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Manifestation of Heterosis for Some Metric Characters in Intraspecific Crosses of *Triticum aestivum* L.

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ABSTRACT

Estimates of heterosis and heterobeltiosis from F_1 hybrids derived from 20 spring wheat crosses were computed for traits like plant height, flag leaf area, number of fertile tillers per plant, spike length, spikelets per spike, grains per spike, 1000-grain weight and grain yield per plant. Highly significant genetic variability was present in the experimental material for all the traits under study. Highest heterotic effects of 32.09 and 26.91% over mid and better parent for grain yield per plant was noted for the hybrids Uqab 2000 × MH. 97 and Fsd. 85 × Inqalab 91, respectively. Maximum heterosis of 19.74, 16.55 and 7.53% for grains per spike, spike length and spikelets per spike and maximum heterobeltiosis of 12.01 and 6.86% for grains per spike and spike length was found in Inqalab 91 × Fsd. 85. For 1000-grain weight highest heterotic effects of 29.65 and 17.33% over their respective mid and better parent were found in Inqalab 91 × MH. 97. Additive with the involvement of overdominance type of gene action was present in almost all the traits. The study reveals good scope for commercial exploitation of heterosis as well as isolation of pure lines from the progenies of heterotic F_1's.

Key Words: Wheat; Metric traits; Heterosis; Heterobeltiosis; Gene action; Pakistan

INTRODUCTION

Major emphasis in wheat (*Triticum aestivum* L.) breeding is the development of improved varieties. Significant efforts have been devoted to find the economically feasible systems for the production of F_1 hybrids. Owing to continuous selection of the existing wheat material, the chances of genetic improvement have considerably decreased and there is a constant need to develop new population amenable to selection by hybridization. The possible heterosis exploitable in this naturally self-pollinated crop continues to be a critical question in the hybrid wheat research. Fewer studies have been made on the manifestation of heterosis in wheat crosses. The results obtained show varying degree of heterotic response depending upon the genotype of the parents used. Sadeque *et al*. (1991) reported negative heterosis for plant height over tallest parent while maximum heterosis over better parent for spike length and grain yield per plant. Wang *et al.* (1997) studied heterosis of six agronomic characters in 12 cross combinations of spring wheat. They reported significant positive heterosis for 1000-grain weight and spike length while negative heterosis for grain number and spikelet number. Subhani *et al.* (2000) investigated yield components and indicated maximum heterosis of 36.39, 18.28 and 15.17% for grain yield, 1000-grain weight and tillers per plant, respectively; whereas, 1000-grain weight also exhibited maximum (17.29%) heterobeltiosis. Chowdhry *et al.* (2001) indicated the occurrence of heterosis and heterobeltiosis in F_1 generation for traits like plant height, number of fertile tillers per plant, 1000-grain weight and grain yield per plant. Maximum heterosis (110.34%) for grain yield per plant over mid parent was illustrated by Akhter *et al.* (2003).

Heterosis studies not only provide reliable information about the increase or decrease of F_1's over their mid and better parents but also can give worthwhile information both for general and specific combining ability of the breeding material at hand. The present study was, therefore, undertaken to estimate the extent of heterosis in different wheat crosses which might be useful to accelerate breeding efforts in the country.

MATERIALS AND METHODS

The studies were carried out at the Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad. The experimental material comprising of five wheat varieties viz., Inqalab 91, Uqab 2000, Punjab 96, MH. 97 and Fsd. 85 were crossed in a full diallel fashion during crop season 2001-02. Seeds of F_1 crosses along with their parents were planted in the field on November 8, 2002 following randomized complete block design with three replications keeping inter-plant and inter-row distances at 15 and 30 cm, respectively. A single row of 5 m length served as an experimental unit. Three seeds per hill were sown to ensure the crop stand, which were thinned to single seedling per site after germination. Non-experimental plants were also raised at the borders to eliminate competition among marginal plants. All agronomic and plant protection practices were kept normal and equal for entire experiment.

At maturity, 10 guarded plants were taken randomly from each treatment and data were recorded for traits like plant height (cm), flag leaf area (cm^2), number of fertile tillers per plant, spike length (cm), number of spikelets per spike, number of grains per spike, 1000-grain weight (g) and grain yield per plant (g).

To determine the significant differences among hybrids and parents, the data thus collected were subjected to analysis of variance technique (Steel & Torrie, 1984). The per cent increase (+) or decrease (-) of F_1 over mid parent as well as better parent was calculated to estimate the possible heterotic effects (Fonseca & Patterson, 1968). A 't' test was used to evaluate the difference of F_1 means from the respective mid parent and better parent values, following the method as delineated by Wynne *et al.* 1970.

