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Estimation of Heterosis for Grain Yield and its Related Traits in Wheat (*Triticum aestivum* L.) under Leaf Rust Conditions

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Abstract: Eight bread wheat (*Triticum aestivum* L.) cultivars were crossed in a diallel fashion and evaluated for heterosis in F_1 generation for grain yield and other economic traits under leaf rust conditions. Highly significant differences were found among genotypes for all the traits studied. Significant positive heterosis and heterobeltiosis was observed for grain yield per plant in almost all crosses. Estimates for positive significant heterosis over mid and better parents for plant height were 68 and 32% of total crosses where as 44 and 35 crosses gave significant positive increased tillers per plant over their mid and better parents, respectively. Positive and significant heterotic effects were measured as 11.61, 61.90, 30.67, 2.3, 51.89, 126.64, 111.71 and 45.91% from crosses SA42 x Nacozari, MH 97 x Crow, Parula x Chenab70, Crow x Nacozari, Crow x Chenab70, SA42 x Nacozari, MH97 x SA42 and Nacozari x Chenab for plant height, tillers per plant, grains per spike, spikelets per spike, grain weight, grain yield, biological yield per plant and harvest index, respectively.

Key words: Bread wheat, crosses, heterosis, grain yield, economic traits, Pakistan

INTRODUCTION

Bread wheat (*Triticum aestivum* L.) is one of the major staple food crops throughout the world, especially in Pakistan. The importance of wheat is increasing day by day due to increased human population pressure in the country. It is the dire need of the day to boost up per acre wheat yield that is subjected to continuous genetic improvement. The successful hybrid maize production has created sense of considerable interest among wheat breeders for utilization in hybrid wheat production. The presence of sufficient hybrid vigor is an important pre-requisite for the successful production of any hybrid varieties. Previously, exploitation of the heterotic effects for grain yield were largely attributed to cross-pollinated crops but Briggle *et al.*[1] reported presence of heterosis in considerable quantity for grain yield and yield components in various F_1 wheat crosses. Hamada[2] estimated highly significant positive heterotic effects relative to the mid-parent or better parent and its values were obtained for number of spikes per plant, number of kernels per spike, 1000-kernel weight and grain yield per plant. Saleem and Hussain[3] observed a fair degree of heterosis for wheat grain yield per plant, grain number, grain weight. Boland and Walcott[4] reported significant heterosis for wheat grain yield per plant. Kumar and Ganguli[5] observed a positive heterosis for 1000 grain weight and harvest index while, Khan *et al.*[6] estimated most marked heterosis for characters like grains per spike, 1000 grain weight and grain yield per plant. Sharma and Singh[7] reported heterosis for wheat grain yield reaching 60% while fair degree of heterosis for number of grains per spike. Ho[8] calculated heterosis for grain weight per plant (112%), number of spikes per plant (109%), 1000 grain weight (106%) and plant height (103%) in F_1 hybrids in spring wheat. Malik *et al.*[9] emphasized that all hybrids exhibited an average increase of 6.8, 35.8, 21.4, 2.2, 22.8 and 31.2% over better parent for plant height, number of tillers per plant, spike length, number of grains per spike, 100 grain weight and yield per plant, respectively. Krishna and Ahmad[10] reported highest mean heterosis for 1000 grain weight (14.6%), grain yield (12.52%) and harvest index (9.72%)in wheat. Joshi *et al.*[11] calculated maximum values of heterbeltiosis, 13.30, 44.30 and 36.37% from three F_1 crosses of wheat.

Nedelea and Moiscu [12] reported significant heterosis over mid parents for grain weight per spike. Winzeler *et al.*[13] reported high relative heterosis for grain yield per ear, varying between 29.9 and 47.6% with an average of 42.1%. However, Sedeque *et al.*[14] reported that most of the wheat hybrids showed negative heterosis for plant height over the tallest parent and maximum

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heterosis over the better parent for number of spikes per plant was 141.7% and maximum heterosis over the better parent and mid-parental value (182.9 and 215.4%, respectively) for grain yield per plant.

Owing to high yield and yield related traits, disease resistance is also an important trait. Anzalone[15] reported that leaf rust occurs more frequently and yield losses upto 50%. During rust epidemic year 1978, a loss of 10% in grain yield was primarily attributed to leaf rust attack that compelled country to Pakistan to import large quantities of wheat[16]. It is apparent that wheat production of the country can be stabilized if the wheat varieties have potential against rusts incidence especially leaf rust. The possible heterosis exploitation continues to be a critical question in the hybrid wheat research program. The choice of parental material used in the hybridization scheme is of prime importance for development of suitable genotype. The parents that are genetically superior and diverse in the traits if selected and utilized for designing a meaningful breeding programme to contribute for the development of better quality, high yielding and leaf rust resistant wheat varieties. The present study was undertaken to estimate the heterosis and heterobeltiosis for various plant traits in F_1 crosses of wheat.

