.* (2018).

3.4 Number of effective tillers per plant

The estimates of heterosis over mid parent ranged from 2.65% (AKAW 4842 x Raj 4238) to 27.85% (GW 11 x DWAP 1540) and were significant and positive in crosses AKAW 4924 x RW 5, DBW 39 x MP 3353, GW 11 x DWAP 1540 and GW 455 x UP 2968. The estimates of heterosis over better parent varied from 14.02% (GW 455 x UP 2968) to 45.62% (GW 11 x DWAP 1540) and were significant and positive in all the crosses. The estimates of inbreeding depression ranged from -8.02% (AKAW 4842 x Raj 4238) to 14.16 % (DBW 39 x MP 3353) and found significant and positive in crosses 39 x MP 3353 and GW 11 x DWAP 1540. Number of effective tillers per plant is one of the important component traits, which is directly related with increased grain yield per plant. Out of five cross combinations, only cross AKAW 4842 x Raj 4238 resulted in non-significant and positive heterosis and heterobeltiosis, remaining crosses resulted in significant and positive heterosis and heterobeltiosis. Similar findings were reported for this character by Vanpariya *et al.* (2006), Baloch *et al.* (2016), Aware and Potdukhe (2018) and Khokhar *et al.* (2019). Negative inbreeding depression is desirable for this trait. The cross AKAW 4842 x Raj 4238 showed high desirable inbreeding depression. Similar conclusions were drawn by Aware and Potdukhe (2018) and Kumar *et al.* (2018).

3.5 Length of main spike

The estimates of heterosis over mid parent ranged from 4.57% (AKAW 4842 x Raj 4238) to 17.92% (DBW 39 x MP 3353) and were significant and positive in crosses AKAW 4924 x RW 5, DBW 39 x MP 3353, GW 11 x DWAP 1540 and GW 455 x UP 2968. The estimates of heterosis over better parent varied from 7.80% (GW 455 x UP 2968) to 31.06% (DBW 39 x MP 3353) and were significant and positive in all the crosses. The estimates of inbreeding depression ranged from 2.27% (AKAW 4842 x Raj 4238) to 9.55 % (GW 455 x UP 2968) and were significant, positive in crosses AKAW 4924 x RW 5, DBW 39 x MP 3353, GW 11 x DWAP 1540 and GW 455 x UP 2968. For length of main spike, four crosses namely, AKAW 4924 x RW 5, DBW 39 x MP 3353, GW 11 x DWAP 1540 and GW 455 x UP 2968 had significant and positive heterosis over mid parent, while all the five crosses showed significant and positive heterosis over better parent. Vanpariya *et al.* (2006), Khokhar *et al.* (2019) reported significant and positive heterosis for length of main spike. None of the cross showed negative inbreeding depression for length of main spike and is supported by earlier report of Kumar *et al.* (2018).

3.6 Number of spikelets per main spike

The estimates of heterosis over mid parent ranged from 7.53% (AKAW 4842 x Raj 4238) to 14.06% (AKAW 4924 x RW 5) and were significant, positive in crosses AKAW 4924 x RW 5, DBW 39 x MP 3353 and GW 455 x UP 2968. The estimates of heterosis over better parent varied from 10.52% (AKAW 4842 x Raj 4238) to 21.67% (AKAW 4924 x RW 5) and were significant, positive in crosses AKAW 4924 x RW 5, DBW 39 x MP 3353, GW 11 x DWAP 1540 and GW 455 x UP 2968. The estimates of inbreeding depression ranged from -3.16% (DBW 39 x MP 3353) to 10.14 % (AKAW 4842 x Raj 4238) and were significant and positive in cross AKAW 4842 x Raj 4238. Number of spikelets per main spike is an important yield attribute in wheat. For this trait, AKAW 4924 x RW 5, GW 11 x DWAP 1540 and GW 455 x UP 2968 showed significant and positive heterosis over mid parent. All the crosses except cross 1 showed significant and positive heterosis over better parent. Significant and positive heterosis for this character has been reported by Vanpariya *et al.* (2006) and Baloch *et al.* (2016). Negative inbreeding depression is desirable for Number of spikelets per main spike. The crosses DBW 39 x MP 3353 and GW 455 x UP 2968 showed desirable negatively inbreeding depression and similar conclusions were drawn by Aware and Potdukhe (2018) and Kumar *et al.* (2018).

