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Study of heterosis and inbreeding depression for economic and biochemical traits in bread wheat (*Triticum aestivum* L.)

Ashwani Kumar, AK Razdan, Vivak Sharma, Nimit Kumar and Deepak Kumar

Abstract
A set of diallel crosses involving 8 parents was made to have information on the extent of heterosis rent and inbreeding depression for economic and biochemical traits. The crosses showing heterosis for grain yield were not heterotic for all the characters. Significant and positive mid parent and better parent heterosis were observed in four cross combinations *viz.*, HD2967 × WH1080, PBW343 × RSP561, Raj3077 × RSP561, and RSP561 × DPW621-50 for grain yield per plant. Significant inbreeding depression was recorded frequently for yield and yield contributing traits, however, in a few traits it was observed significant negative indicated that F_2 was superior to F_1 considered desirable combination for trait(s). The study reveals good scope for commercial exploitation of heterosis as well as isolation of pure lines among the progenies of heterotic F_1 for improvement of yield levels in bread wheat.

Keywords: wheat, heterosis, heterobeltiosis, inbreeding depression

Introduction
Wheat (*Tritium aestivum* L.) is the second most important crop that contributes significantly to the global food and food security (Kumar *et al.* 2013) [7]. In India, wheat is cultivated on over an area of about 43.388 million hectares with a production of 93.50 million tonnes and productivity of 3093 kg/ha (Anonymous, 2017) [2]. Wheat is a major staple food in Jammu region and is being cultivated over an area of 0.2474 million hectare with production and productivity of 0.5407 million tonnes and 19.52 kg/ha, respectively (Anonymous, 2016) [3].
The study of heterosis and inbreeding depression in most of the crops including wheat is an important tool in interpreting genetic parameters. The nature and magnitude of heterosis and inbreeding depression could play a vital role for the plant breeder in formulating the appropriate breeding procedures (Kumar *et al.* 2016) [9]. Exploitation of heterotic effects is mainly accredited to cross pollinated crops but now-a-days the incidence is common in self-pollinated crops such as wheat, providing an option for commercially utilizing wheat (Singh *et al.* 2004; Kumar *et al.* 2011) [17, 6]. The study of heterosis helps the breeders in eliminating less productive crosses in F_1 generation itself. The rejection of crosses, which shows no heterosis, would enable the breeder to concentrate the attention to few, but possibly more productive crosses.
The inbreeding depression refers to decrease in fitness and vigour due to inbreeding. The degree of inbreeding is measured by the inbreeding coefficient. Inbreeding depression results are due to fixation of unfavourable recessive genes in F_2, while in case of heterosis the unfavourable recessive genes of one line or parent are covered by favourable dominant genes of other parent. The fixation of all favourable dominant genes in one homozygous line is impossible due to linkage between some unfavourable recessive and favourable dominant genes.
Keeping in view the general rule of breeding and the necessity of finding out superior heterotic crosses for grain yield, therefore conducted this study with the objective of estimating the extent of heterosis in various wheat crosses obtained through half diallel mating scheme.

Material and Methods
The experimental material of the present study were comprised of eight genotypes of bread wheat *viz.*, HD2967, WH1105, PBW343, Raj3077, RSP561, WH1080, DPW621-50 and PBW550, were planted at research farm of Division of Plant Breeding and Genetics, Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences & Technology of Jammu

for hybridization in diallel mating design during *Rabi* 2015-16 for developing 28 F_1's (one way). F_1's were advanced to F_2's generation through off-season nursery at IIWBR, Lahaul-Spiti (H.P.). All the parents their F_1's and F_2's were evaluated in Randomized Complete Block Design with three replications during *Rabi* 2016-17. Seeds of 64 genotypes (8 parents + 28F_1's + 28F_2's seeds = 64 genotypes) were sown by hand dibbling method and the length of each row was kept 3m long by maintaining row to row and plant to plant distances of 30 cm and 15 cm, respectively at Research Farm of Division of Plant Breeding and Genetics, SKUAST-J. Observations were recorded on ten randomly selected competitive plants of each parent and F_1's and forty plants in F_2's in every replication for following traits *viz.*, flag leaf area (cm^2), number of effective tillers per plant, spike length (cm), number of spikelets per spike, number of grains per spike, 1000-grain weight (g), grain yield per plant (g), biological yield per plants, harvest index, total protein content and gluten content. In case of maturity traits (days to 50 percent flowering & days to maturity), the data was recorded on the whole plot basis. Data from ten plants were averaged replication wise and the mean value was subjected for statistical analysis for all characters studied. For the estimates of heterosis and inbreeding depression the test of significance was carried out with 't' test as given here under:

Estimation of heterosis

The percent increase (+) or decrease (-) of F_1 cross over mid parent as well as better parent was calculated to observe heterotic effects for all the parameters. The estimate of heterosis over the mid parent and better parent (heterobeltiosis) was calculated using the procedure of Matzingar *et al*. (1962) [11].

$$\text{Heterosis (\%)} = \frac{F_1 - MP}{MP} \times 100$$

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

Where,

F_1 = Mean value of F_1

MP = Mean of mid parent value of the particular F_1 cross (P_1 + P_2)/2

BP = mean of better parent value in the particular F_1 cross

The difference of F_1 mean from the respective mid-parent and better parent value was evaluated by using a t-test according to Wynne *et al*. (1970) [21]

$$t = \frac{F_{1ij} - MP_{ij}}{(3/8\ \sigma^2 e)^{1/2}} \times 100$$

Where,

F_{1ij} = the mean of ijth F_1 cross

MPij = mid parent value of the ijth cross

σ^2 e = estimate of error variance

Estimation of inbreeding depression

Inbreeding depression is estimated when both F_1 and F_2 populations of the same cross are available. It was calculated the procedure of Singh and Narayanan (1993) [16].

$$\text{Inbreeding depression} = \frac{F_1 - F_2}{F_1} \times 100$$

Where,

F_1 and F_2 are the means over replications of a particular cross. The significance was tested using the same method as used for heterosis.

Result and Discussion

In the present investigation, heterosis was estimated as deviation of the performance of F_1 hybrids and inbreeding depression of F_2 generation has been studied for all traits. The estimates of heterosis and inbreeding depression were given in Table 1 and Table 2.

Days to 50 percent flowering

Since earliness is desirable, for days to 50% flowering. Cross WH1105 × WH1080 (-27.04 % and -29.70 %) showed maximum desirable heterosis and heterobeltiosis. Positive inbreeding depression is desirable for days to 50 percent flowering. The cross WH1105 × PBW550 (7.69 %) showed maximum inbreeding depression.

Flag leaf area

Positive heterosis and heterobeltiosis are desirable for this character. Cross RSP561 × DPW621-50 (76.79 % and 73.29 %) showed highest desirable mid-parent heterosis and better parent heterosis. Negative inbreeding depression is desirable for flag leaf area per plant. The cross PBW343 × RSP561 (-22.49%) showed maximum inbreeding depression.

Days to maturity

Genotypes with early maturing habits are considered desirable. Highest negative significant mid parent and better parent heterosis was recorded in RSP561 × WH1080 (-18.62 %) and RSP561 × DPW621-50 (-19.56 %), respectively. Positive inbreeding depression is desirable for days to maturity. The crosses HD2967 × WH1105 (2.73%) showed maximum inbreeding depression.

Plant height

Dwarfness is desirable for this trait. Cross HD2967 × WH1105 (-12.32 % and -17.87 %) showed highest desirable mid-parent heterosis and better parent heterosis, respectively. Positive inbreeding depression is desirable for plant height. The cross HD2967 × PBW550 (21.08%) showed high inbreeding depression.

Number of effective tillers per plant

Number of productive tillers directly contributes to plant yield; positive heterosis for tillers per plant is therefore desirable in wheat. Highest desirable mid-parent and better parent heterosis was recorded in cross WH1105 × PBW550 (90.85 %) and HD2967 × WH1080 (78.82 %), respectively. Negative inbreeding depression is desirable for number of effective tillers per plant. Twenty one crosses exhibited significant inbreeding depression out of which six crosses showed negative and significant magnitude. The cross WH1105 × RSP561 (-15.31%) showed high desirable inbreeding depression.

Spike length

Spike length is a major yield component and is directly proportional to grains/spike. The longer the spike length, higher will be the grain yield. Highest desirable mid-parent and better parent heterosis was recorded in cross Raj3077 × RSP561 (43.86 % and 41.75 %) respectively. Negative inbreeding depression is desirable for spike length. The cross

WH1105 × PBW550 (-21.60%) showed high desirable inbreeding depression.

Number of spikelet per spike
Higher number of spikelets per spike is desirable for grain yield. Highest desirable heterosis and heterobeltiosis was recorded in cross Raj3077 × RSP561 (25.27 %) and RSP561 × WH1080 (22.22 %), respectively. Negative inbreeding depression is desirable for number of spikelets per spike. The cross HD2967 × Raj3077 (-22.36%) showed high desirable inbreeding depression.

