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ESTIMATION OF HETEROSIS IN DIFFERENT CROSSES OF BREAD WHEAT (*TRITICUM AESTIVUM* L.)

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ABSTRACT

Here we report some of the heterotic wheat crosses produced by crossing fifteen parents in a line x tester mating scheme. Analysis of variance revealed significant differences at 1% level of significance among the genotypes. Manifestation of heterosis was done over mid parent, better parent and the two standard checks i.e. UP 2684 and PBW 343. The generated data registered JUPIBJY/URES X UP 2572 as the best heterotic hybrid for harvest index against the checks UP 2684 and PBW 343 with the values of 27.39% and 50.54% respectively. Likewise HP 1749 X UP 2572 showed maximum heterosis (18.66%) over the check PBW 343. The data provides information on heterotic advantage of important yield and associated components. The highest heterotic genotypes can be exploited in future breeding programs to attain self-sufficiency in food grains. However, comprehensive field evaluation over locations and years is advocated for the crosses having significant heterosis before their commercial exploitation.

INTRODUCTION

To get maximum yield associated with best quality combinations are the aims of the breeding programs. The use of heterosis for getting high yield with improved quality has been largely used in cross-pollinated crops. Term heterosis was coined by Shull (1914), who defined it as the development stimulus resulting from the union of different gametes and hybrid vigour as "the manifestation of heterosis". In self-pollinated crops evidences are available to confirm the potential use of heterosis (Haq and Laila, 1991), suggesting the easiest ways of the possibility of commercial exploitation of genetic potential in wheat crops. Heterotic studies can also be used for getting information about the increase or decrease of F_{1s} over their mid parent (average or relative heterosis) and better parent (heterobeltiosis). Its use for elaborating the general and specific combining ability, in the selection process is also confirmed (Inamullah *et al*., 2006) Exploitation of heterosis in wheat crop may be regarded as one of the major breakthrough in the field of plant breeding. Moreover, the scope for utilization of heterosis mainly depends upon the direction and magnitude of heterosis. Heterosis may be expressed in the form of plant height, general plant vigour, number of spikes per plant, number of kernals per spike, kernel weight, total Grain yield per plot, maturity and several other characters (Briggle, 1963). Yield, is no doubt of primary importance and there are several associated traits with this, the total yield depends on the product of these components, which individually may not display heterosis. Singh *et al*. 2004, suggested that especially heterosis over better parent (heterobeltiosis) can be useful for determining true heterotic cross combinations. Heterosis shows combining ability of parents also being included in breeding programme. Selecting suitable parents is the basic need for designing a useful and successful hybridization programme. The studies on heterosis in wheat has also been done by Srivastava and Singh (2008); ZhaoPeng *et al*. (2009); Ashutosh *et al*. (2011); Batool *et al*. (2013); Beche *et al*. (2013) and Devi *et al*. (2013).

Keeping in view the general rule of breeding and the necessity of finding out superior heterotic crosses, we, therefore conducted this study with the objective of estimating the extent of heterosis in various wheat crosses obtained through line x tester mating scheme.

MATERIALS AND METHODS

In order to formulate valuable information regarding heterotic aspects of wheat hybrids this investigation was undertaken during *Rabi* 2010-2011at the N.E. Borlaug Crop Research Centre of G.B. Pant University of Agriculture and Technology, Pantnagar, India. A set of 12 lines *viz*. CHOI X M 95, CPAN 3067, FRET/TUKURU/FRET 2, HP 1749, HPW 224, HW 3042, JACANA/RHEA, JUPIBJY/URES/3/HD 2206/..., K 9006, KAUZ/ /ALTAR84/AOS/3/MILAN/KAUZ/4/HUITES, UP 2778 and HD 2997 were crossed with three testers *viz*. UP 2572, DBW 17 and UP 2338. A line x tester scheme was implied to produce a set of thirty six hybrids. The resultant hybrids and their parents were planted in randomized complete block design in three replications.

Observations were recorded on the whole plot basis for yield, days to 75% heading and days to maturity whereas the characters like plant height, spike length, flag leaf area, 1000 grain weight were taken over five randomly selected competitive plants from a plot. For flag leaf area (cm^2), length and the maximum width of flag leaf was measured and the area was calculated using the following formula suggested by Muller (1991).

Leaf area = Length X maximum width X 0.74

For an in depth analysis of data recorded on various quantitative characters and estimation of certain genetic parameters the statistical analysis using ANOVA was followed and subjected to analysis of variance to test the significance of the various quantitative characters. UP 2684 and PBW 343 were used as the standard parent (check) as these are best released and high yielding varieties for UP region. For the estimates of heterosis the test of significance was carried out with't' test as given hereunder:

For heterobeltiosis

$$t = \frac{\bar{F}_1 - \overline{BP}}{\sqrt{2Me/r}}$$

For standard heterosis

$$t = \frac{\bar{F}_1 - \overline{CP}}{\sqrt{2Me/r}}$$

For relative heterosis

$$t = \frac{\bar{F}_1 - \overline{MP}}{\sqrt{3Me/2r}}$$

Where,

$\bar{F}_1$	=	Mean of F_1 hybrid
$\overline{BP}$	=	Mean of better parent
$\overline{CP}$	=	Mean of check parent
$\overline{MP}$	=	Mean of mid-parental value
Me	=	Error mean square from ANOVA table and,
r	=	Number of replications

These calculated't' values were compared with Table't' value at error degrees of freedom at P=0.05 and P=0.01 level of significance for relative heterosis, heterobeltiosis and standard heterosis. The differences in the magnitudes of relative heterosis, heterosis over male and female parents were tested as per the method proposed by Panse and Sukhatme (1961).