MATERIALS AND METHODS

Eight bread wheat varieties ranging from susceptible to resistant to leaf rust disease were crossed in all possible combinations including reciprocals during February-March 1999 at Ayub Agricultural Research Institute (Wheat Section), Faisalabad, Pakistan. The brief description of varieties is given (Table 1).

F_1 crosses along with parents were planted in the field during 1999-2000 in a Randomized Complete Block Design with three replications, keeping plant to plant and row to row distances as 15 and 30 cm, respectively. Recommended agronomic practices were performed uniformly to whole of the experiment. Rust susceptible variety Morocco was planted as spreader around the experimental area. On the beginning of culm elongation of plant, the spreader rows were artificially inoculated with pathogen of mixture of prevalent races for leaf rust (*Puccinia recondita*). On the appearance of leaf rust on spreader rows, all the genotypes were inoculated with inoculums collected from spreader. Frequent light irrigations were applied after inoculation to create humidity for rust. At maturity ten guarded plants were selected at random from each plot and data were recorded for plant height, fertile tillers per plant, spikelets per spike, number of grains per spike, 100-grain weight, grain yield, biological yield per plant and harvest index. The data were subjected to statistical analysis by using the analyses of variance technique[17] to determine the significant differences among genotypes for all characters.

The percent increase (+) or decrease (-) of F_1 over mid parent and as well as better parent was calculated to estimate possible heterotic effects for traits studied following Matzingar *et al.*[18]. In order to determine significant difference of F_1 hybrid means from respective mid parent and better parent values, t-test was applied by using the formulae as mentioned by Wynne *et al.*[19].

Table 1: Characteristics of eight bread wheat varieties

Name of variety	Origin	Characteristics
SA42 C271/LR64//SON64	Pakistan	Shot duration, dwarf plant, bold spike and grain, highly susceptible to leaf rust, high yielding, yield potential 5.5 ton ha^{-1}
Lu26 BLS/KHUSHAL69	Pakistan	Short duration long stature, bold grain with high protein, susceptible to leaf rust, yield potential 5.6 ton ha^{-1}
MH97 (ATTILA) ND/VG9144/K AL/BB/3/YACO/4/VEE#5	Pakistan	Long duration, dwarf plant, more tillering, small grain, resistant to leaf rust, high yielding, yield potential 6.7 ton ha^{-1}
Nacozari F 76 BLUE JAY'S'	Mexico	Semi dwarf, medium in maturity, resistant to leaf rust, yield potential 4.2 ton
Chenab70 C271-WT (E) XSON64	Pakistan	Medium in maturity, long stature, long head, high susceptible to leaf rust, high yielding, yield potential 6 ton ha^{-1}
Crow FR1316/3/MCM/KT//Y50/4/ZA75/5/BJY'S'	Mexico	Medium in duration, Semi dwarf, resistant to leaf rust, yield potential 5.2 ton ha^{-1}
Parula FRN/3/2*FR//KAD/GB/4/BB/CHA	Mexico	Dwarf, medium in maturity, bold grain, resistant to leaf rust, yield potential 4.8 ton ha^{-1}
Inqilab91 WL711/CROW'S'	Pakistan	Semi dwarf, medium in maturity, long spike, bold grain, resistant to leaf rust, high yielding, wider adopter, yield potential 7 ton ha^{-1}

RESULTS AND DISCUSSION

Statistical analysis of variance revealed significant differences at 1% probability level among wheat genotypes for all traits studied (Table 2). For plant height, the negative heterosis is preferred in wheat breeding because dwarfness is desirable for resistant to lodging and more responsiveness to fertilizer. Moreover, dwarf wheat varieties in Pakistan played significant role in green revolution. As shown in Table 3, the 44 crosses exhibited significant heterosis, among which six crosses showed negative and 38 crosses showed positive heterosis. While 52 crosses indicated heterobeltiosis out of which 34 negative and 18 positive. The hybrids LU-26 x Chenab70, LU-26 x Inqilab 91 and Chenab70 x MH-97 with their respective reciprocals displayed desirable performance for negative heterosis and heterobeltiosis. The maximum negative heterosis 2.66% by LU-26 x Chenab 70 and heterobeltiosis 11.55% by Parula x Chenab 70 were estimated. Similarly, maximum positive heterosis was found in hybrids SA-42 x Nacozari (11.61%), Crow x MH-97 (11.51%) and heterobeltiosis in Parula x Crow (8.05%) and Crow x MH97 (8.03%). The results indicated that 68 and 32% of total hybrids increased over mid and better parents, respectively. Similar results are also reported by Malik *et al.*[9]. Negative heterosis was found by Sedeque *et al.*[14].