Spike density
Positive spike density is desirable for heterosis and heterobeltiosis. Highest desirable heterosis and heterobeltiosis was recorded in cross WH1080 × DPW621-50 (32.36 % and 18.23 %), respectively. Negative inbreeding depression is desirable for spike density. The cross HD2967 × Raj3077 (-55.66%) showed high desirable negative inbreeding depression.

Number of grains per spike
Number of grains per spike directly determines the yield potential of a genotype. Positive heterosis and heterobeltiosis are desirable for this character. Highest desirable mid-parent and better parent heterosis was recorded in cross HD2967 × DPW621-50 (31.72 % and 31.61 %) respectively. Negative inbreeding depression is desirable for number of grains per spike. The cross WH1105 × DPW621-50 (-32.64%) showed high desirable negatively inbreeding depression.

1000-grain weight
It is an important selection criteria in breeding programs as it has a positive correlation with grain yield in wheat. Highest desirable mid-parent and better parent heterosis was recorded in cross Raj3077 × DPW621-50 (7.99 %) and WH1105 × Raj3077 (12.79 %), respectively. Negative inbreeding depression is desirable for 1000-grain weight. The cross PBW343 × DPW621-50 (-17.14%) showed high desirable negative inbreeding depression.

Grain yield per plant
Positive significant heterosis is desirable for this trait. Highest desirable mid-parent and better parent heterosis was recorded in cross Raj3077 × RSP561 (37.70 % and 28.39 %), respectively. Negative inbreeding depression is desirable for grain yield per plant. The cross HD2967 × RSP561 (-89.82%) showed high desirable inbreeding depression.

Biological yield per plant
Positive value is desirable for biological yield per plant. Highest desirable mid-parent and better parent heterosis was recorded in cross RSP561 × DPW621-50 (66.51 % and 64.56 %), respectively. Negative inbreeding depression is desirable for biological yield per plant. The cross DPW621-50 × PBW550 (-95.06%) showed high desirable inbreeding depression.

Harvest index
Positive significant heterosis for harvest index. Cross DPW621-50 × PBW550 (13.74%) showed the positive significant heterobeltiosis for harvest index. Most of the crosses showed negatively significant heterobeltiosis for the trait. Negative inbreeding depression is desirable for harvest index. The cross RSP561 × PBW550 (-29.15%) showed high desirable negative inbreeding depression.

Total protein content and gluten content
Highest desirable mid-parent and better parent heterosis was recorded in cross WH1080 × PBW550 (12.68 % and 9.55 %) and (12.42 % and 12.06 %), respectively. Negative inbreeding depression is desirable for these traits. The cross WH1105 × Raj3077 (-9.58%) and (-9.48%) showed high desirable inbreeding depression for total protein content and gluten content, respectively.

In the present study, estimates of mid and better parent heterosis were computed to identify the superior cross combinations for their potential use in hybrid breeding programme. Significant and positive mid parent and better parent heterosis were observed in four cross combinations *viz*., HD2967 × WH1080, PBW343 × RSP561, Raj3077 × RSP561, and RSP561 × DPW621-50 for grain yield per plant. The high yield in the cross, RSP561 × DPW621-50 over both mid parent and better parent could be attributed by flag leaf area, number of effective tillers per plant, spike length, number of grains per spike, 1000-grain weight and biological yield per plant. Also parents involved in the cross were good general combiners indicating fixable type of gene action. These results are in agreement with finding of Yagdi and Karan (2000), Salgotra *et al*. (2002) and Singh *et al*. (2012) [22, 13, 19].

High heterosis for grain yield per plant in cross combination PBW343 × RSP561 over both mid parent and better parent could be attributed to number of effective tillers per plant, spike length, number of spikelets per spike and biological yield per plant but non-fixable type of gene action as indicated by one of the parents being poor general combiner. Similarly, high yield in cross combination Raj3077 × RSP561 over both mid and better parents might be due to spike length, number of spikelets per spike, 1000-grain weight and biological yield per plant but non-fixable type of gene action as indicated by one of the parents being poor general combiner. Mahajan *et al*. (1999) [10], Mehla *et al*. (2000) [12], Abdullah *et al*. (2002) [1], Verma *et al*. (2007) [20] and Kumar and Kerkhi (2014) [8] suggested that heterosis in general was more pronounced over mid parent than better parent which matches with the findings of the present investigation. The high yield cross combination HD2967 × WH1080 over both mid parent and better parent could be attributed to flag leaf area, number of effective tillers per plant, spike length, number of spikelets per spike, 1000-grain weight and biological yield per plant but non-fixable type of gene action as indicated by none of the parent being good general combiner.