RESULTS AND DISCUSSION

Exploitation of heterosis in cultivated plants is one of the most important accomplishments of the science of genetics in agriculture. Although production of hybrids may be the best to exploit the heterosis in F_{1S} but in Indian conditions, such attempts have not met with success due to problems of instability of male sterility, pollen fertility, free pollen dispersal and seed setting. It is therefore, necessary to see heterotic combinations in the first filial generation (F_1) in respect of yield and its components. Although production of hybrids may be the best exploitation of heterosis, however desired success has not been met in wheat because of several associated problems such as fertility restoration, pollination and seed setting. However, such heterotic F_1 combinations, which in F_2 and subsequent generations show a considerable measure of residual heterotic effects, can be exploited to isolate transgressive segregants.

Analysis of variance and range of variability

The analysis of variance of RBD revealed that mean sum of squares due to differences among the genotypes was significant for all the characters studied. This indicates the existence of a sufficiently high degree of genetic variability in the breeding material to be exploited in the study. Broad ranges observed for each trait (Table 1). The mean values for all the eleven traits of F_1 hybrids were compared with the values of mid parent, better parent and both the standard checks.

Estimates of heterosis

Estimates of heterosis over better parent (heterobeltiosis), mid parent (relative heterosis) and check (standard heterosis) expressed as percentage increase or decrease, are presented in Table 2 for different characters.

Days to 75% heading

Now a day's development of early and extra early genotypes seems to be a priority to fit the wheat variety in intensive cropping systems (Potato-wheat, sugarcane-wheat, cotton-wheat, rice-wheat) and in this context, negative heterotic response for heading and maturity is desirable. Negative heterotic response in a cross is generally important for the development of short duration wheat varieties (Shen *et al*. 1982). Heterobeltiosis for days to heading ranged from -4.14 (UP 2778 X UP 2338) to 1.08 (FRET/TUKURU/FRET 2 X DBW 17) and Relative heterosis ranged from -3.95 (CHOI/M 95 X DBW 17) to 0.88 (K 9006 X UP 2572). Perusal of the results reveals that the crosses UP 2778 X UP 2338 (-4.14) and CHOI/M 95 X DBW 17 (-3.95) showed significant negative heterobeltiosis and mid parent heterosis respectively, for early heading. However none of the cross showed significant negative heterosis over the checks. The importance of negative heterosis for this trait has been highlighted by Ashutosh *et al*. (2011).

Days to maturity

Heterobeltiosis for this trait ranged from -1.56 (HP 1749 X UP 2572) to 4.49 (JAKANA/RHEA X UP 2338). Relative heterosis ranged from -2.68 (CPAN 3067 X UP 2572) to 2.90 (K 9006 X UP 2338) and the standard heterosis over the check, UP 2684 ranged from 2.88 (FRET/TUKURU/FRET2 X DBW 17) to 3.13 (JAKANA/RHEA X UP 2338).The crosses CPAN 3067 × UP 2572 showed maximum negative heterobeltiosis (-0.79) and relative heterosis (-2.68). FRET/TUKURU/FRET 2 X DBW 17

Table 1: Analysis of variance for different characters

Character	Source of Variation	Mean Squares			Range of variation
D.F		Replication2	Treatment50	Error100	
1.	Days to heading	7.00	7.28**	3.73	92-100
2.	Days to maturity	3.04	12.80**	1.55	124-132
3.	Flag leaf area	35.18	168.49**	5.23	32.25-66.33
4.	Plant height	27.68	92.67**	14.30	75.67-106.18
5.	Spike length	0.13	4.50**	0.98	10.61-16.65
6.	Productive tillers per plant	1.05	13.98**	0.64	8.83-20.33
7.	Number of spikelets per spike	2.12	2.29**	0.40	16.87-21.83
8.	Grain yield per plot	117.52	4411.01**	134.74	101.10-278.80
9.	Harvest index	2.58	107.92**	3.73	24.00-55.28
10.	Number of grains per spike	7.12	187.02**	3.99	30.37-69.97
11.	1000 grain weight	0.81	56.57**	0.89	25.40-49.03

*and ** Significant 5% and 1% level of significance

showed significant negative standard heterosis (-2.88) over the check UP 2684, indicating dominance for early maturity duration in these crosses. However none of the cross showed significant negative value against the check PBW343. The importance of negative heterosis for this trait has been highlighted by Nanda *et al.* (1974), Simon (1989) and Devi *et al*. (2013).

Flag leaf area

Positive heterosis for flag leaf area can be exploited as a beneficial trait as it increases the chance of getting healthy and good quality grain and significant in photosynthetic process. Flag leaf is responsible for more than 70% photosynthesis and thus is important for grain filling. The range of heterobeltiosis and relative heterosis were -33.88 (HPW 224 X DBW 17) to +32.14 (CHOI/M 95 X UP 2338) and -19.90 (HP 1749 X UP 2572) to 33.72 (CHOI/M 95 X UP 2338), respectively. Impressive positive standard heterosis was observed in cross HPW 224 × UP 2572 i.e. 21.82, 86.49 against both the checks UP 2684 and PBW 343 respectively. Heterosis for flag leaf area in wheat crosses had been found by Batool *et al.* (2013).

Plant height

Short statured cultivars of wheat became much more popular after the commencement of green revolution in 1960s which drew the attention and attempts of plant breeders to breed for reduced plant height. Moreover the negative estimates of heterosis and heterobeltiosis for plant height are preferred over their mid and better parent in wheat breeding because dwarfness is a desirable character (Budak & Yildirim, 1996). In this regard in our study we identified the cross UP 2778 × DBW 17 showing maximum (-11.42) amount of negative heterosis over the check UP 2684. However none of the other crosses showed sufficient negative heterobeltiosis, mid parent heterosis and standard heterosis over the check PB W343. Negative heterosis for plant height has also been reported by Yadav and Murty (1976), Randhawa and Minhas (1977), Shen *et al.* (1982), Simon (1989), ZhaoPeng *et al.* (2009) and Beche *et al.* (2013).

