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HETEROSIS FOR YIELD AND PHYSIOLOGICAL TRAITS IN WHEAT UNDER WATER STRESS CONDITIONS

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ABSTRACT

Water shortage is one of the major limitations that affect plant growth and development, and consequently yield and such losses can be compensated through heterosis breeding. Wheat cultivars viz., TD-1, Kiran, Sarsabz, Moomal, SKD-1 and TJ-83 crossed in a 6 × 6 diallel mating design. The F_1 hybrids and parental lines were sown in a randomized complete block design with factorial arrangement. Two irrigation treatments, non-stress and water stress at anthesis were applied during 2010 at Sindh Agriculture University, Tandojam, Pakistan. Water stress has considerable effect on yield and physiological traits that allowed determining the heterotic effects. The F_1 hybrids i.e. TD-1 × TJ-83, Kiran × Sarsabz, Kiran × Moomal and Sarsabz × Moomal showed greater mid and high parent heterotic response under both environments for relative water content, leaf area, seeds spike^{-1}, seed index, harvest index and yield plant^{-1}. The hybrids with high heterosis for other traits revealed less heterosis for stomatal conductance, especially in water stress conditions and proved their drought tolerance. The better parent effects were higher in non-stress than stress suggested that if exploitation of hybrid vigor is feasible in wheat, the above hybrids would be the choice F_1 hybrids to be grown in water-deficit conditions for higher yields.

Key words: *Triticum aestivum* L., abiotic stress, F_1 hybrids, hybrid vigor, agronomic traits

INTRODUCTION

One approach to improve drought tolerance in different crop species is to utilize heterosis based on the principle that heterosis for yield and yield components may increase under water stress conditions. In maize (Betran *et al*., 2003) and pearl millet (Yadaw *et al*., 2000), high estimates of hybrid vigor for yield have been obtained under stress conditions. In barley, it has been observed that heterozygosity rather than heterogeneity was important for grain yield under water stress environment (Einfeldt *et al*., 2005). The information on the magnitude of heterosis in bread wheat, especially under divergent moisture regimes is constrained. In many crop plants, the correlations of genetic distance with the expression of heterosis recorded low. It may be due to the fact that, environment can variably influence the performance of parental lines and hybrids, thus it can alter the relationship between genetic distance and heterosis (Solomon *et al*., 2007).

It has been predicted that, in the years to come, water shortage will become more severe. Thus, it is expected that drought will be one of the most important natural disasters which will affect plant growth and will limit the crop yield. Considerable endeavors in the past for breeding improved drought tolerance have been put in many field crops. Great effort had been directed towards the use of classical breeding methods by focusing on yield and its components in wheat. Such traits are genetically intricate and are not easy to maneuver. Thus, little accomplishment has been obtained so far in increasing drought tolerance in wheat genotypes over the last five decades (Munir *et al*., 2006). An essential issue in hybrid breeding is the choice of potential parents to be crossed and identification of superior hybrid combinations. Thus, the exploitation of heterosis has remained as one of the exceptional achievements of plant breeding in different crop plants.

Exploitation of hybrid vigor in wheat is more striking than its conventional plant breeding approaches because of the prospect of obtaining higher yields as compared to pure lines. In self-pollinated crops such as wheat, the exploitation of heterosis depends primarily on extent of heterosis (Singh *et al*., 2004). Heterosis is the superiority of the F_1 hybrids over the mid / better parental values. It is the interaction of allelic or non-allelic genes under the influence of particular environment. Heterosis has been observed in many crop species and has been the objective of considerable importance to study as means of increasing productivity of crop plants.