The heterotic expression normally declines in F_2 generation as the dominance or dominance interaction effects dissipate in this generation due to reduced heterozygosity, there by resulting into inbreeding depression. Significant inbreeding depression in present investigation was observed for different traits. The crosses WH1105 × PBW550 for days to 50 percent flowering, PBW343 × DPW621-50 for flag leaf area; HD2967 × WH1105 for days to maturity; Raj3077 × DPW621-50 for plant height; WH1105 × RSP561 for number of effective tillers per plant; WH-1105 × PBW-550 for spike length; HD2967 × Raj3077 for number of spikelets per spike; HD2967 × RSP561 for grain yield per plant; RSP561 × PBW550 for harvest index and WH1105 × Raj3077 for total protein content exhibited desirable

Table 1: Estimates of heterosis, heterobeltiosis (F_1 generation) and inbreeding depression (F_2 generation) in 8 × 8 half diallel for economic traits.

Traits→	Days to 50% flowering			Flag leaf area			Days to maturity			Plant height			No. of effective tillers per plant		
Crosses↓	Mid parent	Better parent	Inbreeding Depression	Mid parent	Better parent	Inbreeding Depression	Mid parent	Better parent	Inbreeding Depression	Mid parent	Better parent	Inbreeding Depression	Mid parent	Better parent	Inbreeding Depression
HD-2967 x WH-1105	-22.01 **	-22.76 **	4.56**	-11.74 **	-16.74**	-12.75**	-13.62**	-14.22**	2.72**	-12.32**	-17.87**	-6.69**	24.39	22.89	-10.78**
HD-2967 x PBW-343	-23.43 **	-25.64 **	-1.29**	-17.84 **	-23.43**	5.94	-12.23**	-14.69**	0.27*	-07.61**	-15.14**	-1.55**	40.40**	30.86*	14.59
HD-2967 x Raj-3077	-17.95 **	-23.08 **	2.50**	04.16 **	03.34**	-6.46**	-11.76**	-16.08**	-1.11**	-08.15**	11.70**	-2.69**	43.90**	42.17**	-3.39**
HD-2967 x RSP-561	-26.17 **	-28.18 **	0.00*	29.59 **	12.49**	3.43	-18.09**	-20.00**	-1.67**	-09.46**	15.53**	2.23	75.31**	75.31**	30.28**
HD-2967 x WH-1080	-26.17 **	-28.18 **	2.53**	22.66 **	18.91**	28.28**	-16.44**	-18.12**	0.55**	-02.67	-06.35**	2.23	83.13**	78.82**	40.79**
HD-2967 x DPW-621-50	-25.64 **	-25.64 **	-3.02**	22.81 **	04.82**	12.00*	-14.22**	-14.22**	1.36**	-05.02*	-10.43**	1.98	25.71*	17.02	1.33**
HD-2967 x PBW-550	-17.11 **	-24.68 **	1.70	13.19 **	09.01**	14.30**	-12.95**	-15.38**	-0.28	11.97**	05.46*	21.08**	29.80*	20.99	-14.29**
WH-1105 x PBW-343	-22.33 **	-23.86 **	-1.29**	24.91 **	23.31**	23.32**	-13.29**	-15.13**	-1.67**	06.70**	04.47	9.37**	30.72*	20.48	11.47
WH-1105 x Raj-3077	-19.17 **	-23.53 **	1.28	-01.43	-06.32**	12.55**	-10.37**	-14.18**	0.00	-01.09	-03.73	0.52	25.30*	25.30	9.10
WH-1105 x RSP-561	-26.42 **	-29.09 **	2.14*	21.26 **	00.20	4.24	-16.61**	-19.11**	0.27*	07.12**	06.66*	5.44**	19.51	18.07	-15.31**