3.7 Grain filling period

The estimates of heterosis over mid parent ranged from -13.31% (GW 455 x UP 2968) to 11.66% (AKAW 4842 x Raj 4238) and were significant and positive in crosses AKAW 4842 x Raj 4238, DBW 39 x MP 3353 and GW 11 x DWAP 1540, while it was negative direction in crosses AKAW 4924 x RW 5 and GW 455 x UP 2968. The estimates of heterosis over better parent varied from -4.44% (AKAW 4924 x RW 5) to 12.38% (AKAW 4842 x Raj 4238) and were significant and positive in crosses AKAW 4842 × Raj 4238, DBW 39 x MP 3353 and GW 11 x DWAP 1540. The estimates of inbreeding depression ranged from -14.25 % (AKAW 4924 x RW 5) to 8.04 % (GW 11 x DWAP 1540) and were significant and positive in crosses 3 and 4. In case of grain filling period, AKAW 4842 x Raj 4238, DBW 39 x MP 3353 and GW 11 x DWAP 1540 showed significant and positive heterosis over mid parent and better parent. The results of heterosis for grain filling period was in close agreement with the findings of Bhatiya (2006). AKAW 4924 x RW 5 and GW 455 x UP 2968 showed significant and negative inbreeding depression. The results are in agreement with the findings of Bhatiya (2006).

3.8 Number of grains per main spike

The estimates of heterosis over mid parent ranged from 3.45 % (AKAW 4842 x Raj 4238) to 14.88% (GW 11 x DWAP 1540) and were significant and positive in GW 11 x DWAP 1540 and GW 455 x UP 2968 crosses. The estimates of heterosis over better parent varied from10.48% (AKAW 4842 x Raj 4238) to 17.25% (GW 11 x DWAP 1540) and were significant and positive in all five crosses. The estimates of inbreeding depression ranged from -0.79 % (GW 455 x UP 2968) to 4.99 % (GW 11 x DWAP 1540) and were non-significant in all five crosses. For number of grains per main spike, GW 11 x DWAP 1540 and GW 455 x UP 2968 showed significant and positive heterosis over mid parent, while all five crosses showed significant and positive heterosis over better parent for this trait. The present findings are in accordance with those of Vanpariya *et al.* (2006), Rasul *et al.* (2008) and Khokhar *et al.* (2019). All the crosses showed non-significant inbreeding depression for this trait and it is in agreement of earlier reports of Aware and Potdukhe (2018) and Kumar *et al.* (2018).

3.9 100 grain weight

The estimates of heterosis over mid parent ranged from 9.52% (AKAW 4842 x Raj 4238) to 25.05% (AKAW 4924 x RW 5). All the five crosses exhibited significant and positive mid parent heterosis. The estimates of heterosis over better parent varied from 12.65% (AKAW 4842 x Raj 4238) to 29.73% (AKAW 4924 x RW 5) and were significant and positive in all five crosses. The estimates of inbreeding depression ranged from -2.35% (GW 11 x DWAP 1540) to 9.03 % (DBW 39 x MP 3353) and was significant and positive in AKAW 4842 x Raj 4238 and DBW 39 x MP 3353. With respect to 100 grain weight, all five crosses were found significant and positive heterosis over mid-parent and better parent. This result is in agreement with the findings of Vanpariya *et al.* (2006) and Rasul *et al.* (2008). The cross GW 11 x DWAP 1540 showed high desirable negative inbreeding depression. Similar conclusions were drawn by Aware and Potdukhe (2018) and Kumar *et al.* (2018).

3.10 Grain yield per plant

The heterosis over mid parent ranged from 10.71% (AKAW 4842 x Raj 4238) to 31.59% (AKAW 4924 x RW 5). All the five crosses depicted significant and positive mid parent heterosis. Heterosis over better parent ranged from 19.68 % (AKAW 4842 x Raj 4238) to 44.03 % (AKAW 4924 x RW 5) and were significant and positive in all five crosses. The estimates of inbreeding depression ranged from -12.04% (AKAW 4924 x RW 5) to 14.32 % (DBW 39 x MP 3353) and found significant and positive in DBW 39 x MP 3353. Grain yield in wheat is one of the most important economic characters and the final product of the multiplicative interaction of contributing traits. It is imperative to know the causes of heterosis for grain yield. All the five crosses depicted significant and positive heterosis over mid parent and better parent for this trait. Significant and positive heterosis for this character has been reported by Vanpariya *et al.* (2006), Rasul *et al.* (2008), Lal *et al.* (2013), Dedaniya *et al.* (2018) and Bajaniya *et al.* (2019). Negative inbreeding depression is desirable for grain yield per plant. The cross GW 455 x UP 2968 showed desirable inbreeding depression and similar conclusions were drawn by Kumar *et al.* (2018).