Spike length

Spike length can be considered as one of the most important yield components during selection, which contributes towards productivity. For spike length appreciable amount of heterotic response over the better parent was observed in the cross CPAN 3067 × UP 2338 (15.38). The cross K 9006 X UP 2338 showed significant standard heterosis over both the checks, namely, PBW 343 and UP 2684 with the heterotic values of 13.94 and 23.85 respectively. Thus these crosses emerged as the best crosses possessing significant positive heterosis over better parent, mid parent and standard checks. Positive heterosis for spike length has been cited by Wan *et al.* (1973), Bao *et al.* (2009) and Ashutosh *et al.* (2011).

Productive tillers per plant

Heterobeltiosis for this character ranged from -42.62 (JAKANA/RHEA X UP 2572) to 39.54 (FRET/TUKURU/FRET2 X UP 2338) while, relative heterosis ranged from -29.29 (JAKANA/RHEA X UP 2572) to 43.44 (FRET/TUKURU/FRET2 X UP 2338).The cross FRET/TUKURU/FRET 2 X UP 2338 emerged as the best cross for productive tiller number with highest expression of heterobeltiosis (39.54) and significant positive better parent heterosis (43.44). This cross may prove to be the best source for tillers number per plant, an important yield contributing traits. The same hybrid may be advanced and utilized for single plant selection. The estimates of standard heterosis however, found to be either non-significant or the crosses showed negative heterosis for this trait. Similar findings were also reported by Wan *et al.* (1973), Nanda *et al.* (1974), Sinolinding and Rehman (1974), Chowdhry *et al.* (1996) and Muhammad *et al.* (2009).

Number of spikelets per spike

The highest magnitude of positive heterotic response for number of spikelets per spike in terms of mid parent heterosis was shown by the cross CHOI/M 95 X UP 2338 (15.57) followed by FRET/TUKURU/FRET 2 X UP 2572 which also showed significant heterobeltiosis (8.08) and standard heterosis (9.88) over check UP 2684. Heterosis for this trait is in general agreement with the findings of Iqbal *et al.* (1990), Mujahid *et al.* (2000), Baloch *et al.* (2001) and Devi *et al.* (2013). Utilizable heterosis over the check PBW 343 was shown by none of the cross. Exploitation of this trait may contribute to increase the grain yield in wheat breeding programmes.

Grain yield per plot

Exploitation of heterosis for increased yield was largely attributed to cross-pollinated crops. Evidences are now available to confirm the presence of heterotic effects in self

Table 2: Expression of heterosis of F1 generation over mid parents, better parents and standard checks for various traits under study