It is now well established fact that heterosis does occur with selective combination of parents. Breeding for water stress tolerance is a difficult job because of the intricacy of the related traits, screening methods, environmental factors and their interactions. Selection of genotypes with better performance in water stress conditions should increase production of rainfed areas (Rashidi and Seyfi, 2007), because the climatic variability greatly affects the genotypes performance. The major setback in drought tolerance breeding is the poor understanding of genetics and inheritance of drought tolerance traits and complete ignorance of physiological attributes related to drought tolerance. Alternatively, yield improvements in water-limited environments can be achieved by selecting for secondary traits contributing to drought resistance in breeding programs. Ganapathy and Ganesh (2008) noted maximum desirable heterosis over mid parent for root length, root dry weight, leaf relative water content and chlorophyll stability index. Similar trend of desirable heterosis over better parent observed for root length and root dry weight. They evaluated 40 hybrids, of which CPMB-ACM-03-017 × MDU-5 recorded significantly higher heterosis over mid parents and better parents for physiological traits while some other hybrids manifested positive and considerable heterosis over mid and better parents for root traits. The present studies, therefore intended to exploit the magnitude of heterosis for yield and physiological traits under water stress conditions.

MATERIALS AND METHODS

Wheat varieties viz., TD-1, Kiran, Sarsabz, Moomal, SKD-1 and TJ-83 with dissimilar origin and traits were crossed in a 6 × 6 half-diallel mating method during 2009 and 15 F_1 hybrids were developed. The F_1 hybrids along with their parents were grown in a Randomized Complete Design and managed in factorial fashion with two irrigation treatments and four replications during 2010 at Sindh Agriculture University, Tandojam, Pakistan. The irrigation treatments were; non-stress and water stress at anthesis. The data analyzed for determining differences between treatments, and parental lines and F_1 hybrids through analysis of variance after Gomez and Gomez (1984), while the percent increase or decrease of F_1 hybrids over mid or better parents used to estimate heterotic effects as suggested by Fehr (1987).

RESULTS AND DISCUSSION

Mean performance of the parents and F_1 hybrids for yield and physiological traits: Mean squares from analysis of variance of wheat genotypes evaluated under non-stress and water stress imposed at anthesis were significant for grains spike^{-1}, grain yield palnt$^{-1,}$ seed index, grain yield kg ha^{-1}, relative water content (RWC), stomatal conductance and leaf area (Table 1). These results indicated that water stress caused significant impact on yield and physiological traits of wheat varieties. The average performance of parents and their F_1 hybrids for yield traits is presented in Table 2. On an average, the water stress caused -24.06% reduction in grain yield plant^{-1}, -26.96% in grains spike^{-1}, -20.37% in seed index and -11.00% in harvest index. Among the parental cultivars, the TD-1, Sarsabz, Moomal and SKD-1 generally performed well with minimum reductions in stress conditions for yield traits. In 15 F_1 hybrids developed from six half diallel crosses, the hybrids, TD-1 × TJ-83, Kiran × Sarsabz and Kiran × Moomal recorded minimum declines in yield traits due to water stress.

For physiological parameters, the average reduction of -62.59% occurred in stomatal conductance, -32.11% in leaf area and -51.53% in relative water content (Table 3). Under water stress, the length, fresh weight and dry weight of roots and shoots, stomatal frequency and stomatal density decreased by 24.21, 1.27, 17.18, 25.00, 14.25 and 14.24%, respectively while root-shoot ratio increased by 31.18% over the control values (Khan *et al*., 2010). The parents like TD-1, Sarsabz and SKD-1 maintained higher relative water content and greater leaf area and provided less stomatal conductance (Table 3). Regarding the mean performance of F_1 hybrids in stress conditions, the hybrids TD-1 × T.J-83, Kiran × Sarsabz and Sarsabz × Moomal recorded maximum RWC (47.00%), more leaf area (24.00 cm^2) and minimum stomatal conductance (137.00 mmol m^{-2} s^{-1}), respectively. In plant breeding, it is normally assumed that when good performing parents are crossed with each other, they are anticipated to produce better hybrids but this assumption was not always true (Baloch and Bhutto, 2003).