3.11 Biological yield per plant

The heterosis over mid parent ranged from 1.69% (AKAW 4842 x Raj 4238) to 19.31% (AKAW 4924 x RW 5) and observed significant and positive in crosses AKAW 4924 x RW 5, DBW 39 x MP 3353, GW 11 x DWAP 1540 and GW 455 x UP 2968. Heterosis over better parent ranged from 4.70% (AKAW 4842 x Raj 4238) to 25.38% (AKAW 4924 x RW 5) and noted significant and positive in crosses AKAW 4924 x RW 5, DBW 39 x MP 3353, GW 11 x DWAP 1540 and GW 455 x UP 2968. The estimates of inbreeding depression ranged from -7.30% (AKAW 4842 x Raj 4238) to 6.30% (DBW 39 x MP 3353) and found significant and positive in DBW 39 x MP 3353. For biological yield per plant, four crosses namely, AKAW 4924 x RW 5, DBW 39 x MP 3353, GW 11 x DWAP 1540 and GW 455 x UP 2968 had significant and positive heterosis over mid parent and better parent. Significant and positive heterosis for this character has been reported by Baloch *et al.* (2016). AKAW 4842 x Raj 4238, AKAW 4924 x RW 5, GW 11 x DWAP 1540 and GW 455 x UP 2968 showed negative and significant inbreeding depression for this trait and similar conclusions were drawn by Kumar *et al.* (2018).

3.12 Harvest index

The heterosis over mid parent ranged from 8.63% (AKAW 4842 x Raj 4238) to 13.76% (DBW 39 x MP 3353) for harvest index. All the five crosses had significant and positive mid parent heterosis. Heterosis over better parent ranged from 13.40% (AKAW 4842 x Raj 4238) to 26.17% (DBW 39 x MP 3353) and were significant and positive in all five crosses. The estimates of inbreeding depression ranged from -7.17% (AKAW 4924 x RW 5) to 8.32% (DBW 39 x MP 3353) and it was significant and positive in cross DBW 39 × MP 3353. In case of harvest index, all the five crosses depicted significant and positive heterosis over mid parent and better parent. Vanpariya *et al.* (2006) also reported significant and positive heterosis for harvest index. Negative inbreeding depression is desirable for harvest index. Cross AKAW 4924 x RW 5 showed high desirable negative inbreeding depression and similar findings were reported by Kumar *et al.* (2018).

Table 1 Analysis of variance (mean squares) between families and between progenies within family of six generations for different characters in bread wheat

Source of variation	d.f.	Days to flowering	Days to maturity	Plant height (cm)	No. of effective tillers per plant	Length of main spike	No. of spikelets per main spike
			Analysis of variance between families				
Replications	2	0.43	0.04	1.48	0.01*	0.001	0.001
Crosses	4	10.39**	26.01**	11.47**	2.24**	2.42**	1.89**
Error	8	0.23	0.03	0.42	0.002	0.001	0.00
χ^2		NS	NS	S	NS	S	NS
			Analysis of variance between progenies within family				
			AKAW 4842 x Raj 4238 (Cross 1)				
Replications	2	2.43	0.39	10.21	0.04	0.006	0.0001
Generations	5	7.20**	10.18**	27.73**	4.36**	1.01**	1.56**
Error	10	1.24	0.19	2.81	0.01	0.05	0.005
			AKAW 4924 x RW 5 (Cross 2)				
Replications	2	0.62	0.40	1.67	0.03	0.03	0.0001
Generations	5	12.28**	7.77**	13.63**	7.29**	1.63	3.81**
Error	10	0.47	0.32	0.45	0.01	0.01	0.002
			DBW 39 x MP 3353 (Cross 3)				
Replications	2	1.48	0.12	7.05	0.003	0.005	0.009
Generations	5	6.71**	8.69**	24.06**	3.92**	3.40**	6.38**
Error	10	0.54	0.07	1.90	0.006	0.002	0.004

			GW 11 x DWAP 1540 (Cross 4)				
Replications	2	2.81	0.006	0.06	0.009	0.0006	0.004
Generations	5	7.20**	20.88**	21.05**	10.06**	1.59**	2.32**
Error	10	0.87	0.14	0.18	0.006	0.0004	0.005
			GW 455 x UP 2968 (Cross 5)				
Replications	2	0.75	0.005	0.05	0.02	0.0005	0.001
Generations	5	7.77**	25.57**	24.32**	1.25**	1.00**	2.72**
Error	10	1.19	0.06	0.07	0.01	0.0007	0.002

Cont…..