RESULTS AND DISCUSSION

Analysis of variance presented in Table I revealed that the differences among genotypes for all the metric traits under study was highly significant ($P \leq 0.01$). The detailed sketch of heterotic effects over mid and better parents is presented here as under:

Plant height. The perusal of Table II revealed that maximum plant height of 109.37 cm was found for the parent Uqab 2000 while the minimum height of 97.06 cm was recorded from the parent Punjab 96. Among the crosses, maximum (115.02 cm) plant height was observed for the cross Uqab 2000 × Fsd. 85 while the minimum (100.02 cm) height was exhibited by the hybrid Inqalab 91 × Punjab 96.

Heterotic effects for plant height of F_1 crosses over their respective mid and better parents are presented in Table III. Positive heterosis was observed in almost all the crosses with the exception of one cross i.e., Inqalab 91 × Punjab 96 which gave negative value of -0.32% but it showed non-significant effects. Significant positive increase over the mid parent was expressed by one out of 19 crosses i.e., Fsd. 85 × Punjab 96 (1.63%) while 14 crosses exhibited highly significant increase in height over mid parent lead by the cross MH. 97 × Uqab 2000 with an effect of 8.23%; while remaining four crosses indicated non-significant heterosis. Nine out of 20 cross combinations showed negative heterobeltiosis. Highest negative estimate of heterosis over better parent was shown by the hybrid Punjab 96 × Fsd. 85 (-3.57%) followed by Inqalab 91 × Punjab 96 (-3.48%) with highly significant effects. Positive heterobeltiosis ranged from 0.45 (MH. 97 × Fsd. 85) to 6.72% (Punjab 96 × MH. 97) of which most of the crosses showed highly significant heterobeltiosis. The results were in accordance with those of Sadeque *et al.* (1991) and Chowdhry *et al.* (2001) who reported positive as well as negative heterotic effects over mid and better parents for this triat.

For the study of plant height, negative estimates of heterosis are preferred over their mid and better parents in wheat breeding, because dwarfness is preferred as desirable character due to its responsiveness to fertilizer and resistance to lodging. Therefore, the hybrids showing negative heterotic effects could be exploited further in future breeding programme.

Flag leaf area. Individual comparison of means for flag leaf area (Table II) revealed considerable variability for this character, ranging from 40.32 (MH. 97) to 63.78 cm^2 (Fsd. 85 × Punjab 96). Among the parents Fsd. 85 and Uqab 2000 showed the highest flag leaf area of 58.54 and 56.49 cm^2, respectively. While among the crosses Fsd. 85 × Punjab 96, Punjab 96 × Fsd. 85 and Uqab 2000 × Fsd. 85 displayed highest mean values of 63.78, 62.09 and 60.69 cm^2 for flag leaf area, respectively. The hybrids with greater flag leaf area are desirable because they provide more photosynthetic activity for the growth of the plant.

A perusal of Table III indicates that 16 F_1 crosses out of 20 showed positive heterosis over their mid parents for flag leaf area, in which seven crosses showed highly significant increase while the remaining nine crosses exhibited non-significant effects. The highly significant crosses were Punjab 96 × MH. 97, its reciprocal hybrid and Fsd. 85 × Punjab 96 with heterotic effects of 19.50, 16.92 and 16.40%, respectively. Forty per cent crosses out of 20 indicated positive heterosis over their better parents. The only cross which exhibited positive and significant heterobeltiosis was Fsd. 85 × Punjab 96 with an increase of 8.96% (Table III). While all the other crosses showed positive and non-significant effects. The remaining 60% crosses displayed negative effects, four crosses showed significant and two crosses highly significant negative heterotic effects over their better parents. The results indicated that additive type with partial dominance gene action was present. But the involvement of over dominance in some crosses was also exhibited due to heterobeltiosis for the said trait. Flag leaf area contributes tremendously in the development of grain and appreciably adds to the grain yield. Presence of heterotic effects for this trait can thus be exploited for boosting grain production in wheat. Jafar

Table I. Analysis of variance for some polygenic traits of spring wheat in a 5 × 5 diallel cross