Sl. No.	Crosses	Days to 75% heading				Days to maturity				Flag leaf area			
		Hetero -beltiosis	Mid Parent Heterosis	Standard Heterosis		Hetero-beltiosis	Mid Parent Heterosis	Standard Heterosis		Hetero-beltiosis	Mid Parent Heterosis	Standard Heterosis	
				Check UP 2684	Check PBW 343			Check UP 2684	Check PBW 343			Check UP 2684	Check PBW 343
1	CHOI/M 95 X UP 2572	0.7	-2.06	1.06	0.7	-0.51	-1.40*	1.04	2.65**	-21.59**	-4.09	-27.84**	10.47*
2	CHOI/M 95 X DBW 17	-1.06	-3.95**	-1.06	-1.41	2.38**	0	1.04	2.65**	18.23**	24.20**	-23.56**	17.03**
3	CHOI/M 95 X UP 2338	-1.72	-3.39*	0.71	0.35	2.12*	-0.26	0.78	2.39**	32.14**	33.72**	-20.91**	21.08**
4	CPAN 3067 X UP 2572	0.35	-1.89	0.71	0.35	-0.79*	-2.68**	-0.26	1.32	-20.39**	-18.06**	-26.74**	12.16*
5	CPAN 3067 X DBW 17	-0.35	-2.76	-0.35	-0.71	0.27	-2.07**	-1.05	0.53	-7.1	6.48	-19.37**	23.44**
6	CPAN 3067 X UP 2338	-1.03	-2.22	1.42	1.05	0.79	-1.55*	-0.53	1.06	-15.93**	-0.48	-27.03**	11.72*
7	FRET/TUKURU/FRET2 X UP 2572	0	-1.07	-1.76	-2.12	0.27	-1.70*	-2.09**	-0.53	-2.43	3.79	-10.20**	37.47**
8	FRET/TUKURU/FRET2 X DBW 17	1.08	0.18	-0.7	-1.06	-0.54	1.06	-2.88**	-0.33	-3.31	7.65	-21.61**	20.01**
9	FRET/TUKURU/FRET2 X UP 2338	-0.79	-2.82	-2.47	-2.82	0	-0.53	-2.35**	-0.79	-3.59	10.88*	-21.92**	19.54**
10	HP 1749 X UP 2572	0.36	-0.36	-0.7	-1.06	-1.56	-2.07**	-1.05	0.53	-20.98**	-19.90**	-27.28**	11.33*
11	HP 1749 X DBW 17	-0.36	-0.89	-1.41	-1.76	-1.06	-1.97**	-2.35**	-0.79	1.36	17.72**	-9.24**	38.95**
12	HP 1749 X UP 2338	0.71	-1.05	-0.35	-0.71	0.27	-0.67	-1.05	0.53	3.35	23.89**	-7.45*	41.68**
13	HPW 224 X UP 2572	-2.11	-2.29	-1.76	-2.12	-0.51	-0.77	-1.04	2.65**	1.36	14.81**	21.82**	86.49**
14	HPW 224 X DBW 17	-1.41	-1.76	-1.41	-1.76	0.27	-1.43*	1.05	0.53	-33.88**	-14.01**	-20.53**	21.664**
15	HPW 224 X UP 2338	0.7	-0.17	1.42	1.05	2.38**	0.65	1.04	2.65**	-19.60**	7.34*	-3.38	47.92**
16	HW 3042 X UP 2572	-1.41	-1.41	-1.06	-1.41	-0.26	-0.89	1.3	2.92**	-13.52**	-13.00**	-20.41**	21.84**
17	HW 3042 X DBW 17	-0.71	-0.88	-0.7	-1.06	2.65**	0.52	1.3	2.92**	8.43*	26.74**	-1.41	50.94**
18	HW 3042 X UP 2338	-1.06	-2.09	-0.7	-1.06	3.44**	1.29	2.09*	3.71**	4.66	26.23**	-4.83	45.69**
19	JAKANA/RHEA X UP 2572	-2.08	-1.4	-0.35	-0.71	0.77	0.64	2.35**	3.98**	-1.97	7.65*	-9.78**	38.11**
20	JAKANA/RHEA X DBW17	0.35	-0.53	-0.36	-0.01	3.97**	2.34**	2.61**	4.24**	0.93	8.76*	-23.73**	16.76**
21	JAKANA/RHEA X UP 2338	-1.74	-2.08	0.04	-0.36	4.49**	2.87**	3.13**	4.77**	7.89	20.42**	-18.46**	24.84**
22	JUPIBJY/URES X UP 2572	-0.35	-0.53	0.01	-0.36	1.86*	0.13	-0.01	1.59	-3.99	-8.16**	-11.65**	35.26**
23	JUPIBJY/URES X DBW 17	-1.06	-1.41	-1.06	-1.41	0	-0.27	-1.83*	-0.27	-21.54**	-4.57	-21.26**	20.55**
24	JUPIBJY/URES XUP 2338	-2.11	-2.96*	-1.41	-1.76	1.59	1.33	-0.26	1.32	-7.72*	15.62**	-7.38*	41.79**
25	K9006 X UP2 572	1.06	0.88	1.06	0.7	1.84*	0.65	1.04	2.65**	-6.77*	0.71	0.76	54.26**
26	K9006 X DBW 17	-0.35	-0.35	-0.35	-0.71	1.59	1.32	0.26	1.85*	-24.36**	-5.35	-18.25**	25.15**
27	K9006 X UP2338	0.71	-0.52	0.71	0.35	3.18**	2.90**	1.83*	3.45**	-10.92**	14.66**	-3.72	47.39**
28	KAUZ//ALTER 84 X UP 2572	0	-0.53	-0.7	-1.06	-0.78	-1.29	-0.26	1.32	-27.34**	-13.95**	-33.13**	2.38
29	KAUZ//ALTER 84 X DBW 17	-0.71	-1.06	-1.41	-1.76	1.06	0.13	-0.26	1.32	13.07*	14.18**	-26.89**	11.92*
30	KAUZ//ALTER 84 X UP 2338	-1.07	-2.63	-1.76	-2.11	2.65**	1.70*	1.3	2.92**	28.35**	32.04**	-18.63**	24.57**
31	UP 2778 X UP 2572	-2.11	-3.47*	-1.76	-2.12	1.84*	0.65	1.04	2.65**	2.99	3.12	-5.22	45.09**
32	UP 2778 X DBW 17	-0.35	-1.91	-0.35	-0.71	1.59	1.32	0.26	1.85*	-11.44**	3.89	-18.76**	24.37**
33	UP 2778 X UP 2338	-4.14*	-4.47	-1.76	-2.12	1.06	0.79	0.26	1.32	3.76	25.58**	-4.82	45.71**
34	HD 2997 X UP 2572	0	-1.05	0.36	-0.01	2.89**	1.82**	2.35**	3.98**	-6.27	9.39*	-13.75**	32.05**
35	HD 2997 X DBW 17	0	-1.22	0.01	-0.36	1.06	0.66	0.26	1.32	2.29	3.08	-32.82**	2.82
36	HD 2997 X UP 2338	-2.76	-2.76	-0.35	-0.71	1.32	0.92	1	1.59	26.83**	32.69**	-16.72**	27.49**

Table 2: Cont.........