Table 1 Contd…..

Source of variation	d.f.	Grain filling period (days)	No. of grains per main spike	100 grain weight (g)	Grain yield per plant (g)	Biological yield per plant	Harvest index (%)
			Analysis of variance between families				
Replications	2	0.69	0.0001	0.0001	0.0001	0.0001	0.012
Crosses	4	24.34**	1.28**	0.16**	25.89**	77.24**	25.57**
Error	8	0.86	0.001	0.0001	0.0001	0.0001	0.004
χ^2		S	S	S	NS	NS	NS
			Analysis of variance between progenies within family				
			AKAW 4842 x Raj 4238 (Cross 1)				
Replications	2	1.83	0.001	0.001	0.0001	0.0005	0.03
Generations	5	25.48**	12.87**	0.22**	10.55**	34.76**	18.41**
Error	10	3.73	0.002	0.001	0.0007	0.0004	0.03
			AKAW 4924 x RW 5 (Cross 2)				
Replications	2	3.21	0.001	0.000	0.0003	0.0001	0.008
Generations	5	37.19**	10.39**	0.95**	24.52**	47.65**	37.79**
Error	10	2.81	0.003	0.0004	0.0003	0.0005	0.02
			DBW 39 x MP 3353 (Cross 3)				
Replications	2	0.01	0.001	0.0004	0.0001	0.0003	0.06
Generations	5	10.90**	7.51**	0.41**	16.93**	11.62**	35.99**
Error	10	0.02	0.002	0.0004	0.0002	0.0006	0.03
			GW 11 x DWAP 1540 (Cross 4)				
Replications	2	12.74	0.002	0.0001	0.0005	0.0001	0.006
Generations	5	89.65**	15.53**	0.37**	18.48**	16.16**	36.82**
Error	10	7.07	0.01	0.0002	0.0002	0.0003	0.02
			GW 455 x UP 2968 (Cross 5)				
Replications	2	7.13	0.01*	0.0003	0.0002	0.0002	0.06
Generations	5	46.07**	17.48**	0.27**	16.21**	19.31**	22.93**
Error	10	4.07	0.002	0.0001	0.0003	0.0004	0.02

* and ** Significant at 5 and 1 per cent levels, respectively
Chi-square for Bartlett's test of homogeneity of error variances,
S= Significant; NS = Non-significant

Table 2 Heterosis over mid parent (MP), heterosis over better parent (BP) and inbreeding depression (ID) for days to flowering, days to maturity, plant height (cm) and number of effective tillers per plant of five crosses in bread wheat