		Mean Squares							
Source of variance	**D.F**	**Plant height**	**Flag leaf area**	**Fertile tillers per plant**	**Spike length**	**No. of spikelets per spike**	**No. of grains per spike**	**1000-grain weight**	**Grain yield per plant**
Replications	2	2.944^{ns}	102.188**	9.224*	0.477^{ns}	0.279^{ns}	21.586^{ns}	16.875**	1.569^{ns}
Genotypes	24	60.987**	70.977**	8.285**	3.775**	2.731**	196.137**	25.157**	21.670**
Error	48	1.699	12.382	2.707	0.190	0.333	16.486	2.947	1.133

ns=Non-significant; *=Significant ($P \leq 0.05$);**=Highly significant ($P \leq 0.01$)

Table II. Performance of parents and their intraspecific crosses for plant height, yield and its components in spring wheat

Genotypes	Plant height (cm)	Flag leaf area (cm^2)	Fertile tillers per plant	Spike length (cm)	Spikelets per spike	Grains per spike	1000-grain weight (g)	Grain yield per plant (g)
Inqalab 91	103.63jk	49.27h	12.70bcde	15.06bcd	21.60defghi	71.30efghi	35.97defgh	22.40hi
Uqab 2000	109.37de	56.49bcdefg	12.60bcde	15.34abc	22.90abc	87.33a	35.23gh	26.41cde
Punjab 96	97.06n	51.05efgh	11.47cde	14.16efgh	21.30ghi	66.33fghijkl	34.37h	21.23ij
MH. 97	98.56mn	40.32i	18.10a	12.04j	19.90j	64.50ijkl	29.13i	19.65j
Fsd. 85	106.70fgh	58.54abcd	13.80bcd	12.55j	21.37fghi	62.10kl	37.93bcdefg	22.55ghi
Inqalab 91 × Uqab 2000	107.13defg	50.84efgh	12.20bcde	15.85ab	22.70bcd	81.03abc	36.93cdefgh	24.44efg
Inqalab 91 × Punjab 96	100.02lm	50.21fgh	13.10bcde	15.57abc	22.00cdefgh	74.00cdef	36.93cdefgh	27.57bc
Inqalab 91 × MH. 97	104.79ghij	50.85efgh	13.27bcde	14.34def	21.40fghi	63.13jkl	42.20a	26.10cde
Inqalab 91 × Fsd. 85	108.69def	51.88defgh	11.47cde	16.09a	23.10abc	79.87abcd	39.20abcd	26.75bcd
Uqab 2000 × Inqalab 91	107.02efg	51.16efgh	11.27de	15.35abc	22.47bcdef	83.47ab	39.83abc	24.98def
Uqab 2000 × Punjab 96	108.00def	55.36cdefgh	12.60bcde	15.33abc	23.27ab	82.37ab	35.80efgh	26.94bcd
Uqab 2000 × MH. 97	111.72c	49.62gh	14.67bc	14.42def	22.03cdefgh	78.83bcd	39.13abcde	30.42a
Uqab 2000 × Fsd. 85	115.02a	60.69abc	10.40e	14.41def	22.83abc	77.53bcde	39.03abcdef	24.92def
Punjab 96 × Inqalab 91	101.84kl	50.52fgh	10.47e	14.79cde	21.60efghi	70.80efghij	38.03bcdefg	21.45ij
Punjab 96 × Uqab 2000	107.77def	57.19bcdef	12.70bcde	15.56abc	23.03abc	81.10abc	35.77fgh	26.67cd
Punjab 96 × MH. 97	105.19ghij	54.59cdefgh	14.87b	13.72fgh	21.70defghi	68.33fghijk	34.30h	24.95def
Punjab 96 × Fsd. 85	102.89jk	62.09ab	11.53cde	14.25defg	22.90abc	73.70cdefg	40.07abc	25.62cdef
MH. 97 × Inqalab 91	104.41hij	50.95efgh	12.07bcde	13.51ghi	20.80ij	59.70l	40.87ab	21.86i
MH. 97 × Uqab 2000	112.52bc	52.21defgh	14.30bcd	13.71fgh	21.03hi	72.70defgh	38.93abcdef	26.50cde
MH. 97 × Punjab 96	104.23ij	53.42defgh	14.10bcd	13.43hi	21.10hi	65.70hijkl	37.57bcdefgh	26.45cde
MH. 97 × Fsd. 85	107.18cefg	55.53bcdefgh	13.50bcde	12.51j	20.97hi	66.40fghijkl	39.90abc	25.54cdef
Fsd. 85 × Inqalab 91	109.54d	53.35defgh	11.50cde	14.99cde	22.33bcdefg	79.37bcd	41.77a	28.62ab
Fsd. 85 × Uqab 2000	114.58ab	57.61abcde	12.10bcde	15.39abc	23.80a	87.43a	41.43a	30.18a
Fsd. 85 × Punjab 96	103.54jk	63.78a	11.23de	14.80cde	22.63bcde	70.97efghi	39.13abcde	24.06fgh
Fsd. 85 × MH. 97	106.30fghi	52.78defgh	12.10bcde	12.82ij	21.07hi	66.13ghijkl	39.63abc	23.84fgh