WH-1105 x WH-1080	-27.04 **	-29.70 **	-3.45**	18.19 **	08.28**	18.75**	-16.09**	-18.34**	-0.27	-03.31	-05.98*	-4.41**	26.19*	24.71	22.64**
WH-1105 x DPW-621-50	-22.65 **	-23.40 **	3.77**	36.35 **	10.91**	21.90**	-14.32**	-14.92**	-0.55**	-03.14	-03.84	-2.25**	31.07**	23.40	15.92*
WH-1105 x PBW-550	-11.94 **	-19.28 **	7.69**	12.89 **	02.79	-1.73**	-11.84**	-13.71**	1.10**	-02.60	-03.17	-1.45**	90.85**	75.90**	23.61**
PBW-343 x Raj-3077	-16.05 **	-19.05 **	1.26	-05.82 **	-11.57**	-7.11**	-07.83**	-09.88**	0.27*	-04.03	-08.49**	0.97	22.88	13.25	2.13**
PBW-343 x RSP-561	-24.68 **	-28.79 **	0.85	-01.58	-19.49**	-22.49**	14.39**	-18.67**	0.27*	08.08**	06.27*	6.44**	85.43**	72.84**	37.14**
PBW-343 x WH-1080	-24.68 **	-28.79 **	-1.70**	-08.29 **	-16.95**	14.56**	-14.32**	-18.34**	0.27*	-01.19	-05.87*	4.16	41.94**	29.41*	10.91
PBW-343 x DPW-621-50	-22.11 **	-24.36 **	1.27	00.29	19.22**	-20.61**	-12.71**	-15.15**	-0.27	08.62**	05.60*	13.91**	36.59**	19.15	-0.89**
PBW-343 x PBW-550	-14.75 **	-20.41 **	1.28	14.92**	03.43*	8.96	-09.88**	-09.88**	0.82**	-01.61	-04.21	3.94	51.43**	51.43**	13.65
Raj 3077 x RSP-561	-19.73 **	-26.67 **	-0.41**	19.91**	03.40	-5.89**	-12.54**	-18.67**	0.27*	-03.73	-06.69**	-0.45*	26.83*	25.30	3.33**
Raj 3077 x WH-1080	-20.40 **	-27.27 **	1.67	-05.83**	-09.41**	-7.66**	-12.47**	-18.34**	0.00	-02.25	-02.34	3.81	45.24**	43.53**	13.11
Raj 3077 x DPW-621-50	-17.61 **	-22.76 **	-0.41**	31.09**	11.16**	15.02**	-10.54**	-14.92**	0.00	01.16	-00.85	4.61*	26.50*	19.15	9.35
Raj 3077 x PBW-550	-06.06 **	-09.16 **	3.23**	06.57**	01.85	-2.94**	-07.83**	-09.88**	0.27*	-09.27**	-11.18**	-6.06**	38.56**	27.71	-8.05**
RSP-561 x WH-1080	-24.85 **	-24.85 **	5.65**	17.73**	05.02**	-7.31**	-18.62**	-18.89**	0.00	03.27	0.01	8.06**	37.35**	34.12*	4.39*
RSP-561 x DPW-621-50	-23.68 **	-25.76 **	-0.41**	76.79**	73.29**	18.21**	-17.63**	-19.56**	-1.38**	02.89	01.72	2.05	44.00**	34.04**	23.02**
RSP-561 x PBW-550	-18.97 **	-28.18 **	-2.95**	67.50**	50.32**	18.21**	-14.62**	-18.89**	-0.55**	06.77**	05.70*	5.81**	69.54**	58.02**	18.75**
WH-1080 x DPW-621-50	-25.55 **	-27.58 **	3.77**	49.84**	31.35**	25.07**	-16.89**	-18.57**	-0.82**	-03.72	-05.72*	-9.76**	31.84**	25.53*	24.97**
WH-1080 x PBW-550	-18.97 **	-28.18 **	2.11*	25.81**	24.96**	9.77	-14.79**	-18.79**	-0.83**	-04.80*	-06.90**	1.24	49.68**	36.47**	16.38*
DPW-621-50 x PBW-550	-14.64 **	-22.44 **	0.41	33.30**	17.54**	8.24	-12.47**	-14.92**	-0.82**	-06.11**	-06.24*	-0.73**	09.76	-04.26	4.44*
S.E.	0.93	1.07	1.05	0.61	0.70	0.56	0.68	0.79	0.76	1.86	2.15	2.34	0.50	0.58	0.55