Crosses	Heterosis (%) over		ID (%)
	MP	BP	
	Days to flowering		
AKAW 4842 x Raj 4238 (Cross 1)	7.14** ± 0.65	9.01** ± 0.70	3.72** ± 0.72
AKAW 4924 x RW 5 (Cross 2)	3.08* ± 0.64	7.40** ± 0.64	3.69** ± 0.57
DBW 39 x MP 3353 (Cross 3)	2.95* ± 0.62	6.68** ± 0.60	-0.23 ± 0.69
GW 11 x DWAP 1540 (Cross 4)	-6.88** ± 0.57	-6.09** ± 0.58	-3.69** ± 0.59
GW 455 x UP 2968 (Cross 5)	5.24** ± 0.45	8.37** ± 0.63	4.98** ± 0.44
	Days to maturity		
AKAW 4842 x Raj 4238 (Cross 1)	3.01** ± 0.51	4.99** ± 0.54	0.93 ± 0.52
AKAW 4924 x RW 5 (Cross 2)	2.55** ± 0.61	3.94** ± 0.74	0.31 ± 0.74
DBW 39 x MP 3353 (Cross 3)	3.10** ± 0.60	4.81** ± 0.93	2.71** ± 0.63
GW 11 x DWAP 1540 (Cross 4)	2.76** ± 0.69	4.32** ± 0.82	3.97** ± 0.60
GW 455 x UP 2968 (Cross 5)	-3.00** ± 0.51	-0.96 ± 0.55	2.06** ± 0.54
	Plant height (cm)		
AKAW 4842 x Raj 4238 (Cross 1)	10.57** ± 0.96	13.53** ± 1.07	2.85 ± 1.10
AKAW 4924 x RW 5 (Cross 2)	3.17** ± 0.71	3.33** ± 0.82	5.54** ± 0.76
DBW 39 x MP 3353 (Cross 3)	7.00** ± 1.15	11.07** ± 1.32	-1.09 ± 1.08
GW 11 x DWAP 1540 (Cross 4)	6.94** ± 0.74	9.76** ± 0.88	2.76** ± 0.74
GW 455 x UP 2968 (Cross 5)	7.98** ± 0.69	11.96** ± 1.08	7.70** ± 0.84
	No. of effective tillers per plant		
AKAW 4842 x Raj 4238 (Cross 1)	2.65 ± 0.42	21.60** ± 0.51	-8.02* ± 0.44
AKAW 4924 x RW 5 (Cross 2)	27.08** ± 0.37	28.44** ± 0.42	-0.12 ± 0.36
DBW 39 x MP 3353 (Cross 3)	7.54* ± 0.41	17.72** ± 0.48	14.16** ± 0.40
GW 11 x DWAP 1540 (Cross 4)	27.85** ± 0.36	45.62** ± 0.43	12.45** ± 0.34
GW 455 x UP 2968 (Cross 5)	9.44** ± 0.42	14.02** ± 0.52	5.08 ± 0.41

*and ** Significant at 5 and 1 per cent levels respectively.

Cont…..

Table 2 Heterosis over mid parent (MP), heterosis over better parent (BP)and inbreeding depression (ID) for length of main spike (cm), number of spikelets per main spike, grain filling period (days) and number of grains per main spike of five crosses in bread wheat

Crosses	Heterosis (%) over		ID (%)
	MP	BP	
	Length of main spike (cm)		
AKAW 4842 x Raj 4238 (Cross 1)	4.57 ± 0.22	10.90** ± 0.22	2.27 ± 0.22
AKAW 4924 x RW 5 (Cross 2)	11.11** ± 0.21	13.46** ± 0.29	6.34** ± 0.19
DBW 39 x MP 3353 (Cross 3)	17.92** ± 0.19	31.06** ± 0.23	8.94** ± 0.20

GW 11 x DWAP 1540 (Cross 4)	14.09** ± 0.20	20.07** ± 0.25	8.41** ± 0.20
GW 455 x UP 2968 (Cross 5)	5.90** ± 0.18	7.80** ± 0.23	9.55** ± 0.20
	No. of spikelets per main spike		
AKAW 4842 x Raj 4238 (Cross 1)	7.53 ± 0.79	10.52 ± 0.91	10.14* ± 0.79
AKAW 4924 x RW 5 (Cross 2)	14.06** ± 0.82	21.67** ± 0.95	6.76 ± 0.83
DBW 39 x MP 3353 (Cross 3)	10.83 ± 0.89	15.74* ± 0.99	-3.16 ± 0.87
GW 11 x DWAP 1540 (Cross 4)	11.89* ± 0.75	15.23** ± 0.91	5.89 ± 0.75
GW 455 x UP 2968 (Cross 5)	10.50* ± 0.73	14.16* ± 0.85	-2.30 ± 0.79
	Grain filling period (days)		
AKAW 4842 x Raj 4238 (Cross 1)	11.66** ± 0.57	12.38** ± 0.59	-0.64 ± 0.60
AKAW 4924 x RW 5 (Cross 2)	-11.64** ± 0.88	-4.44 ± 1.04	-14.25** ± 0.94
DBW 39 x MP 3353 (Cross 3)	5.55** ± 0.69	8.05** ± 0.95	7.48** ± 0.71
GW 11 x DWAP 1540 (Cross 4)	11.61** ± 0.77	12.20** ± 0.85	8.04** ± 0.72
GW 455 x UP 2968 (Cross 5)	-13.31** ± 0.64	-6.58** ± 0.71	-3.59** ± 0.65
	No. of grains per main spike		
AKAW 4842 x Raj 4238 (Cross 1)	3.45 ± 1.60	10.48* ± 1.86	1.09 ± 1.52
AKAW 4924 x RW 5 (Cross 2)	7.85 ± 1.67	14.26** ± 1.91	4.92 ± 1.76
DBW 39 x MP 3353 (Cross 3)	6.66 ± 1.57	11.29* ± 1.63	1.85 ± 1.57
GW 11 x DWAP 1540 (Cross 4)	14.88** ± 1.86	17.25** ± 2.25	4.99 ± 1.73
GW 455 x UP 2968 (Cross 5)	10.05* ± 1.40	15.64** ± 1.51	-0.79 ± 1.62

*and ** Significant at 5 and 1 per cent levels respectively.