Fertile tillers per plant are an important yield component and its positive heterosis is useful in wheat breeding programme. Forty-four and thirty five crosses (Table 3) gave considerable increase over their mid and better parents, respectively. Over all 79 and 62% of total crosses displayed heterosis and heterobeltiosis positively ranging from 3.77 to 61.9 and 0.90 to 46.39%, respectively. The cross MH97 x Crow gave maximum heterosis (61.9%) and Nacozari x SA-42 showed 46.39% increase over better parents. Only seven crosses had significant negative heterosis and 12 crosses exhibited heterobeltiosis. Similarly Malik *et al.*[9] calculated 35.81% increase of productive tillers over better parent.

Number of grains per spike is an essential component of grain yield. It is obvious from the Table 4 that all hybrids displayed significant heterosis out of which 54 crosses showed positive and only two crosses depicted negative heterosis. While, significant heterobeltiosis was recorded in 43 crosses positively and eight crosses performed negatively. Over all desirable crosses for producing more grains per spike over mid parent and better parent were 96 and 77%, respectively. Higher heterosis was noted in crosses Parula x Chenab70 (30.67%), Chenab70 x Parula (28.65%), Nacozari x MH97 (26.24%), Inqilab 91 x MH-97 (26.32%), MH-97 x Parula (25.89%) and Chenab70 x MH-97 (25.54%). While, the hybrids proved to be desirable giving more grains over better parents were, Parula x Chenab 70 (27.80%), Chenab70 x Parula (25.82%), Nacozari x MH-97 (25.44%), MH-97 x Parula (24.57%) and Chenab70 x MH-97 (24.07%). Hence it is revealed that the parents MH-97, Chenab 70, Parula and Nacozari are best for synthesizing more grains per spike to be utilized in breeding programme. The results are in agreement with finding of Hamada[2].

As evident in Table 4, seven crosses showed significant heterosis out of those four crosses showed positive and three crosses negative heterosis for spikelets per spike. Nineteen hybrids displayed significantly reduced spikelets per spike than better parents. Only one cross (Nacozari x Inqilab91) showed significant positive heterobeltiosis. Maximum heterosis for spikelets was found in crosses Crow x Nacozari (4.23%), Nacozari x Crow (4.06%), NacozarixInqilab 91 (3.99%) and Inqilab91xNacozari (3.83%). Similar findings were reported by Winzeler *et al.*[13].

Grain weight is also an important component contributing for grain yield production. Positive heterosis is desirable for this trait. Positive heterosis was significant in 49 crosses whereas negative heterosis was found in only three crosses (Table 5). Twenty-seven hybrids showed significant positive heterobeltiosis and seven crosses had negative values for this trait. Thus 87.5 and 48.2% of total crosses showed significant positive heterosis and heterobeltiosis ranging from 6.42 to 51.89% and 0 to 42.48%, respectively. Best crosses over mid parent and also better parent were proved to be desirable for more 100-grain weight were; Crow x Chenab70 and Nacozari x SA-42 with their reciprocals. However, the higher values for heterotic effect were observed in cross SA42 x Crow and its reciprocal. These results are in

Table 2: Means squares values from 8x8 cross analysis of variance for different traits in wheat

SOV	DF	Plant height	Tillers/plant	Grains/spike	100 grains weight	Grain yield/plant	Biological yield/plant	Harvest index
Replication	2	5.87ns	0.06ns	0.009ns	0.001ns	0.41ns	5.36ns	0.80ns
Genotypes	63	127.8**	12.11**	53.94**	1.24**	62.23**	472.5**	31.70**
Parents	7	285.76**	4.15**	90.36**	1.33**	26.95**	112.99**	104.84**
Crosses	55	103.91**	12.43**	34.85**	1.05**	51.36**	432.5**	20.74**
Parent vs. crosses	1	336.1**	49.95**	849.31**	10.87**	907.27**	5188.97**	122.35**
Error	126	2.06	0.04	0.04	0.03	0.47	1.49	2.85

* = Significant at 5% probability level, ** = Significant at 1% probability level, ns = Non-Significant