Sl. No.	Crosses	Plant height				Spike length (cm)				No. of productive tillers per plant			
		Hetero-beltiosis	Mid Parent Heterosis	Standard Heterosis		Hetero-beltiosis	Mid Parent Heterosis	Standard Heterosis		Hetero-beltiosis	Mid Parent Heterosis	Standard Heterosis	
				Check UP 2684	Check PBW 343			Check UP 2684	Check PBW 343			Check UP 2684	Check PBW 343
1	CHOI/M 95 X UP 2572	8.33*	4.51	-6.79*	4.33	-3.99	0.55	4.94	14.07*	-13.61**	-5.1	-28.58**	-15.61**
2	CHOI/M 95 X DBW 17	25.97**	14.72**	-9.16**	1.68	4.24	14.25*	3.64	12.66	-1.72	3.64	-18.77**	-4.01
3	CHOI/M 95 X UP 2338	15.81**	10.93**	-8.43**	2.51	9.1	14.65**	8.48	17.93**	-10.58*	4.41	-26.09**	-12.66**
4	CPAN 3067 X UP 2572	-0.04	-0.5	-7.73*	3.29	-9.79	0.22	-1.39	7.18	-19.43**	-11.93**	-34.12**	-22.15**
5	CPAN 3067 X DBW 17	36.16**	19.63**	-1.53	10.23**	11.32	14.90*	-2.64	5.83	2.62	7.67	-16.09**	-0.84
6	CPAN 3067 X UP 2338	24.03**	14.46**	-1.92	9.79**	15.38*	16.90*	3.61	12.63	4.8	21.82**	-14.30**	1.27
7	FRET/TUKURU/FRET2 X UP 2572	1.41	-0.91	-10.55**	0.13	-2.64	1.66	6.41	15.66*	-11.85*	-8.09	-14.19**	-29.33**
8	FRET/TUKURU/FRET2 X DBW 17	22.54**	10.41**	-11.38**	-0.79	-2.92	6.69	-2.89	5.56	-36.15**	-30.63**	-52.69**	-44.09**
9	FRET/TUKURU/FRET2 X UP 2338	25.44**	18.58**	-0.82	11.03**	3.17	8.72	3.19	12.17	39.54**	43.44**	-13.05**	2.74
10	HP 1749 X UP 2572	3.15	1.05	-8.56**	2.36	-13.98*	-6.28	-5.99	2.19	-28.25**	-26.41**	-48.76**	-39.45**
11	HP 1749 X DBW 17	28.31**	15.29**	-7.20*	3.88	1.91	7.41	-6.91	1.19	16.86**	19.02**	-13.41**	2.32
12	HP 1749 X UP 2338	18.55**	11.78**	-6.26*	4.93	14.22*	15.19**	4.34	13.42*	7.25	17.53**	-23.41**	-9.49*
13	HPW 224 X UP 2572	4.69	0.71	-3.33	8.21*	-25.96**	-24.34**	-19.01**	-12.03	3.05	4.78	-27.69**	-14.56**
14	HPW 224 X DBW 17	26.88**	6.23*	-8.24**	2.72	-8.91	2.13	-4.69	3.6	-3.61	-0.99	-28.58**	-15.61**
15	HPW 224 X UP 2338	19.94**	6.14*	-5.16	6.17	-0.31	7.29	4.31	13.39*	-2.79	5.67	-31.79**	-19.41**
16	HW 3042 X UP 2572	2.09	1.34	-7.12*	3.97	-11.86*	-10.5	-3.67	4.42	9.28*	14.75**	-18.05**	-3.17
17	HW 3042 X DBW 17	39.29**	23.38**	0.74	12.77**	-9.53	2.01	-4.11	4.23	0	0.59	-25.05**	-11.39**
18	HW 3042 X UP 2338	21.11**	12.64**	-4.23	7.20*	4.75	13.40*	11.02	20.68**	-22.85**	-13.60**	-42.15**	-31.65**
19	JAKANA/RHEA X UP 2572	-0.14	-0.41	-8.30**	2.65	-11.36*	-4.25	-3.12	5.31	-42.62**	-29.29**	-37.51**	-26.16**
20	JAKANA/RHEA X DBW17	26.08**	11.09**	-8.82**	2.07	-0.48	5.81	-7.38	0.68	-16.72**	-0.87	-9.30**	7.17
21	JAKANA/RHEA X UP 2338	23.29**	14.09**	-2.51	9.13**	14.14*	16.18**	6.23	15.47*	-22.45**	0.63	-15.55**	-0.211
22	JUPIBJY/URES X UP 2572	0.95	-3.81	-6.79*	4.34	-14.73**	-14.51**	-6.33	1.82	5.7	11.11*	-20.55**	-6.12
23	JUPIBJY/URES X DBW 17	29.19**	7.52*	-6.57*	4.59	-17.25**	-5.23	-9.1	-1.19	9.73*	10.52*	-17.51**	-2.53
24	JUPIBJY/URES XUP 2338	24.41**	8.97**	-1.63	10.12**	-3.06	6.66	6.48	15.75*	-3.56	8.12	-27.51**	-14.35**
25	K9006 X UP2 572	7.22*	2.54	-1	10.82**	-9.93*	-4.07	12.14	21.89**	18.84**	21.59**	-15.55**	-0.21
26	K9006 X DBW 17	28.66**	7.53*	-6.95*	4.17	-12.29*	5.75	9.2	18.69**	-27.47**	-25.95**	-46.26**	-36.49**
27	K9006 X UP2338	18.65**	4.35	-6.18*	5.03	-8.49	6.32	13.94*	23.85**	3.51	13.18**	-26.44**	-13.08**
28	KAUZ//ALTER 84 X UP 2572	4.65	2.27	-7.665*	3.36	-14.07*	-9.72	-6.08	2.09	2.75	5.26	-26.79**	-13.50**
29	KAUZ//ALTER 84 X DBW 17	28.42**	15.71**	-7.108*	3.98	-3.79	5.13	-4.99	3.28	18.31**	20.63**	-12.33**	3.59
30	KAUZ//ALTER 84 X UP 2338	23.41**	16.65**	-2.42	9.23**	8.71	13.87*	7.36	16.69*	5.76	15.77**	-24.66**	-10.97**
31	UP 2778 X UP 2572	3.29	2.72	-5.68	5.58	-12.61*	-7.59	-4.49	3.82	14.41**	18.26**	-22.51**	-8.44*
32	UP 2778 X DBW 17	22.47**	8.25**	-11.42**	-0.49	-4.15	4.09	-6.61	1.52	-32.53**	-27.17**	-50.01**	-40.93**
33	UP 2778 X UP 2338	26.07**	17.01**	-0.32	11.59**	5.25	5.53	2.54	11.46	23.44**	27.77**	-21.98**	-7.81
34	HD 2997 X UP 2572	2.29	1.99	-6.11*	5.09	-16.72**	-3.51	-8.98	-1.06	27.60**	28.27**	-12.52**	3.38
35	HD 2997 X DBW 17	15.88**	2.13	-16.19**	-6.19	-2.4	-0.82	-19.97**	-13.01	14.69**	19.14**	-15.02**	0.42
36	HD 2997 X UP 2338	20.44**	11.47**	-4.77	6.60*	2.17	8.45	-8.25	-0.27	30.00**	20.16**	-23.41**	-9.49*

Table 2: Cont.........