* &** significant at 5% and 1% level, respectively

Table 1: cont...

Traits→	Spike length			No. of spikelet/ spike			Spike density			No. of grains /spike			1000-grain weight		
Crosses↓	Mid parent	Better parent	Inbreeding Depression	Mid parent	Better parent	Inbreeding Depression	Mid parent	Better parent	Inbreeding Depression	Mid parent	Better parent	Inbreeding Depression	Mid parent	Better parent	Inbreeding Depression
HD-2967 x WH-1105	13.56**	05.48	5.92	07.47	0.733	-2.81**	-08.29**	-16.19**	-6.98	03.31	00.85	-5.19	-00.43	-00.98	-4.38**
HD-2967 x PBW-343	20.74**	09.30	12.94**	06.67	04.99	-5.38**	-17.06**	-26.47**	-20.19**	04.21	00.86	-9.38	01.25	-02.33	6.35**
HD-2967 x Raj-3077	15.27**	06.24	11.03**	03.26	02.59	-22.36**	-11.42**	-18.95**	-55.66**	-02.04	-08.04	-26.07**	05.22**	01.93	4.83*
HD-2967 x RSP-561	21.47**	13.50*	8.47*	05.67	00.26	-11.13**	-12.27**	-12.59	-23.46**	03.56	00.00	-21.50**	03.61*	00.81	12.99**
HD-2967 x WH-1080	13.71**	10.22*	18.66**	17.02**	09.19*	4.09*	01.89	-07.25	-18.55*	15.27**	07.50	1.58**	12.74**	06.27**	4.57*
HD-2967 x DPW-621-50	12.39**	11.69*	8.24*	16.95**	15.31**	5.41*	03.01	00.87	-4.13*	31.72**	31.61**	1.80**	04.79**	00.70	-0.63*
HD-2967 x PBW-550	03.42	00.51	13.73**	09.97*	08.84	-2.03**	-16.10*	-17.39*	-52.41**	16.13**	11.15**	2.48**	07.60**	04.80**	6.63**
WH-1105 x PBW-343	33.33**	29.67**	5.67	17.71**	15.71**	-1.81	-17.45**	-20.17**	-8.77	17.99**	11.56**	-4.39	-00.97	-03.94*	9.74**
WH-1105 x Raj-3077	22.00**	20.98**	4.24	17.19**	16.58**	7.44**	-06.31	-06.45	2.72**	06.16	-02.55	-7.33	-09.49**	12.79**	-10.45**
WH-1105 x RSP-561	18.98**	18.22**	-6.82**	20.44**	14.14**	-9.40**	00.74	-07.65	-9.09	27.81**	20.58**	27.75**	00.86	-02.40	8.89**
WH-1105 x WH-1080	20.14**	08.43	12.16**	18.54**	10.47*	-2.37**	-06.43	-21.44**	-18.32*	15.20**	05.06	-20.96**	03.03	-03.40	-0.25**
WH-1105 x DPW-621-50	01.48	-05.19	-10.82**	02.84	01.53	-12.81**	00.08	-06.75	-1.13**	-02.16	-04.57	-32.64**	03.91*	-00.68	2.62
WH-1105 x PBW-550	11.83*	01.17	-21.60**	12.58**	11.57**	-15.79**	-02.50	-12.14	-18.09*	22.65**	14.73**	-11.51*	01.77	-01.42	8.69**
PBW-343 x Raj-3077	21.89**	19.52**	12.51**	14.44**	11.92**	2.08**	-10.08	13.17*	-13.39	08.65*	05.27	-6.65	-00.75	-07.14**	5.99**
PBW-343 x RSP-561	28.81**	24.49**	6.15*	17.02**	12.74**	-2.64**	12.76*	-22.41**	-10.65	07.89*	07.63	-14.18**	-01.45	-07.40**	11.24**
PBW-343 x WH-1080	13.38**	-00.18	12.91**	20.74**	14.36**	4.27	-02.14	-20.03**	-11.91	23.95**	19.27**	-1.12*	01.61	-07.40**	4.10
PBW-343 x DPW-621-50	13.82**	03.61	3.52	16.69**	13.27**	11.14**	-02.02	-11.48	8.07**	15.42**	11.81**	6.32**	-11.23**	-17.58**	-17.14**
PBW-343 x PBW-550	07.60	-05.05	14.75**	06.07	03.34	2.11**	-08.09	-19.61**	-21.08**	10.42**	09.16*	8.96**	-02.30	-08.11**	2.41
Raj 3077 x RSP-561	43.86**	41.75**	19.01**	25.27**	18.13**	17.11**	-13.02*	-20.15**	-5.65	21.22**	17.74**	10.18**	01.89	01.44	2.49
Raj 3077 x WH-1080	-05.89	-15.70**	-11.06**	11.73**	03.36	-9.75**	16.46*	-02.11	2.00**	03.07	02.34	-28.63**	07.29**	04.29*	3.06
Raj 3077 x DPW-621-50	23.67**	14.64**	2.33	11.05**	10.20*	-1.05**	-10.07	-16.09*	-4.30*	14.99**	08.05*	-12.83**	07.99**	07.10**	1.53
Raj 3077 x PBW-550	-01.19	-11.27*	-5.83**	07.87*	07.46	-4.43**	09.50	-01.20	2.28**	05.03	02.93	-21.63**	-03.14	-03.68*	-8.76**
RSP-561 x WH-1080	06.31	-03.50	-12.39**	24.40**	22.22**	5.26*	17.15*	06.29	15.23**	18.89**	14.67**	-5.77	04.41	01.05	3.51
RSP-561 x DPW-621-50	23.93**	16.48**	0.00*	06.27	-00.51	-10.65**	-14.13*	-15.63*	-12.35	18.69**	14.70**	7.71**	05.68**	04.34**	2.91
RSP-561 x PBW-550	23.86**	12.71*	16.40**	06.70	00.26	-13.47	-13.66*	-15.29*	-37.58**	16.01**	14.96**	-1.38*	02.83	02.72	2.24
WH-1080 x DPW-621-50	-12.50**	-15.70**	-16.45**	17.45**	08.16	1.42**	32.36**	18.23*	15.42**	14.42**	06.80	-8.67	07.80**	05.65**	-0.04*
WH-1080 x PBW-550	-04.23	-04.48	1.41	19.61**	10.54*	8.71**	24.09**	14.58	7.34**	24.23**	20.90**	-7.03	06.81**	03.27	1.90
DPW-621-50 x PBW-550	00.72	-02.71	-0.09*	10.12**	09.69*	2.56	08.01	04.17	1.67**	12.42**	07.69	-4.53	00.12	-01.25	0.00*
S.E.	0.46	0.74	0.59	0.74	0.85	1.08	0.12	0.14	0.17	1.85	2.14	2.27	0.61	0.70	0.73