Table III. Heterosis (Ht) and heterobeltiosis (Hbt) percentage in F_1 for plant height, flag leaf area, fertile tillers per plant and spike length in spring wheat.

Cross	Plant height		Flag leaf area		Fertile tillers per plant		Spike length	
	Ht.%	Hbt.%	Ht.%	Hbt.%	Ht.%	Hbt.%	Ht.%	Hbt.%
Inqalab 91 × Uqab 2000	0.59^{ns}	-2.05**	-3.86^{ns}	-10.01*	-3.56^{ns}	-3.94^{ns}	4.28*	3.30^{ns}
Inqalab 91 × Punjab 96	-0.32^{ns}	-3.48**	0.11^{ns}	-1.65^{ns}	8.41^{ns}	3.15^{ns}	6.57**	3.41^{ns}
Inqalab 91 × MH. 97	3.65**	1.12^{ns}	13.53**	3.22^{ns}	-13.85*	-26.70**	5.81**	-4.78*
Inqalab 91 × Fsd. 85	3.35**	1.86*	-3.75^{ns}	-11.38**	-13.46^{ns}	-16.91*	16.55**	6.86**
Uqab 2000 × Inqalab 91	0.49^{ns}	-2.15**	-3.25^{ns}	-9.44*	-10.94^{ns}	-11.29^{ns}	0.96^{ns}	0.02^{ns}
Uqab 2000 × Punjab 96	4.63**	-1.26^{ns}	2.96^{ns}	-2.00^{ns}	4.71^{ns}	0.00	3.93*	-0.07^{ns}
Uqab 2000 × MH. 97	7.46**	2.15**	2.51^{ns}	-12.17**	-4.45^{ns}	-18.97**	5.31**	-6.02**
Uqab 2000 × Fsd. 85	6.46**	5.17**	5.52^{ns}	3.67^{ns}	-21.21**	-24.64**	3.33^{ns}	-6.06**
Punjab 96 × Inqalab 91	1.49^{ns}	-1.73*	0.71^{ns}	-1.05^{ns}	-13.38^{ns}	-17.59*	1.25^{ns}	-1.75^{ns}
Punjab 96 × Uqab 2000	4.42**	-1.46^{ns}	6.36^{ns}	1.24^{ns}	5.54^{ns}	0.79^{ns}	5.47**	1.41^{ns}
Punjab 96 × MH. 97	7.54**	6.72**	19.50**	6.93^{ns}	0.56^{ns}	-17.86**	4.68*	-3.15^{ns}
Punjab 96 × Fsd. 85	0.99^{ns}	-3.57**	13.30**	6.06^{ns}	-8.71^{ns}	-16.43*	6.67**	0.61^{ns}
MH. 97 × Inqalab 91	3.28**	0.75^{ns}	13.74**	3.41^{ns}	-21.65**	-33.33**	-0.32^{ns}	-10.29**
MH. 97 × Uqab 2000	8.23**	2.88**	7.86^{ns}	-7.58^{ns}	-6.84^{ns}	-20.99**	0.12^{ns}	-10.65**
MH. 97 × Punjab 96	6.56**	5.75**	16.92**	4.63^{ns}	-4.62^{ns}	-22.10**	2.47^{ns}	-5.20**
MH. 97 × Fsd. 85	4.44**	0.45^{ns}	12.35**	-5.14^{ns}	-15.36*	-25.41**	1.75^{ns}	-0.32^{ns}
Fsd. 85 × Inqalab 91	4.16**	2.66**	-1.02^{ns}	-8.86*	-13.21^{ns}	-16.67*	8.58**	-0.44^{ns}
Fsd. 85 × Uqab 2000	6.05**	4.76**	0.16^{ns}	-1.59^{ns}	-8.33^{ns}	-12.32^{ns}	10.36**	0.33^{ns}
Fsd. 85 × Punjab 96	1.63*	-2.96**	16.40**	8.96*	-11.08^{ns}	-18.60*	10.77**	4.47*
Fsd. 85 × MH. 97	3.57**	-0.38^{ns}	6.78^{ns}	-9.83*	-24.14**	-33.15**	4.24^{ns}	2.12^{ns}

ns= Non-significant;*= Significant ($P \leq 0.05$);** = Highly significant ($P \leq 0.01$)

(1994) and Khan *et al.* (1995) also reported similar findings for this trait.