Sl. No.	Crosses	No. of spikelets per spike				1000 grain weight			
		Hetero-beltiosis	Mid Parent Heterosis	Standard Heterosis		Hetero-beltiosis	Mid Parent Heterosis	Standard Heterosis	
				Check UP 2684	Check PBW 343			Check UP 2684	Check PBW 343
1	CHOI/M 95 X UP 2572	3.79	3.88	5.52*	-0.63	-9.17**	-3.81*	23.10**	4.17
2	CHOI/M 95 X DBW 17	3.63	4.84*	5.18*	-0.95	12.05**	17.81**	49.56**	26.56**
3	CHOI/M 95 X UP 2338	6.11*	15.57**	7.70*	1.42	11.20**	30.76**	33.91**	13.32**
4	CPAN 3067 X UP 2572	-1.65	-1.32	-0.02	-5.85*	-1.21	13.69**	33.89**	13.29**
5	CPAN 3067 X DBW 17	0.16	-0.75	-0.69	-6.48**	-12.04**	0.56	17.39**	-0.67
6	CPAN 3067 X UP 2338	2.99	11.91**	4.01	-2.05	51.22**	64.01**	51.21**	27.96**
7	FRET/TUKURU/FRET2 X UP 2572	8.08**	9.25**	9.88**	3.48	-7.17**	-6.21**	28.45**	8.69**
8	FRET/TUKURU/FRET2 X DBW 17	-2.69	-2.53	-3.2	-8.85**	11.22**	13.23**	53.92**	30.25**
9	FRET/TUKURU/FRET2 X UP 2338	-4.55	3	-5.05	-10.59**	9.33**	35.83**	51.31**	28.04**
10	HP 1749 X UP 2572	-2.76	-2.04	0.32	-5.53*	3.52	4.85**	43.95**	21.82**
11	HP 1749 X DBW 17	-0.32	1.65	2.84	-3.16	0.06	2.1	39.13**	17.73**
12	HP 1749 X UP 2338	0.65	10.43**	3.84	-2.21	0.14	24.63**	39.24**	17.82**
13	HPW 224 X UP 2572	5.11*	5.90**	6.86**	0.63	-7.53**	-4.78**	33.02**	12.57**
14	HPW 224 X DBW 17	-1.51	-1.01	-1.36	-7.12**	-7.04**	-3.55*	33.74**	13.18**
15	HPW 224 X UP 2338	0	8.25**	0.15	-5.69*	7.85**	35.95*	55.16**	31.30**
16	HW 3042 X UP 2572	-3.79	-1.6	-2.19	-7.89**	-3.82*	3.02	30.35**	10.31**
17	HW 3042 X DBW 17	-9.64**	-8.71**	-10.42**	-15.64**	1.29	7.72**	35.19**	14.40**
18	HW 3042 X UP 2338	6.39*	13.54**	3.34	-2.69	11.98**	30.35**	31.62**	11.38**
19	JAKANA/RHEA X UP 2572	3.63	4.92*	5.35*	-0.79	-8.99**	-7.86**	23.33**	4.37*
20	JAKANA/RHEA X DBW17	-2.2	-2.2	-3.04	-8.69**	1.11	1.6	34.95**	14.19**
21	JAKANA/RHEA X UP 2338	5.58	13.76**	4.68	-1.42	3.86	26.77**	37.29**	16.18**
22	JUPIBJY/URES X UP 2572	2.8	5.05*	4.51	-1.58	-1.6	1.1	33.36**	12.85**
23	JUPIBJY/URES X DBW 17	3.72	4.69*	2.83	-3.16	6.88**	8.99**	42.65**	20.71**
24	JUPIBJY/URES XUP 2338	6.03*	13.26**	3.17	-2.84	18.79**	43.29**	52.37**	28.92**
25	K9006 X UP2 572	0.65	0.82	2.67	-3.32	6.04**	14.64**	43.71**	21.61**
26	K9006 X DBW 17	2.3	3.75	4.35	-1.74	4.56*	12.25**	39.56**	18.09**
27	K9006 X UP2338	3.45	12.92**	5.52*	-0.63	26.06**	45.51**	45.21**	22.88**
28	KAUZ//ALTER 84 X UP 2572	2.72	3.91	6.86**	0.63	12.50**	14.67**	52.47**	29.02**
29	KAUZ//ALTER 84 X DBW 17	-3.22	-0.91	0.65	-5.21*	4.92*	6.15**	40.04**	18.51**
30	KAUZ//ALTER 84 X UP 2338	1.12	11.36**	5.18*	-0.95	2.82	24.85**	34.89**	13.47**
31	UP 2778 X UP 2572	2.97	3.74	4.68	-1.42	13.68**	15.86**	60.10**	35.48**
32	UP 2778 X DBW 17	0.16	0.67	0.32	-5.53*	15.67**	18.77**	62.90**	37.85**
33	UP 2778 X UP 2338	5.69*	14.41**	5.86*	-0.32	7.28**	34.16**	51.09**	27.85**
34	HD 2997 X UP 2572	1.92	3.33	6.53*	0.32	10.48**	17.54**	49.73**	26.71**
35	HD 2997 X DBW 17	0.32	2.96	4.85	-1.26	-0.37	5.24**	32.98**	12.53**
36	HD 2997 X UP 2338	-1.44	8.76**	3	-3	78.51**	47.966**	50.65**	27.49**

Table 2: Cont.........