Cont…..

Table 2 Heterosis over mid parent (MP), better parent (BP)and inbreeding depression (ID) for 100 grain weight (g), grain yield per plant (g), biological yield per plant (g) and harvest index (%) of five crosses in bread wheat

Crosses	**Heterosis (%) over**		**ID (%)**
	MP	**BP**	
	100 grain weight (g)		
AKAW 4842 x Raj 4238 (Cross 1)	9.52** ± 0.14	12.65** ± 0.17	5.33* ± 0.13
AKAW 4924 x RW 5 (Cross 2)	25.05** ± 0.15	29.73** ± 0.18	3.48 ± 0.13
DBW 39 x MP 3353 (Cross 3)	10.49** ± 0.14	16.59** ± 0.19	9.03** ± 0.13
GW 11 x DWAP 1540 (Cross 4)	10.02** ± 0.15	13.08** ± 0.19	-2.35 ± 0.12
GW 455 x UP 2968 (Cross 5)	16.49** ± 0.16	22.44** ± 0.19	4.53 ± 0.16
	Grain yield per plant (g)		
AKAW 4842 x Raj 4238 (Cross 1)	10.71* ± 0.62	19.68** ± 0.65	-5.69 ± 0.74
AKAW 4924 x RW 5 (Cross 2)	31.59** ± 0.77	44.03** ± 0.77	-12.04 ± 0.84
DBW 39 x MP 3353 (Cross 3)	22.53** ± 0.86	39.13** ± 0.92	14.32** ± 0.91
GW 11 x DWAP 1540 (Cross 4)	21.05** ± 0.68	31.77** ± 0.73	-5.60 ± 0.70
GW 455 x UP 2968 (Cross 5)	17.91** ± 0.71	29.37** ± 0.73	-7.47* ± 0.67

Biological yield per plant (g)			
AKAW 4842 x Raj 4238 (Cross 1)	1.69 ± 0.77	4.70 ± 0.99	-7.30** ± 0.72
AKAW 4924 x RW 5 (Cross 2)	19.31** ± 0.82	25.38** ± 0.96	-4.75* ± 0.89
DBW 39 x MP 3353 (Cross 3)	7.64** ± 0.77	10.06** ± 0.88	6.30** ± 0.78
GW 11 x DWAP 1540 (Cross 4)	6.76** ± 0.76	11.28** ± 0.85	-1.86* ± 0.75
GW 455 x UP 2968 (Cross 5)	5.66** ± 0.80	9.34** ± 0.87	-5.83** ± 0.76
Harvest index (%)			
AKAW 4842 x Raj 4238 (Cross 1)	8.63* ± 1.58	13.40** ± 1.80	1.36 ± 1.80
AKAW 4924 x RW 5 (Cross 2)	10.64* ± 2.03	14.69* ± 2.13	-7.17 ± 2.17
DBW 39 x MP 3353 (Cross 3)	13.76** ± 1.71	26.17** ± 1.83	8.32* ± 1.81
GW 11 x DWAP 1540 (Cross 4)	13.42** ± 1.61	18.53** ± 1.72	-3.69 ± 1.59
GW 455 x UP 2968 (Cross 5)	11.32* ± 1.74	18.06** ± 1.83	-1.32 ± 1.53

*and ** Significant at 5 and 1 per cent levels respectively.