Fertile tillers per plant. Statistical comparisons of the differences among genotypes (Table II) revealed that cross Punjab 96 × MH. 97 had highest number of fertile tillers per plant (14.87) closely followed by three other crosses viz., Uqab 2000 × MH. 97 (14.67), MH. 97 × Uqab 2000 (14.30) and MH. 97 × Punjab 96 (14.10); whereas, the cross combination Uqab 2000 × Fsd. 85 had lowest mean value of 10.40 followed by Punjab 96 × Inqalab 91 (10.47). Among the parents, MH. 97 had highest mean of 18.10 while Punjab 96 had least mean of 11.47 for number of fertile tillers per plant. A broad range of variation among the F_1 hybrids was observed for this trait.

Percentage increase or decrease of F_1's over their parental means and better parents are presented in Table III for fertile tillers per plant. Negative heterosis was observed in majority of crosses with the exception of four crosses i.e., Inqalab 91 × Punjab 96, Punjab 96 × Uqab 2000, Uqab 2000 × Punjab 96 and Punjab 96 × MH. 97, giving positive values of 8.41, 5.54, 4.71 and 0.56%, respectively. Similar results were obtained for heterobeltiosis where only two crosses Inqalab 91 × Punjab 96 and Punjab 96 × Uqab 2000 showed positive effects of 3.15 and 0.79%, respectively. But

Table IV. Heterosis (Ht) and heterobeltiosis (Hbt) percentage in F_1 hybrids for spikelets per spike, grains per spike, 1000-grain weight and grain yield per plant in spring wheat

Cross	Spikelets per spike		Grains per spike		1000-grain weight		Grain yield per plant	
	Ht.%	Hbt.%	Ht.%	Hbt.%	Ht.%	Hbt.%	Ht.%	Hbt.%
Inqalab 91 × Uqab 2000	2.02^{ns}	-0.87^{ns}	2.16^{ns}	-7.21^{*}	3.75^{ns}	2.69^{ns}	0.16^{ns}	-7.45^{**}
Inqalab 91 × Punjab 96	2.56^{ns}	1.85^{ns}	7.53^{*}	3.79^{ns}	5.02^{ns}	2.69^{ns}	26.37^{**}	23.08^{**}
Inqalab 91 × MH. 97	3.13^{ns}	-0.93^{ns}	-7.02^{ns}	-11.45^{**}	29.65^{**}	17.33^{**}	24.14^{**}	16.54^{**}
Inqalab 91 × Fsd. 85	7.53^{**}	6.94^{**}	19.74^{**}	12.01^{**}	6.09^{*}	3.34^{ns}	19.04^{**}	18.62^{**}
Uqab 2000 × Inqalab 91	0.97^{ns}	-1.89^{ns}	5.23^{ns}	-4.43^{ns}	11.89^{**}	10.75^{**}	2.36^{ns}	-5.41^{*}
Uqab 2000 × Punjab 96	5.28^{**}	1.60^{ns}	7.20^{*}	-5.69^{ns}	2.87^{ns}	1.61^{ns}	13.08^{**}	1.99^{ns}
Uqab 2000 × MH. 97	2.96^{ns}	-3.78^{*}	3.84^{ns}	-9.73^{**}	21.60^{**}	11.07^{**}	32.09^{**}	5.20^{**}
Uqab 2000 × Fsd. 85	3.16^{ns}	-0.29^{ns}	3.77^{ns}	-11.22^{**}	6.70^{*}	2.90^{ns}	1.78^{ns}	-5.65^{*}
Punjab 96 × Inqalab 91	0.70^{ns}	0.00	2.88^{ns}	-0.70^{ns}	8.15^{**}	5.75^{ns}	-1.96^{ns}	-4.24^{ns}
Punjab 96 × Uqab 2000	4.22^{*}	0.58^{ns}	5.55^{ns}	-7.14^{*}	2.78^{ns}	1.51^{ns}	11.97^{**}	1.00^{ns}
Punjab 96 × MH. 97	5.34^{**}	1.88^{ns}	4.46^{ns}	3.02^{ns}	8.03^{*}	-0.19^{ns}	22.04^{**}	17.50^{**}
Punjab 96 × Fsd. 85	7.34^{**}	7.18^{**}	14.77^{**}	11.11^{**}	10.83^{**}	5.62^{*}	17.04^{**}	13.61^{**}
MH. 97 × Inqalab 91	0.24^{ns}	-3.70^{*}	-12.08^{**}	-16.27^{**}	25.55^{**}	13.62^{**}	3.97^{ns}	-2.40^{ns}
MH. 97 × Uqab 2000	-1.71^{ns}	-8.15^{**}	-4.24^{ns}	-16.76^{**}	20.97^{**}	10.50^{**}	15.04^{**}	0.33^{ns}
MH. 97 × Punjab 96	2.43^{ns}	-0.94^{ns}	0.43^{ns}	-0.95^{ns}	18.32^{**}	9.31^{**}	29.40^{**}	24.58^{**}
MH. 97 × Fsd. 85	1.62^{ns}	-1.87^{ns}	4.90^{ns}	2.95^{ns}	18.99^{**}	5.18^{ns}	21.01^{**}	13.23^{**}
Fsd. 85 × Inqalab 91	3.96^{*}	3.40^{*}	18.99^{**}	11.31^{**}	13.04^{**}	10.11^{**}	27.36^{**}	26.91^{**}
Fsd. 85 × Uqab 2000	7.53^{**}	3.93^{*}	17.02^{**}	0.11^{ns}	13.26^{**}	9.23^{**}	23.28^{**}	14.27^{**}
Fsd. 85 × Punjab 96	6.09^{**}	5.93^{**}	10.51^{**}	6.98^{ns}	8.25^{**}	3.16^{ns}	9.88^{**}	6.67^{*}
Fsd. 85 × MH. 97	2.10^{ns}	-1.40^{ns}	4.48^{ns}	2.53^{ns}	18.19^{**}	4.48^{ns}	12.95^{**}	5.69^{ns}