Sl.	Crosses	No. of grains per spike				Harvest index (%)				Grain yield per plot			
		Hetero-beltiosis	Mid Parent Heterosis	Standard Heterosis		Hetero-beltiosis	Mid Parent Heterosis	Standard Heterosis		Hetero-beltiosis	Mid Parent Heterosis	Standard Heterosis	
				Check UP 2684	Check PBW 343			Check UP 2684	Check PBW 343			Check UP 2684	Check PBW 343
1	CHOI/M 95 X UP 2572	1	5.21*	-13.76**	0.66	-0.49	1.5	-3.18	14.41**	-1.87	11.87*	31.31**	51.32**
2	CHOI/M 95 X DBW 17	-37.05**	-35.74**	-43.98**	-34.61**	-1	6.41*	7.52*	27.052**	48.43**	40.15**	49.83**	72.67**
3	CHOI/M 95 X UP 2338	13.94**	34.75**	-2.71	13.57**	21.12**	52.18**	13.21**	33.78**	33.49**	62.90**	34.76**	55.28**
4	CPAN 3067 X UP 2572	8.70**	10.15**	-12.29**	2.38	26.200**	27.43**	25.22**	47.97**	8.16	9.23*	44.73**	66.79**
5	CPAN 3067 X DBW 17	6.61*	11.82**	-5.13*	10.74**	1.93	6.53*	10.71**	30.82**	12.74**	21.20**	47.89**	70.43**
6	CPAN 3067 X UP 2338	15.99**	33.99**	-6.41**	9.23**	-1.03	27.09**	-1.79	16.04**	12.88**	50.57**	48.08**	70.65**
7	FRET/TUKURU/FRET2 X UP 2572	9.90**	13.18**	-13.67**	0.77	-32.80**	-25.55**	-18.81**	-4.07	-33.84**	-29.51**	0.94	16.32*
8	FRET/TUKURU/FRET2 X DBW 17	10.82**	1.01**	-1.38	15.12**	-11.82**	-7.17*	6.49	25.84**	-0.61	14.25**	51.56**	74.76**
9	FRET/TUKURU/FRET2 X UP 2338	-11.73**	-1.78	-34.68**	-23.75**	-9.67**	23.91**	9.23*	28.95**	9.18*	52.77**	66.60**	91.99**
10	HP 1749 X UP 2572	18.85**	23.92**	1.66	18.66**	-32.82**	-3..35**	-34.64**	-22.77**	-43.44**	-43.18**	-24.32**	-12.78
11	HP 1749 X DBW 17	2.82	4.86*	-8.49**	6.81*	2.16	11.52**	10.96**	31.12**	-2.05	5.82	29.87**	49.66**
12	HP 1749 X UP 2338	-2.55	15.32**	-16.66**	-2.71	20.37**	49.35**	8.80*	28.57**	18.21**	58.24**	56.74**	80.62**
13	HPW 224 X UP 2572	-6.49*	-6.33*	-24.28**	-13.95**	13.06**	18.84**	10.01**	3..00**	19.55**	29.98**	59.97**	84.35**
14	HPW 224 X DBW 17	-31.77**	-27.64**	-39.28**	-29.13**	-5.31	4.7	2.84	21.52**	31.75**	32.06**	48.70**	71.36**
15	HPW 224 X UP 2338	10.46**	26.35**	-12.91**	1.66	-32.20**	-16.79**	-40.44**	-29.63**	-23.93**	-3.9	-14.55*	-1.53
16	HW 3042 X UP 2572	7.64**	16.41**	-0.43	16.22**	-3.74	-2.45	-3.79	13.69**	1.29	21.78**	35.54**	56.19**
17	HW 3042 X DBW 17	-0.05	-1.98	-11.06**	3.82	-3.23	0.78	5.1	24.19**	29.39**	44.84**	46.05**	68.30**
18	HW 3042 X UP 2338	-12.97**	6.26*	-19.50**	-6.04*	3.16	32.82**	3.12	21.85**	50.93**	73.71**	34.02**	54.44**
19	JAKANA/RHEA X UP 2572	-3.26	-3.2	-24.01**	-11.29**	1.38	2.12	0.11	18.29**	-2.66	-0.71	30.24**	50.09**
20	JAKANA/RHEA X DBW17	-15.51**	-10.19**	-24.84**	-12.24**	1.64	6.48*	10.4	30.46**	-16.96**	-11.56*	6.75	23.02**
21	JAKANA/RHEA X UP 2338	-22.43**	-11.45**	-39.14**	-28.96**	4.23	33.61**	2.92	21.61**	-6.89	23.35**	19.69**	37.93**
22	JUPIBJY/URES X UP 2572	-2.36	-0.18	-19.79**	-6.37*	27.50**	29.19**	27.39**	50.54**	-8.45*	-2.45	39.68**	60.97**
23	JUPIBJY/URES X DBW 17	-27.93**	-25.06**	-35.87**	-25.14**	-10.87**	-7.16*	-3.2	14.38**	-7.19	6.7	41.63**	63.21**
24	JUPIBJY/URES XUP 2338	8.25**	26.01**	-11.06**	3.82	11.05**	42.95**	10.96**	31.12**	14.27**	59.90**	74.37**	100.94**
25	K9006 X UP2 572	14.37**	12.41**	-13.19**	1.33	-1.86*	-4.3	-2.8	14.85**	-18.76**	-15.34**	18.24**	36.26**
26	K9006 X DBW 17	-13.11**	-6.21*	-22.68**	-9.75**	-7.27*	-6.07*	0.71	19.00**	-36.45**	-28.42**	-7.51	6.59
27	K9006 X UP2338	33.43**	50.14**	1.28	18.23**	3.6	36.08**	9.65**	29.57**	-8.61*	26.06**	33.02**	53.29**
28	KAUZ//ALTER 84 X UP 2572	-6.49*	-2.19	-19.45**	-5.98*	10.48**	15.47**	17.66**	39.03**	-5.79	-2.59	34.91**	55.47**
29	KAUZ//ALTER 84 X DBW 17	0.91	2.55	-10.20**	4.82	7.81*	8.88**	17.10**	38.37**	10.69*	23.80**	58.51**	82.67**
30	KAUZ//ALTER 84 X UP 2338	4.18	23.66**	-10.25**	4.76	4.19	37.15**	10.96**	31.12**	26.15**	73.10**	80.64**	28.17**
31	UP 2778 X UP 2572	-3.18	6.24**	-7.55**	7.92**	12.81**	16.42**	9.77**	29.71**	-20.17**	-11.89**	6.83	23.10**
32	UP 2778 X DBW 17	-25.78**	-23.17**	-29.13**	-17.28**	-1.33	7.22*	7.17	26.63**	20.01**	22.28**	35.45**	56.09**
33	UP 2778 X UP 2338	-9.19**	12.25**	-13.29**	1.21	19.64**	48.99**	9.21	29.05**	52.51**	90.31**	65.74**	90.99**
34	HD 2997 X UP 2572	0.21	6.64**	-10.49**	4.49	-0.38	0.86	-0.59	17.46**	-6.94	-5.73	24.52*	43.49**
35	HD 2997 X DBW 17	10.35**	10.56**	-1.43	15.06**	-3.77	0.29	4.51	23.49**	-18.40**	-12.53**	6.39	22.60**
36	HD 2997 X UP 2338	3.13	24.21**	-7.88**	7.53**	9.44*	40.83**	9.21**	29.05**	14.72**	52.72**	49.58**	72.37**