Table 3: Estimates of heterosis and heterobeltiosis (%) for plant height and number of tillers per plant

	Plant height		Tillers per plant	
Cross	Heterosis	Heterobeltiosis	Heterosis	Heterobeltiosis
LU-26 X SA42	8.81**	3.54**	-12.39**	-16.02**
LU-26 X CH-70	-2.66**	-3.40**	26.11**	25.41**
LU-26X MH 97	4.63**	-2.47**	52.65**	27.31**
LU-26 X Nacozari	5.36**	-3.39**	-6.36**	-10.50**
LU-26X Crow	4.29**	-5.60**	29.57**	26.18**
LU-26 X Parole	5.77**	-6.16**	41.30**	39.04**
LU-26X Inqilab91	-1.80*	-5.21**	26.87**	15.38**
SA42X LU-26	8.65**	3.39**	-10.66**	-14.36**
SA42X CH-70	0.33	-5.22**	-3.77	-7.26**
SA42 X MH 97	6.49**	4.19**	42.79**	15.13**
SA42 X Nacozari	11.61**	7.32**	46.22**	45.78**
SA42X Crow	9.52**	3.89**	5.32*	-1.57
SA42X Parula	7.90**	0.2	43.91**	35.83**
SA42X Inqilab 91	3.80**	2.27**	18.86**	4.07*
CH-70 X LU-26	-2.57**	-3.31**	26.67**	25.97**
CH-70X SA42	0.36	-5.19**	-3.77	-7.26**
CH-70X MH 97	-2.53**	-9.79**	51.56**	25.83**
CH-70X Nacozari	0.03	-8.91**	21.51**	16.76**
CH-70X Crow	5.69**	-4.99**	4.86*	1.57
CH-70X Parula	0.57	-11.38**	-10.93**	-12.83**
CH-70X Inqilab91	3.93**	-0.41	11.50**	0.9
MH 97X LU-26	4.73**	-2.38**	53.10**	27.68**
MH 97X SA42	6.52**	4.22**	43.25**	15.50**
MH 97X CH-70	-2.57**	-9.82**	52.00**	26.20**
MH 97X Nacozari	9.08**	7.17**	57.34**	26.57**
MH 97X Crow	11.33**	7.86**	61.90**	38.01**
MH 97X Parula	0.07	-5.13**	36.68**	15.50**
MH 97X Inqilab91	-1.64	-5.15**	19.92**	8.86**
NacozariX LU-26	5.29**	-3.45**	-5.20*	-9.39**
NacozariX SA42	11.47**	7.19**	46.83**	46.39**
NacozariX CH-70	0.06	-8.89**	19.77**	15.08**
NacozariX MH 97	9.19**	7.27**	57.80**	26.94**
NacozariX Crow	5.49**	4.00**	8.43**	1.05
NacozariX Parula	-1.85	-5.36**	-6.82**	-12.30**
NacozarixInqilab91	2.38*	-2.94**	34.72**	17.65**
CrowX LU-26	4.06**	-5.81**	30.11**	26.70**
CrowX SA42	9.14**	3.53**	5.88**	-1.05
CrowX CH-70	7.23**	-3.61**	5.95**	2.62
CrowX MH 97	11.51**	8.03**	48.92**	26.94**
CrowX Nacozari	5.52**	4.04**	8.99**	1.57
CrowX Parula	7.87**	5.48**	21.16**	19.90**
CrowX Inqilab 91	3.01**	-3.65**	13.11**	5.43**
Parula X LU-26	5.57**	-6.34**	41.85**	39.57**
ParulaX SA42	7.72**	0.03	43.91**	35.83**
ParulaX CH-70	0.37	-11.55**	-9.84**	-11.76**
ParulaX MH 97	-0.07	-5.27**	37.12**	15.87**
ParulaX Nacozari	-1.89	-5.39**	-6.25**	-11.76**
ParulaX Crow	10.51**	8.05**	22.22**	20.94**
ParulaX Inqilab 91	5.89**	-3.01**	-4.90*	-12.22**
Inqilab 91XLU-26	-1.71*	-5.12**	27.36**	15.84**
Inqilab 91X SA42	3.99**	2.46**	17.83**	3.17
Inqilab 91XCH-70	3.99**	-0.35	12.50**	1.81
Inqilab91X MH 97	-1.51	-5.02**	20.73**	9.59**
Inqilab9XNacozari	2.41*	-2.91**	35.23**	18.10**
Inqilab 91X Crow	3.04**	-3.62**	12.62**	4.98**
Inqilab 91X Parula	5.96**	-2.94**	-4.41*	-11.76**

$^*P \leq 0.05$, $^{**}P \leq 0.01$

agreement with those of Kumar and Ganguli[5], Khan *et al.*[6] and Ho[8].