ns= Non-significant; *= Significant ($P \leq 0.05$);** = Highly significant ($P \leq 0.01$)

none of these crosses performed significantly better than mid parents and better parents. All other crosses exhibited decrease in number of tillers per plant over mid and better parents. Maximum negative effects of -24.14, -21.65 and -21.21% were displayed by Fsd. 85 × MH. 97, MH. 97 × Inqalab 91 and Uqab 2000 × Fsd. 85 for heterosis, respectively. While, negative effects of -33.33, -33.15, -26.70 and 25.41% were exhibited by MH. 97 × Inqalab 91, Fsd. 85 × MH. 97, Inqalab 91 × MH. 97 and MH. 97 × Fsd. 85 for heterobeltiosis, respectively. Only three hybrids showed highly significant decrease over their mid and better parents. The negative estimates of heterosis and heterobeltiosis are not desired because less number of tillers per plant means low yield. Thus, the crosses exhibiting positive increase over mid and better parents would be of great value. The present results are in conformity with those of Atta and Khan (1997) and Subhani *et al.* (2000) who reported the occurrence of heterosis and heterobeltiosis in wheat to a varying degree of magnitude for fertile tillers per plant. However, Chakraborty and Tiwari (1995) reported low heterosis for the said trait.

Spike length It is obvious from Table II that maximum spike length was observed for the cross Inqalab 91 × Fsd. 85 with a mean value of 16.09 cm while minimum spike length was noted for the cross MH. 97 × Fsd. 85 with a value of 12.52 cm. Among the parents Uqab 2000 produced maximum spike length of 15.34 cm whereas MH. 97 produced minimum spike length of 12.04 cm.

As regards heterosis it is clearly evident from Table III that almost all the crosses manifested positive heterotic effects over their mid parents. Only one cross MH. 97 × Inqalab 91 exhibited negative and non-significant heterotic effects of -0.32%. Nine crosses out of 19 indicated positive and highly significant, three crosses indicated significant and seven crosses indicated non-significant increase over their mid parents. Highest increase of 16.55% in spike length over the mid parent was exhibited by the hybrid Inqalab 91 × Fsd. 85 and was highly significant. While concerning heterobeltiosis nine F_1 hybrids showed beneficial effects, out of these one hybrid Fsd. 85 × Punjab 96 indicated significant increase (4.47%) and one cross Inqalab 91 × Fsd. 85 indicated highly significant increase (6.86%) while rest of the crosses exhibited non-significant results. The remaining 11 crosses showed negative heterobeltiosis, out of these five hybrids exhibited highly significant and one hybrid significant negative effects over their better parents. The maximum (10.65%) heterobeltiosis was observed for the hybrid MH. 97 × Uqab 2000 followed by MH. 97 × Inqalab 91 (10.29%). The results showed that additive with over dominance effects of gene action are involved in the expression of spike length. Significant positive heterosis over mid and better parent was also illustrated by Wang *et al.* (1997) and Mujahid *et al.* (2000).