*and ** Significant 5% and 1% level of significance

Table 3: Heterotic crosses for yield traits

	Character	Heterobeltiosis	Relative heterosis	Standard heterosis	
				UP 2684 (Check)	PBW 343 (Check)
1.	Days to heading	UP 2778 X UP 2338	CHOI/M 95 X DBW 17	-	-
2.	Days to maturity	CPAN 3067 X UP 2572	CPAN 3067 X UP 2572	FRET/TUKURU/FRET2 X DBW 17	HP 1749 X DBW 17
3.	Flag leaf area	CHOI/M 95 X UP 2338	CHOI/M 95 X UP 2338	HPW 224 X UP 2572	HPW 224 X UP 2572*
4.	Plant height	-	-	UP 2778 X DBW 17*	-
5.	Spike length	CPAN 3067 X UP 2338	CPAN 3067 X UP 2338	K 9006 X UP 2338	K 9006 X UP 2338
6.	Productive tillers per plant	FRET/TUKURU/FRET2 X UP 2338	FRET/TUKURU/FRET2 X UP 2338	-	-
7.	Number of spikelets per spike	FRET/TUKURU/FRET2 X UP 2572	CHOI/M 95 X UP 2338	FRET/TUKURU/FRET2 X UP 2572	-
8.	Grain yield per plot	UP 2778 X UP 2338	UP 2778 X UP 2338	FRET/TUKURU/FRET2 X UP 2338	JUPIBJY/URES X UP 2338
9.	Harvest index	JUPIBJY/URES X UP 2572	CHOI/M 95 X UP 2338	JUPIBJY/URES X UP 2572	JUPIBJY/URES X UP 2572
10.	Number of grains per spike	K 9006 X UP 2338	K 9006 X UP 2338	-	HP 1749 X UP 2572
11.	1000 grain weight	CPAN 3067 X UP 2338	CPAN 3067 X UP 2338	UP 2778 X DBW 17	UP 2778 X DBW 17

NOTE: The underlined crosses indicate maximum heterosis for the concerned trait and concerned parent mentioned in the table

pollinated crops like wheat (Freeman, 1919). Highest estimates of heterobeltiosis (52.51) and mid parent heterosis (90.31) were found in the hybrid UP 2778 X UP 2338 for grain yield per plot. Significant standard heterosis over the checks, UP 2684 and PBW 343 was observed in crosses FRET/TUKURU/FRET2 X UP 2338(66.60) and JUPIBJY/URES X UP 2338 (100.94) for this character. In some crosses where heterosis was observed, over dominance might be involved and it may be concluded that effective selection of desirable recombinants from this material is possible. Heterosis for this trait has also been reported by Chakraborty and Tewari (1995) and Devi *et al*. (2013).

Harvest index

In breeding programmes, harvest index is generally estimated for the evaluation of the genotypes as it is one of the important agronomic traits deciding the yield potential of the cultivar. In our study maximum positive heterosis for harvest index over both the checks, PBW 343 and UP 2684 was displayed by the cross JUPIBJY/URES × UP 2572 with the values of 25.39 and 50.54, respectively. This cross also exhibited significant positive heterosis (27.50) over the better parent. The cross CHOI/M 95 X UP 2338 exhibited significant relative heterosis (52.18). These crosses could be of greater value if exploited in breeding programme. The findings corroborate with the results of Budak and Yildrim (1996) and Srivastava and Singh (2008).

Number of grains per spike

Grains per spike directly determine the yield potential of a genotype (Inamullah *et al.* 2006). For number of grains per spike, the cross K 9006 × UP 2338 exhibited maximum heterobeltiosis (33.43) and significant heterosis over the mid parental value (50.14). The cross HP 1749 X UP 2572 showed significant (18.66) superiority over the standard check, PBW 343. These results could be verified from the findings of Saleem and Hussain (1988); Khan and Bajwa (1989); Tewari and Chakraborty (1992); Baloch *et al*. (2001); Nawracaa *et al*. (2003); Bunta *et al*. (2005); ZhaoPeng *et al*. (2009) and Batool *et al*. (2013).

1000 grain weight

The positive estimate of better parent and mid parent heterosis was observed in the hybrid CPAN 3067 X UP 2338 with the estimated values of 51.22 and 64.01 while, standard heterosis over both the checks was registered by UP 2778 X DBW 17 which were 62.90 and 37.35, against the checks UP 2684 and PBW 343 for 1000 grain weight. Positive heterosis for this trait has been reported by Wan *et al*. (1973); Sip and Skorpik (1981); Palve *et al*. (1986); Saleem and Hussain (1988); Pickett (1993); Chakraborty and Tewari (1995) and Devi *et al*. (2013).

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