Grain yield is a complex of many traits and is desired in positive sense of heterotic effect. As depicted in Table 5, all of the crosses exhibited significant heterotic and heterobeltiosis effect except for only two crosses, which showed non-significant effects. All the crosses had positive effects but only two showed negative effects in heterobeltiosis. Hence 96.4 and 96.4% of total crosses gave significant positive heterosis and heterobeltiosis ranging from 4.44 to 126.64% and 3.87 to 114.23%, respectively.

Table 4: Estimates of heterosis and heterobeltiosis (%) for grains per spike and spikelets per spike

	Number of grains per spike		Number of spikelets per spike	
Cross	Heterosis	Heterobeltiosis	Heterosis	Heterobeltiosis
LU-26 X SA42	8.71**	-0.53*	-2.68	-7.05**
LU-26 X CH-70	7.02**	5.31**	-0.96	-1.90
LU-26X MH 97	3.53**	0.71*	-0.35	-0.35
LU-26 X Nacozari	15.12**	12.68**	-1.94	-5.83**
LU-26X Crow	11.66**	4.37**	-0.09	-0.35
LU-26 X Parole	10.85**	6.73**	0.00	-0.18
LU-26X Inqilab91	12.26**	3.59**	1.02	-2.46
SA42X LU-26	8.77**	-0.47*	0.00	-4.49*
SA42X CH-70	6.13**	-4.29**	1.08	-2.56
SA42 X MH 97	17.59**	4.94**	1.51	-3.04
SA42 X Nacozari	14.25**	2.53**	0.24	-0.32
SA42X Crow	3.34**	1.00**	-0.42	-5.13**
SA42X Parula	18.02**	4.35**	-3.53*	-8.01**
SA42X Inqilab 91	3.29**	2.35**	-3.24	-4.33*
CH-70 X LU-26	7.09**	5.38**	-1.31	-2.25
CH-70X SA42	8.67**	-2.00**	1.41	-2.24
CH-70X MH 97	25.54**	24.07**	0.26	-0.69
CH-70X Nacozari	19.53**	18.87**	-1.34	-4.38*
CH-70X Crow	13.47**	4.50**	0.70	-0.52
CH-70X Parula	28.65**	25.82**	2.36	1.21
CH-70X Inqilab91	15.11**	4.67**	-1.60	-4.10*
MH 97X LU-26	3.60**	0.78*	-2.82	-2.82
MH 97X SA42	14.89**	2.53**	1.68	-2.88
MH 97X CH-70	20.43**	19.02**	0.44	-0.52
MH 97X Nacozari	23.86**	23.08**	-2.28	-6.16**
MH 97X Crow	14.50**	4.31**	-0.62	-0.88
MH 97X Parula	25.89**	24.57**	1.41	1.23
MH 97X Inqilab91	24.39**	11.92**	3.23	-0.33
NacozariX LU-26	15.20**	12.75**	-1.60	-5.51**
NacozariX SA42	16.41**	4.47**	-0.24	-0.80
NacozariX CH-70	24.97**	24.29**	-1.17	-4.21*
NacozariX MH 97	26.24**	25.44**	-2.11	-6.00**
NacozariX Crow	9.34**	0.18	4.06*	-0.32
NacozariX Parula	14.33**	12.43**	-7.02**	-10.86**
NacozarixInqilab91	10.32**	-0.18	3.99*	3.40*
CrowX LU-26	11.53**	4.25**	0.09	-0.18
CrowX SA42	1.29**	-1.00**	-0.25	-4.97**
CrowX CH-70	14.94**	5.85**	0.87	-0.35
CrowX MH 97	12.47**	2.46**	-0.79	-1.06
CrowX Nacozari	12.37**	2.96**	4.23*	-0.16
CrowX Parula	18.18**	6.65**	2.21	2.12
CrowX Inqilab 91	1.03**	-0.36	0.43	-3.28
Parula X LU-26	11.00**	6.87**	0.00	-0.18
ParulaX SA42	21.74**	7.64**	-3.36	-7.85**
ParulaX CH-70	30.67**	27.80**	2.01	0.86
ParulaX MH 97	25.89**	24.57**	1.59	1.41
ParulaX Nacozari	18.69**	16.72**	-6.85**	-10.70**
ParulaX Crow	13.48**	2.40**	2.21	2.12
ParulaX Inqilab 91	1.71**	-9.34**	0.34	-3.28
Inqilab 91XLU-26	12.33**	3.65**	1.36	-2.13
Inqilab 91X SA42	0.50*	-0.41	-3.08	-4.17*
Inqilab 91XCH-70	9.58**	-0.36	-1.77	-4.26*
Inqilab91X MH 97	26.32**	13.65**	3.06	-0.49
Inqilab9XNacozari	4.63**	-5.33**	3.83*	3.24
Inqilab 91X Crow	-4.37**	-5.69**	-1.45	-5.08**
Inqilab 91X Parula	-1.04**	-11.80**	0.51	-3.11