Spikelets per spike. A wide range of variability was observed for this important yield component. Overall range of spikelets per spike varied from 19.90 to 23.80. Statistical comparisons of the differences among genotypes (Table II) revealed that cross Fsd.85 × Uqab 2000 (23.80) had highest number of spikelets per spike closely followed by cross Uqab 2000 × Punjab 96 (23.27). Whereas the cross MH. 97 × Inqalab 91 (20.80) had the lowest spikelets per spike closely followed by another cross MH. 97 × Fsd. 85 (20.97). Among the parents, Uqab 2000 and MH. 97 displayed maximum (22.90) and minimum (19.90) values for number of spikelets per spike, respectively.

Spikelets per spike is an effective yield component and a greater number would result in more grains per spike, therefore, positive heterosis is desirable for this trait. The results presented in Table IV revealed that 95% crosses showed positive heterosis over their respective mid parents. The range of positive heterosis varied from 0.24 (MH. 97 × Inqalab 91) to 7.53% (Inqalab 91 × Fsd. 85 and Fsd. 85 ×

Uqab 2000). Out of 19, six hybrids showed highly significant, two hybrids showed significant and 11 hybrids showed non-significant results. The only cross combination MH. 97 × Uqab 2000 exhibited negative and non-significant heterotic effects of -1.71% over its mid parent. So, far as the performance against better parent is concerned, 50% crosses showed positive and other 50% showed negative heterobeltiosis. Three hybrids viz., Punjab 96 × Fsd. 85, Inqalab 91 × Fsd. 85 and Fsd. 85 × Punjab 96 displayed highly significant and positive heterotic effects of 7.18, 6.94 and 5.93% over their better parents, respectively. The highest negative and highly significant effect of -8.15% over the better parent was indicated by the hybrid MH. 97 × Uqab 2000.

These results proved the presence of considerable additive and overdominance effects in the inheritance of spikelets per spike. Studies by Walia *et al.* (1993) and Mujahid *et al.* (2000) reported information similar to the present results as they also found positive heterosis for spikelets per spike.

Grains per spike. It is evident from Table II that maximum (87.43) grains per spike were observed for the hybrid Fsd. 85 × Uqab 2000 whereas the hybrid MH. 97 × Inqalab 91 had the lowest mean of 59.70. Among the parents, Uqab 2000 showed maximum (87.33) grains per spike while Fsd. 85 had least value of 62.10. A broad range of variation was observed between the parents and their F_1 progenies.

The values for heterotic effects presented in Table IV indicated that 85% crosses showed positive increase over their mid parents. The range of heterotic effects for grains per spike was from 0.43 (MH. 97 × Punjab 96) to 19.74% (Inqalab 91 × Fsd. 85). Out of 17 crosses, two were significant, five were highly significant and 10 were non-significant. Highest value of 19.74% was exhibited by hybrid Inqalab 91 × Fsd. 85 followed by its reciprocal cross Fsd. 85 × Inqalab 91 with an increase of 18.99% over their mid parents. Another hybrid Fsd. 85 × Uqab 2000 also showed high heterotic value of 17.02%, all these crosses indicated highly significant increase over the parental value for grains per spike. The remaining 15% crosses exhibited negative heterotic effects over their mid parents. The hybrid MH. 97 × Inqalab 91 indicated maximum negative but highly significant value of -12.08%, while all other hybrids showed non-significant results. Considering heterobeltiosis, 45% cross combinations displayed positive heterotic effects. The cross Inqalab 91 × Fsd. 85 followed by its reciprocal (Fsd. 85 × Inqalab 91) and Punjab 96 × Fsd. 85 showed highly significant and positive heterotic effects of 12.01, 11.31 and 11.11% over their better parents, respectively. Out of 11 crosses, two hybrids namely MH. 97 × Uqab 2000 (-16.76%) and MH. 97 × Inqalab 91 (-16.27%) marked highest negative heterotic effects over their better parents, these effects were highly significant proceeded by such other three crosses.