* &** significant at 5% and 1% level, respectively

Table 2: Estimates of heterosis, heterobeltiosis (F_1 generation) and inbreeding depression (F_2 generation) in 8 × 8 half diallel for economic and biochemical traits.

Traits→	Grain yield / plant			Biological yield/ plant			Harvest index			Total protein content			Gluten content		
Crosses↓	**Mid parent**	**Better parent**	**Inbreeding Depression**	**Mid parent**	**Better parent**	**Inbreeding Depression**	**Mid parent**	**Better parent**	**Inbreeding Depression**	**Mid parent**	**Better parent**	**Inbreeding Depression**	**Mid parent**	**Better parent**	**Inbreeding Depression**
HD-2967 x WH-1105	-19.26**	-20.66**	-25.72	-17.97**	-18.03**	-11.39*	-00.38	-03.89	-7.55*	4.05**	3.70**	-1.30*	4.04**	3.70*	-1.35*
HD-2967 x PBW-343	-12.02*	-16.23**	-64.88**	-15.66**	-18.73**	-59.50**	-4.16	-6.16**	-1.93	-6.93**	-10.80**	2.69*	-6.88**	-10.72**	2.69*
HD-2967 x Raj-3077	-21.12**	-21.82**	8.92**	-09.53**	-12.52**	8.03**	-10.12**	-12.12**	0.59*	00.01	-00.87	-6.85**	-0.01	-0.88	-6.81**
HD-2967 x RSP-561	-23.28**	-27.87**	-89.82**	-06.54	-07.74	-67.95**	-9.58**	-11.98**	-7.21*	00.56	-0.43	-3.28**	0.57	-0.40	-3.23**
HD-2967 x WH-1080	24.06**	22.50**	-40.52	44.15**	39.20**	-7.52*	-1.73	-2.49	-16.86**	03.16**	1.12	-2.76**	3.76**	1.10	-2.77**
HD-2967 x DPW-621-50	24.35**	09.97	-7.58**	45.71**	45.53**	6.29**	-3.00	-4.33	-8.33**	2.16**	1.03	-7.82**	2.54**	1.81*	-7.74**
HD-2967 x PBW-550	-26.94**	-28.66**	-46.31*	-24.74**	-26.78**	-48.52**	1.80	1.63	0.95*	7.66**	2.66**	0.21	5.00**	2.64**	0.21
WH-1105 x PBW-343	-00.26	-03.42	-20.79	00.21	-03.37	-38.11*	-9.54 **	-14.47 **	6.92**	-1.70**	-5.48**	-5.22**	-1.67**	-5.43	-5.17**
WH-1105 x Raj-3077	06.37	03.61	-60.21**	-02.09	-05.40	-94.42**	-16.23 **	-17.36 **	10.61**	1.63*	1.07	-9.58**	1.63*	1.07	-9.48**
WH-1105 x RSP-561	-19.18**	-22.73**	-56.52**	00.25	-00.97	-25.33	-8.70**	-9.53**	-13.61**	0.87	0.21	-5.18**	0.88	0.22	-5.13**
WH-1105 x WH-1080	-09.63	-12.28	-74.06**	15.88**	11.82**	-35.12	-12.72**	-15.15**	-15.55**	8.72**	6.22**	-1.04	9.31**	6.18**	-1.03
WH-1105 x DPW-621-50	-25.29**	-32.90**	-83.19**	-08.55*	-08.59*	-83.00**	-9.42**	-11.43**	0.04*	03.31**	5.62**	-1.07	3.71**	3.30**	-1.06
WH-1105 x PBW-550	09.30	08.59	-15.42*	30.12**	26.68**	-7.86*	-0.35	-4.01	-3.85	11.13**	5.62**	6.49**	8.37**	5.60**	6.43**
PBW-343 x Raj-3077	14.77**	08.35	-19.17	29.65**	20.95**	-1.84**	-1.83	-5.97**	-9.65**	0.82	-02.54**	1.45	0.83	-2.51**	1.43