Heterosis in F_1 hybrids for yield traits: Heterosis is the superiority of the F_1 hybrid over the mid or better parents. It is expressed by allelic and non-allelic interaction of genes in either homozygote dominant or heterozygote conditions under the influence of particular environment (Wu *et al*., 2004). Heterosis observed in many crop species, and has been the objective of considerable importance to plant breeders as a source of increasing productivity of crop plants. It is now well-established fact that heterosis does occur with selective combination of parents. Very little emphasis is diverted to study the heterotic effects in water stress conditions. The present research was therefore, designed to identify the cross combinations which express desirable heterosis in drought conditions. The heterotic performance of F_1 hybrids for yield traits is presented in Tables 4 to 7 and trait-wise results are given here under:

Grains per spike: For grains spike^{-1}, most of the crosses manifested positive heterosis in non-stress and in stress conditions as well. The magnitude of heterosis was about similar in both the environments suggesting that grains spike^{-1} of the hybrids was less affected due to water stress. Among the hybrids, TD-1 × TJ-83 showed highest relative heterosis (14.83%), while Sarsabz × Moomal manifested greatest heterosis of 11.79% over better parent (Table 4). The next high-ranking hybrids were Sarsabz × Moomal with 13.04% relative heterosis and TD-1 × TJ-83 with 11.00% better parent heterosis in non-stress conditions. In stress environment, the best combination was TD-1 × TJ-83 which demonstrated maximum relative heterosis (19.66%) and better parent heterosis (13.68%) while the next ranker was Sarsabz × Moomal that expressed 18.30% relative heterosis, nevertheless Kiran × Sarsabz exhibited 14.06% relative heterosis and 9.38% better parent heterosis showing their drought tolerance in water-deficit environments. Though little bit less than our heterotic values, Hussain *et al*. (2007) also estimated significant relative heterotic and heterobeltiotic effects for grains per spike that varied from 1.61 to 13.12% and 1.48 to 6.86%, respectively. Hybrids like TD-1 × TJ-83, Kiran × Sarsabz, Kiran × Moomal and Sarsabz × Moomal manifested higher heterotic effects in both the environmental conditions proving their superiority in well-watered and in moisture-deficit conditions. Chowdhry *et al*. (2005) reported about twice-greater heterosis than present results but their studies were conducted in normal water conditions while present findings are closer to the results of Farooque and Khalique (2004) and their findings revealed maximum heterosis of 9.25% over better parents.

Grain yield per plant: Grain yield is the product of all the yield components. Higher positive heterotic effects noted in non-stress than in water stress environment, however, very surprisingly the magnitude of both relative and better parent heterosis were about twice greater in stress than in non-stress conditions. In the non-stress conditions, the F_1 hybrid Sarsabz × Moomal gave maximum relative (16.81%) and better parent heterosis (15.04%), whereas TD-1 × TJ-83 expressed next higher relative heterosis (16.12%) and heterobeltiosis (13.12%), yet the Kiran × Sarsabz secured third position by manifesting 15.65% relative heterosis and 11.30% better parent heterosis (Table 5). In stress condition, the maximum relative heterotic effect of 21.28% was recorded in Kiran × Sarsabz while Kiran × Moomal manifested highest better parent heterosis of 15.38%. Next scoring hybrid was TD-1 × TJ-83 that manifested 18.37% relative heterosis, whilst Kiran × Sarsabz gave 12.77% better parent heterosis, yet Sarsabz × Moomal was third ranker, which expressed 17.61 and 6.82% relative heterosis and better parent heterosis, respectively. Hussain *et al*. (2007) estimated fair amount of relative heterotic and heterobeltiotic effects for grain yield ranging from 1.43 to 52.01% and 5.00 to 48.19%, respectively. This difference in the magnitude of heterosis in stress and non-stress may be attributable to the fact that, more number of stress responsive genes might have expressed in stress conditions that enhanced the heterotic effects of the hybrids. The three hybrids such as Kiran × Moomal, Kiran × TJ-83 and Sarsabz × Moomal, nevertheless expressed higher relative and better parent heterosis in stress against non-stress conditions. These results indicated that the above hybrids are more desirable to be grown under water shortage conditions for increasing grain yield per unit area.