The three hybrids namely Inqalab 91 × Fsd. 85, its reciprocal and Punjab 96 × Fsd. 85 with higher degree of positive heterosis over their mid and better parents can be exploited in future breeding programmes. The hybrid vigour expressed for this character has also been reported earlier by Winzeler *et al.* (1993), Jafar (1994) and Munir *et al.* (1999).

1000-grain weight. The individual comparison of means of all genotypes given in Table II revealed that the parent Fsd. 85 had maximum 1000-grain weight of 37.93 g while the other parent MH. 97 had minimum mean of 29.13 g. Among the F_1 hybrids, Inqalab 91 × MH. 97 had maximum 1000-grain weight with a mean value of 42.20 g; whereas, Punjab 96 × MH. 97 showed lowest mean value of 34.30 g for this trait.

Considering mid parent values of the character, positive heterosis was observed for all the 20 cross combinations (Table IV). Highly significant results were indicated by thirteen hybrids ranging from 8.15 (Punjab 96 × Inqalab 91) to 29.65% (Inqalab 91 × MH. 97), while three crosses showed significant results ranging from 6.09 (Inqalab 91 × Fsd. 85) to 8.03% (Punjab 96 × MH. 97), whereas four crosses showed non-significant results ranging from 2.78 (Punjab 96 × Uqab 2000) to 5.02% (Inqalab 91 × Punjab 96). For heterobeltiosis, 95% crosses exceeded the better parents showing overdominance type of gene action. The only cross showing negative heterotic effects over its better parent was Punjab 96 × MH. 97 with a value of -0.19% but it was non-significant. Highly significant increase of 17.33% over the better parent was observed for the cross Inqalab 91 × MH. 97, also showing highest positive effects over mid parent. Eight hybrids showed highly significant and one hybrid showed significant heterobeltiosis while rest of the 10 hybrids out of 19 indicated non-significant results. Eight hybrids namely Inqalab 91 × MH. 97, Uqab 2000 × Inqalab 91, Uqab 2000 × MH. 97, MH. 97 × Inqalab 91, MH. 97 × Uqab 2000, MH. 97 × Punjab 96, Fsd. 85 × Inqalab 91 and Fsd. 85 × Uqab 2000 showing heterosis and heterobeltiosis for this trait could be exploited for boosting grain yield production in wheat. The findings of Atta and Khan (1997), Saad (1999) and Subhani *et al.* (2000) are in accordance with the present study in as much as they reported maximum positive heterosis for 1000-grain weight.

Grain yield per plant. It is evident from Table II that grain yield per plant ranged from 19.65 (MH. 97) to 26.41g (Uqab 2000) for parents and from 21.45 (Punjab 96 × Inqalab 91) to 30.42g (Uqab 2000 × MH. 97) for F_1 hybrids. It was also observed that nine crosses out yielded the high yielding parental genotype Uqab 2000 (26.41g). The cross combinations Uqab 2000 × MH. 97 and Fsd. 85 × Uqab 2000 displayed highest increase of 30.42 and 30.18 g over the mean of superior parent, respectively.

Highly significant positive differences in comparison to mid parents occurred for 15 crosses out of 20, the range limit varied from 9.88 (Fsd. 85 × Punjab 96) to 32.09% (Uqab 2000 × MH. 97). Whereas four cross combinations exhibited non-significant positive increase over their respective mid parents. Only one cross Punjab 96 × Inqalab 91 was found inferior to its mid parent with a heterotic effect of -1.96%. Positive heterobeltiosis was realized in 75% crosses varying from 26.91 (Fsd. 85 × Inqalab 91) to 0.33% (MH. 97 × Uqab 2000). While the remaining 25% crosses exhibited negative heterotic effects over their better parents ranging from -7.45 (Inqalab 91 × Uqab 2000) to -2.40% (MH. 97 × Inqalab 91). Hybrid Fsd. 85 × Inqalab 91 followed by MH. 97 × Punjab 96 and Inqalab 91 × Punjab 96 indicated highest heterotic effects of 26.91, 24.58 and 23.08% over their better parents, respectively. Including these three hybrids, a total of 10 hybrids presented highly significant heterobeltiosis; whereas, one cross exhibited significant effects only, indicating the presences of overdominance for this trait. However, highest negative heterosis (-7.45%) over better parent was found to be highly significant for the cross Inqalab 91 × Uqab 2000 followed by two other crosses with significant negative effects. The present results are in agreement with the findings of earlier researchers like Sadeque *et al.* (1991) and Akhter *et al.* (2003) who reported maximum positive heterosis for most of their crosses for grain yield per plant

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