* $p \leq 0.05$, ** $p \leq 0.01$

Higher values for heterotic effects were estimated in the hybrids SA-42 x Nacozari, Chenab70 x MH-97, MH-97 x SA-42, Inqilab 91x SA-42, SA-42 x Parula and Crow x SA-42 and their respective reciprocals. While, crosses LU-26 x MH-97, MH-97 x Crow, LU-26 x Crow and Inqilab 91 x MH-97 with their respective reciprocals were also proved to be higher grain yield producers over their better parents. Sharma and Singh[7], Boland and Walcott[4], Krishna and Ahmad[10], Joshi *et al.*[11] reported heterotic effects in wheat crosses in this respect.

Fifty crosses gave significant positive heterosis and only four crosses showed negative heterosis for biological yield per plant (Table 6). While, 44 hybrids

Table 5: Estimates of heterosis and heterobeltiosis (%) for 100-grain weight and grain yield per plant

	100-grain weight		Gain yield per plant	
Cross	Heterosis	Heterobeltiosis	Heterosis	Heterobeltiosis
LU-26 X SA42	21.51**	3.87	23.26**	3.74
LU-26 X CH-70	25.20**	2.58	67.39**	34.41**
LU-26X MH 97	16.92**	-1.94	78.34**	72.33**
LU-26 X Nacozari	31.50**	7.74**	33.64**	7.48*
LU-26X Crow	17.16**	1.29	59.55**	58.77**
LU-26 X Parole	-2.84	-11.61**	50.29**	31.17**
LU-26X Inqilab91	8.22**	1.94	53.23**	42.40**
SA42X LU-26	20.75**	3.23	23.41**	3.87
SA42X CH-70	17.70**	11.82**	32.30**	24.82**
SA42 X MH 97	30.23**	27.27**	93.75**	58.60**
SA42 X Nacozari	44.50**	37.27**	126.64**	114.23**
SA42X Crow	30.94**	29.20**	82.62**	53.09**
SA42X Parula	18.14**	10.24**	83.25**	75.59**
SA42X Inqilab 91	25.51**	13.14**	88.12**	49.25**
CH-70 X LU-26	26.77**	3.87	68.01**	34.91**
CH-70X SA42	17.70**	11.82**	31.53**	24.09**
CH-70X MH 97	29.41**	25.71**	116.34**	69.30**
CH-70X Nacozari	5.05	5.05	42.09**	41.80**
CH-70X Crow	50.94**	41.59**	59.26**	27.41**
CH-70X Parula	21.24**	7.87**	43.17**	29.77**
CH-70X Inqilab91	18.64**	2.19	58.03**	20.13**
MH 97X LU-26	16.92**	-1.94	77.86**	71.86**
MH 97X SA42	29.30**	26.36**	94.03**	58.84**
MH 97X CH-70	31.37**	27.62**	116.94**	69.77**
MH 97X Nacozari	7.84*	4.76	47.48**	15.58**
MH 97X Crow	6.42*	2.65	66.23**	61.40**
MH 97X Parula	-7.76*	-15.75**	49.52**	26.74**
MH 97X Inqilab91	7.44*	-5.11*	63.43**	56.96**
NacozariX LU-26	32.28**	8.39**	34.57**	8.23**
NacozariX SA42	45.45**	38.18**	126.64**	114.23**
NacozariX CH-70	7.07*	7.07*	43.33**	43.03**
NacozariX MH 97	6.86*	3.81	47.77**	15.81**
NacozariX Crow	16.04**	8.85**	51.00**	20.99**
NacozariX Parula	42.48**	26.77**	31.12**	19.06**
NacozarixInqilab91	16.10**	0.00	64.28**	25.05**
CrowX LU-26	17.91**	1.94	59.55**	58.77**
CrowX SA42	30.04**	28.32**	83.21**	53.58**
CrowX CH-70	51.89**	42.48**	59.26**	27.41**
CrowX MH 97	5.50	1.77	66.47**	61.63**
CrowX Nacozari	16.04**	8.85**	42.99**	14.57**
CrowX Parula	20.00**	13.39**	32.39**	15.06**
CrowX Inqilab 91	9.60**	0.00	18.12**	10.28**
Parula X LU-26	-2.13	-10.97**	50.00**	30.92**
ParulaX SA42	18.14**	10.24**	83.25**	75.59**
ParulaX CH-70	22.12**	8.66**	42.80**	29.43**
ParulaX MH 97	-7.76**	-15.75**	50.07**	27.21**
ParulaX Nacozari	44.25**	28.35**	30.76**	18.73**
ParulaX Crow	20.83**	14.17**	32.10**	14.81**
ParulaX Inqilab 91	-8.33**	-11.68**	-4.96	-22.06**
Inqilab 91XLU-26	8.22**	1.94	53.46**	42.61**
Inqilab 91X SA42	26.32**	13.87**	87.58**	48.82**
Inqilab 91XCH-70	21.19**	4.38	58.59**	20.56**
Inqilab91X MH 97	8.26**	-4.38	63.66**	57.17**
Inqilab9XNacozari	15.25**	-0.73	64.56**	25.27**
Inqilab 91X Crow	10.40**	0.73	18.35**	10.49**
Inqilab 91X Parula	-9.09**	-12.41**	-4.44	-21.63**