4. Conclusions

Breeding method that can be employed for improvement of a particular character depends upon the type of gene action prevailed in the expression of character. The type and magnitude of gene action may vary for different characters in the same cross and for the same trait in different crosses which necessitates the handling of individual cross in segregating generations in a specific way. Generally, the character governed by fixable additive gene effect can be improved through pedigree selection method. The cases, where high heterosis coupled with negative inbreeding depression prevail, intermating in F_2 generation may be advantageous for improving particular character. In the present study all the crosses depicted significant and positive relative heterosis and heterobeltiosis for grain yield per plant and almost all the component traits. Among which crosses AKAW 4842 x Raj 4238, AKAW 4924 x RW 5, GW 11 x DWAP 1540 and GW 455 x UP 2968 also showed negative inbreeding depression therefore, intermating in F_2 generation may be advantageous for improving particular character for above mentioned crosses. Grain yield per plant and biological yield per plant showed the highest heterosis over mid parent and better parent as well as minimum inbreeding depression over the crosses.

Acknowledgements

Authors thank to Research Scientist (Wheat), Principal and Dean, P.G. Studies and Professor and head (GPB), Junagadh Agricultural University, Junagadh for constant encouragements and support.

Author's contribution

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

Declaration

The authors declare no conflict of interest.

5. References

1. Aware SA and NR Potdukhe. 2018. Heterotic capability of eight crosses for quantitative and qualitative traits in wheat (*Triticum aestivum* L.) with inbreeding depression studies. *International Journal of Current Microbiology and Applied Sciences* **6**: 2436-2444.
2. Bajaniya NA, AG Pansuriya, DM Vekaria, C Singh and JM Patel. 2019. Estimation of heterosis in different crosses of durum wheat (*Triticum durum* L.). *International Journal of Chemical Studies* **7**(3): 3833-3839.
3. Baloch M, AW Baloch, NA Siyal, SN Baloch, AA Soomro, SK Baloch and N Gandahi. 2016. Heterosis analysis in F_1 hybrids of bread wheat. *Sindh University Research Journal* **48**(2): 261-264.
4. Bhatiya VJ. 2006. 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.

5. Bhutto AH, AA Rajpar, SA Kalhoro, A Ali, FA Kalhoro, M Ahmed, S Raza and NA Kalhoro. 2016. Correlation and regression analysis for yield traits in wheat (*Triticum aestivum* L.) genotypes. *Natural Sci*ences **8**(3): 96-104.

6. Briggle LW. 1963. Heterosis in wheat: A Review. *Crop Sciences* **3**(5): 407-412.

7. Cavalli LL. 1952. An analysis of linkage in quantitative inheritance. In "Quantitative Inheritance". Ed. E.C.R. Reeve and C.H. Waddington, HMSO, London. pp. 135-144.

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

9. Fonseca S and FL Patterson. 1968. Hybrid vigor in a seven-parent diallel cross in common winter wheat (*Triticum aestivum* L.). *Crop Sciences* **8**(1): 85-88.

10. Hayman BI. 1958. The separation of epistatic from additive and dominance variation in generation means. *Heredity* **12**: 371-390.

11. Khokhar AA, WA Jatoi, FG Nizamani, RA Rind, MM Nizamani, HF Wang, A Mehmood and MU Khokhar. 2019. Study of heterosis analysis in F_1 population of bread wheat. *Pure and Applied Biology* **8**(2): 1757-1770.

12. Kumar A, AK Razdan, V Sharma, N Kumar and D Kumar. 2018. Study of heterosis and inbreeding depression for economic and biochemical traits in bread wheat (*Triticum aestivum* L.). *Journal of Pharmacognosy and Phytochemistry* **7**(4): 558-564.

13. Lal C, V Kumar and SR Maloo. 2013. Heterosis and inbreeding depression for some quantitative and heat tolerance characters in bread wheat (*Triticum aestivum* L.). *Journal of Wheat Research* **5**(2): 52-55.

14. Panse VG and PV Sukhatme. 1985. Statistical Methods for Agricultural Workers. Indian Council of Agricultural Research, New Delhi. pp. 381.

15. Rasul I, AS Khan and Z Ali. 2008. Estimation of heterosis for yield and some yield components in bread wheat. *International Journal of Agriculture and Biology* **4**(2): 214-216.

16. Singh M and RK Singh. (1984). A comparison of different methods of half-diallel analysis. *Theoretical and Applied Genetics* **67**: 323-326.

17. Singh RK and BD Chaudary. 2004. Biometrical methods in quantitative genetic analysis. Kalyani Publishers, Ludhiana.

18. Vanpariya LG, VP Chovatia and DR Mehta. 2006. Heterosis for grain yield and its attributes in bread wheat (*Triticum aestivum* L.). *National Journal of Plant Improvement* **82**: 100-102.