PBW-343 x RSP-561	14.65**	13.15*	4.14**	15.70**	12.90**	7.49**	-4.01	-8.45**	-2.08	-1.94**	-5.11**	8.30**	-1.92**	-5.07**	8.23**
PBW-343 x WH-1080	-11.45*	-16.69**	-32.83	-01.25	-08.00*	-15.90	-4.18*	-6.89**	-8.31**	0.31	-5.68**	7.17**	0.89	-5.64**	7.11**
PBW-343 x DPW-621-50	-20.25**	-26.23**	22.70**	-05.18	-08.53*	10.79**	-4.00	-7.25 **	7.75**	-5.79**	-8.73**	11.73**	-5.38**	-8.66**	11.64**
PBW-343 x PBW-550	-10.72	-13.00*	38.46**	-04.62	-05.56	39.00**	-3.72	-5.57*	-0.75	2.12**	-6.48**	3.42**	-0.26	-6.43**	3.39**
Raj 3077 x RSP-561	37.70**	28.39**	32.79**	64.05**	56.66**	39.58**	-2.39	-2.82	-6.33*	3.71**	3.60**	0.56	3.69**	3.58**	0.55
Raj 3077 x WH-1080	21.76**	-22.04**	-78.33**	-10.87**	-11.00*	-51.93**	-4.15*	-5.56*	-9.86**	-0.74	-3.54**	-1.20*	-0.13	-03.51*	-1.19*
Raj 3077 x DPW-621-50	17.61**	03.20	11.88**	53.90**	48.67**	-3.02**	-14.18**	-14.94**	8.30**	-0.25	-0.49	0.10	0.17	0.00	0.10
Raj 3077 x PBW-550	01.76	-01.50	-44.69*	-03.68	-09.30*	-65.77**	1.86	-0.57	7.51**	6.89**	1.07	1.82	4.28**	1.07	1.80
RSP-561 x WH-1080	15.92**	07.72	-12.34**	19.62**	14.07**	-19.96	4.27*	2.29	3.69**	5.64**	2.55**	5.39**	6.23**	2.53**	5.34**
RSP-561 x DPW-621-50	35.82**	27.21**	23.21**	66.51**	64.56**	30.33**	-3.92	-5.19*	-6.00	-5.31**	-5.44**	-4.31**	-5.66**	-5.91**	-4.27**
RSP-561 x PBW-550	-17.51**	-20.67**	-65.58**	06.07	04.52	-6.69*	-0.53	-3.32	-29.15**	6.99**	1.06	3.15**	3.55**	0.26	3.12**
WH-1080 x DPW-621-50	-14.32**	-25.05**	-19.81	-05.97	-09.30*	-16.28	0.90	0.30	-1.97	-1.56*	-4.56**	7.21**	-1.34*	-4.52**	7.16**
WH-1080 x PBW-550	-12.25*	-15.36*	-55.17**	-18.51**	-23.37**	-51.70**	5.57**	04.58	-1.31	12.68**	9.55**	-2.23**	12.42**	12.06**	-2.21**
DPW-621-50 x PBW-550	-26.26**	-33.39**	-57.88**	-26.12**	-28.04**	-95.06**	15.50**	13.74**	11.59**	-2.99**	-8.48**	9.04**	0.12	-2.81**	8.97**
S.E.	0.45	0.52	0.58	0.77	0.89	1.12	0.72	0.83	1.51	0.12	0.14	0.32	0.11	0.13	0.26

* &** significant at 5% and 1% level, respectively

(significant negative or positive) inbreeding depression *i.e.* a significant increase in F_2 over F_1 (Table: 1 and Table: 2). Such results were also reported for different crosses and characters by Sharma and Menon (1996) [5], Singh (2003) [18], Joshi *et al*. (2003) [4], Sharma *et al*. (2004) [14], Singh *et al*. (2004) [17], Singh *et al*. (2012) [19], Kumar and Kerkhi (2014) [8] and Kumar *et al*. (2015) [5].

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