* p≤ 0.05, ** p≤ 0.01

exhibited significant positive and six crosses showed significant negative heterobeltiotic effects, for this trait. An on over all basis 89.3 and 78.6% crosses showed significant positive heterosis and heterobeltiosis respectively. These crosses having range of heterosis from -2.1% (Chenab70 x Nacozari) to 111.71% (MH-97xSA-42) and of heterobeltiotic from 1.55% (Crow x Nacozari) to 90.14% (MH-97 x Chenab70). The crosses proved to be higher yielder over their mid parents and better parents, respectively were screened as SA-42 x MH-97 (111.15, 72.88%), MH-97 x Chenab70 (106.45, 0.14%) and LU-26 x MH-97 (98.10, 81.0%).

Table 6: Estimates of heterosis and heterobeltiosis (%) for biological yield per plant and harvest index

Cross	Biological yield per plant		Harvest index	
	Heterosis	Heterobeltiosis	Heterosis	Heterobeltiosis
LU-26 X SA42	49.75**	32.56**	-17.06**	-21.74**
LU-26 X CH-70	46.06**	44.79**	14.35**	-8.78**
LU-26X MH 97	98.10**	81.00**	-10.48**	-15.55**
LU-26 X Nacozari	18.57**	13.13**	13.75**	-5.05
LU-26X Crow	60.52**	46.36**	-1.48	-9.79**
LU-26 X Parole	51.91**	46.61**	-2.27	-16.80**
LU-26X Inqilab91	58.94**	35.24**	-5.33*	-13.96**
SA42X LU-26	50.12**	32.89**	-17.17**	-21.84**
SA42X CH-70	8.89**	-4.34	17.97**	-1.42
SA42 X MH 97	111.15**	72.88**	-8.26**	-8.28**
SA42 X Nacozari	91.19**	76.67**	17.17**	2.79
SA42X Crow	78.20**	45.64**	1.71	-1.49
SA42X Parula	72.73**	48.25**	3.30	-7.45**
SA42X Inqilab 91	80.19**	38.81**	3.04	-0.99
CH-70 X LU-26	46.28**	45.01**	14.56**	-8.61**
CH-70X SA42	10.25**	-3.15	16.09**	-2.99
CH-70X MH 97	106.15**	89.86**	6.69*	-10.83**
CH-70X Nacozari	-2.01	-7.27**	44.51**	36.52**
CH-70X Crow	43.32**	31.73**	12.67**	-3.32
CH-70X Parula	8.65**	5.75*	31.08**	21.09**
CH-70X Inqilab91	47.22**	26.18**	10.14**	-4.83
MH 97X LU-26	88.21**	71.96**	-5.93*	-11.26**
MH 97X SA42	111.71**	73.33**	-8.38**	-8.40**
MH 97X CH-70	106.45**	90.14**	6.85*	-10.70**
MH 97X Nacozari	57.49**	37.93**	-4.50	-16.20**
MH 97X Crow	73.49**	73.09**	-4.16	-7.16**
MH 97X Parula	57.08**	48.40**	-4.64	-14.54**
MH 97X Inqilab91	72.25**	59.18**	-5.42*	-9.10**
NacozariX LU-26	19.72**	14.24**	13.39**	-5.35*
NacozariX SA42	91.72**	77.16**	16.81**	2.48
NacozariX CH-70	-2.12	-7.38**	45.91**	37.85**
NacozariX MH 97	57.56**	37.99**	-4.35	-16.07**
NacozariX Crow	19.19**	4.18*	28.46**	15.95**
NacozariX Parula	-8.96**	-16.02**	43.22**	39.84**
NacozarixInqilab91	43.52**	17.51**	17.00**	6.39*
CrowX LU-26	60.42**	46.27**	-1.45	-9.75**
CrowX SA42	77.09**	44.73**	2.68	-0.55
CrowX CH-70	33.53**	22.73**	20.96**	3.80
CrowX MH 97	72.57**	72.18**	-3.55	-6.56*
CrowX Nacozari	16.17**	1.55	25.01**	12.84**
CrowX Parula	26.33**	19.09**	4.73	-3.38
CrowX Inqilab 91	14.76**	6.27**	2.95	2.10
Parula X LU-26	51.81**	46.51**	-2.42	-16.93**
ParulaX SA42	72.97**	48.46**	3.24	-7.50**
ParulaX CH-70	8.65**	5.75*	30.75**	20.78**
ParulaX MH 97	56.98**	48.31**	-4.29	-14.23**
ParulaX Nacozari	-9.07**	-16.12**	43.07**	39.69**
ParulaX Crow	24.49**	17.36**	6.05*	-2.16
ParulaX Inqilab 91	-13.73**	-24.32**	10.72**	2.93
Inqilab 91XLU-26	54.30**	31.29**	-2.36	-11.26**
Inqilab 91X SA42	80.09**	38.73**	2.79	-1.23
Inqilab 91XCH-70	48.12**	26.96**	9.78**	-5.14
Inqilab91X MH 97	72.42**	59.33**	-5.44*	-9.12**
Inqilab9XNacozari	43.61**	17.58**	17.05**	6.44*
Inqilab 91X Crow	14.85**	6.35**	2.90	2.06
Inqilab 91X Parula	-13.82**	-24.40**	11.45**	3.60

*P≤ 0.05, **P≤0.01

Pertaining to harvest index (Table 6), 27 crosses manifested significant positive heterosis and nine gave significant negative heterotic effects. While significant positive and negative heterobeltiotic effects were obtained from 10 and 27 crosses, respectively. Similarly 48.2 and 17.6% of the total crosses gave significant positive effects of heterosis and heterobeltiosis, ranging from 6.05% (Parula x Crow) to 45.91% (Nacozari x Chenab70) and -0.99% (SA42 x Inqilab91) to 39.84% (Nacozari x Parula), respectively. Others hybrids that displayed higher positive heterotic and heterobeltiotic effects were Chenab70 x Nacozari, Nacozarix Parula and Parula x Nacozari with heterotic percentage values of 44.51, 43.22 and 43.07 and heterobeltiotic percentage values of 36.52, 39.84 and 39.69, respectively.

It is obvious from the results that possibility of exploiting the hybrid vigour for the improvement in grain yield and economic traits exist in wheat. Maximum percentage increase for plant height over mid and better parents was displayed by the cross SA-42 x Nacozari and Parula x Crow, respectively. Similarly maximum decrease was by the cross Chenab70 x LU-26 and Parula x Chenab70. The cross MH-97 x Crow indicated high heterosis and the cross Nacozari x SA-42 showed high heterobeltiosis for fertile tillers. The hybrid Parula x Chenab70 exhibited maximum grains per spike over mid better parents. More heterotic and heterobeltiosis were observed from the CrowxNacozari and NacozarixInqilab 91, respectively. The crosses Crow x Chenab70 and Nacozari x SA-42 gave both higher heterotic and heterobeltiotic effects for 100-grain weight. The hybrids SA-42 x Nacozari and Inqilab 91 x SA-42 gave high yield for both effects.

The crosses SA42 x Nacozari and MH-97 x SA-42 displayed higher heterotic and heterobeltiotic effects for grain yield and biological yield per plant, respectively. However, higher harvest index over mid and better parents was found in the crosses Nacozari x Chenab70 and Nacozari x Parula, respectively. Thus, these crosses can be utilized for the improvement of certain traits in hybridization programme for developing wheat varieties for greater grain yield and other desirable traits under stress condition of leaf rust epidemic. Potential of diverse genotypes may also be exploited for further improving the breeding and selection strategies for the development and release of new leaf rust resistant varieties.

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