Seed index: Wheat genotypes which sustain water stress conditions are assumed to produce bolder seeds with higher seed index. However, several hybrids demonstrated fair amount of heterosis in non-stress and in stress conditions, yet the F_1 hybrids viz., TD-1 × TJ-83 and Kiran × Sarsabz manifested higher relative and better parent heterosis in both the environments (Table 6). The other hybrids like Kiran × TJ-83 and Sarsabz × Moomal gave higher heterotic effects in stress against in non-stress, thus extraordinarily proved their high drought tolerance for seed index. Maintaining bolder seeds in stress condition is desirable attribute and the hybrids such as Sarsabz × Moomal, Kiran × Moomal and TD-1 × TJ-83 recorded substantial amount of heterosis in seed index suggesting their stress tolerance. Present findings are in conformity with those of Rasul *et al*. (2002), Kashif and Khaliq (2004), Chowdhry *et al*. (2005), Inamullah *et al*. (2006) and Akbar *et al*. (2007) who also reported positive heterosis and heterobeltiosis for seed index.

Harvest index: Harvest index is the portion of grain yield from total dry matter and it shows the ability of the plants to translocate physiological matters to grains. In water-deficit conditions, the harvest index usually declines due to un-developed grains. For this trait, the magnitude of heterosis was not substantial. The maximum relative and better parent heterosis of 1.85 and 1.23%, respectively were noted in F_1 hybrid Sarsabz × Moomal. The next maximum value of 1.11 and 1.07% as relative and better parent heterosis, respectively calculated from Kiran × Sarsabz. However, the cross Moomal × TJ-83 with 0.66% as relative heterosis and SKD-1 × TJ-83 with 0.34% as better parent heterosis ranked as third position in non-stress conditions (Table 7). With regard to stress at anthesis, the maximum heterotic effects were noted by cross TD-1 × TJ-83 with relative heterosis of 11.28% and better parent heterosis of 6.15%. The Sarsabz × Moomal occupied second position for relative heterosis (6.27%) and better parent heterosis (3.96%) while third position was retained by Kiran × Sarsabz (2.47%) and Moomal × TJ-83 (2.20%) for relative heterosis and heterobeltiosis, respectively. Yet the F_1 hybrids TD-1 × TJ-83 and Sarsabz × Moomal expressed higher relative and better parent heterosis in stress conditions demonstrating that both the hybrids can produce bolder seeds without showing stress symptoms.

By pooling the review of literature on heterosis studies, Farshadfar *et al*. (2001) observed high relative heterosis and heterobeltiosis for grain yield and harvest index in stress conditions, while Abd-Allah (2009) also noted desirable and significant heterosis for grain yield $plant^{-1}$ in stress conditions. Somewhat higher but similar to most of our yield traits, Fida *et al*. (2004) also measured significant heterotic effects for grains $spike^{-1}$ and grain yield $plant^{-1}$.

Heterosis in F_1 hybrids for physiological traits: The heterotic performance of F_1 hybrids for physiological traits is presented in Tables 8 to 10 and trait-wise results are given here under:

Relative water content (RWC) in leaf: Less transpiration through leaves of cultivars might be considered as better survivors in drought stress conditions. Relative magnitude of heterosis for relative water content was higher in stress than in non-stress conditions. With respect to relative water content, in non-stress conditions the cross TD-1 × TJ-83 exhibited maximum relative heterosis (5.78%) and better parent heterosis (3.20%) (Table 8). However, the next ranking hybrid was TD-1 × Kiran that manifested 2.21% and 1.38% as relative and better parent heterosis, respectively. Yet the third position was secured by the F_1 hybrids Kiran × TJ-83 with 2.13% and TD-1 × Sarsabz with 0.61% relative heterosis and heterobeltiosis, respectively. In stress conditions, the maximum edge of 10.64% as relative heterosis and 9.30% as better parent heterosis recorded in F_1 hybrids TD-1 × TJ-83 and Kiran × Moomal, respectively. The F_1 crosses Kiran × Moomal with 10.47% as relative heterosis and Kiran × TJ-83 with 9.30% as better parent heterosis ranked next scorer among the F_1 hybrids. The third position retained by the F_1 hybrids Kiran × TJ-83 and TD-1 × TJ-83 which gave 9.30 and 4.26% relative and better parent heterosis, respectively. These types of results indicated that drought inducible genes might have been activated due to stress. At least five F_1 hybrids expressed around 10.00% relative and better parent heterosis in stress conditions whereas the extent of heterosis in non-stress was around 5.78%. Some drought tolerant hybrids like TD-1 × TJ-83, Kiran × Moomal and Kiran × TJ-83 recorded maximum heterotic effects and were being more tolerant to others for relative water content. Ganapathy and Ganesh (2008) estimated 51.87% mid parent heterosis for relative water content that was higher than the heterotic values observed in the present studies.

Stomatal conductance: Drought tolerant plants express less conductance in water-deficit conditions because they strive to sustain water losses through transpiration. Majority of the F_1 hybrids exhibited much higher heterotic effects in stress environments, means transpiring more water, thus denoting their drought susceptibility. Negative heterotic effects are preferable and desirable from breeding point of view for stomatal conductance because genotypes, which express fewer conductances in the stress environment, expected to transpire less water. The higher heterotic edge was acquired by the F_1 hybrids, Sarsabz × Moomal,TD-1 × TJ-83 with -15.86% and -23.54% as relative heterosis and heterobeltiosis, respectively in water stress condition, while second position was occupied by the cross Sarsabz × Moomal which expressed -16.15 and -16.61% as relative and better parent heterosis, respectively. The third desirable F_1 cross for stomatal conductance was Kiran × Sarsabz that expressed -10.55% relative and -16.33% better parent heterosis (Table 9). However, the maximum negative heterotic effects (desirable heterosis) in stress conditions were recorded by the hybrids TD-1 × TJ-83, Kiran × Sarsabz and Sarsabz × Moomal, which confirmed that these hybrids transpired less water in stress conditions, hence, were considered desirable F_1 hybrids.

Leaf area: Generally, it assumed that wider leaf area may be used for more food manufacturing process. The maximum heterosis for leaf area was expressed by the F_1 hybrid TD-1 × TJ-83 for both relative (13.08%) and better parent heterosis (6.92%), whereas next higher relative heterosis and better parent heterosis of 11.33 and 4.69% expressed by Moomal × TJ-83. Two other hybrids such as SKD-1 × TJ-83 and Sarsabz × TJ-83 also exhibited fair amount of relative heterosis (9.35 and 7.63%) and better parent heterosis (4.07 and 4.24%), respectively in non-stress conditions (Table 10). In water stress, the maximum relative heterosis (18.09%) shown by Kiran × Sarsabz whereas better parent heterosis was recorded in Sarsabz × Moomal (12.90%). At next position were; the F_1 hybrids TD-1 × TJ-83 and Kiran × Sarsabz which gave 11.46% as relative heterosis and 5.32% as better parent heterosis, respectively. In the remaining hybrids, Sarsabz × Moomal expressed 8.60% relative heterosis while rest of the hybrids manifested negative better parent heterosis except two hybrids mentioned earlier. At large, F_1 hybrids were more variable in the expression of heterosis, however, the hybrids TD-1 × TJ-83 and Moomal × TJ-83 recorded relatively higher heterotic effects in non-stress while Kiran × Sarsabz and Sarsabz × Moomal revealed greater heterosis in stress environment. Thus, first group of two hybrids are desirable for well-watered and latter two hybrids are suitable to be grown in water-deficit conditions. In consonance with our findings, Choudhry *et al.* (2005) also estimated significant mid-parent and better parent heterosis of 28.72 and 28.70%, respectively.

Conclusion: If the hybrid crop development is feasible in wheat, the F_1 hybrids viz., TD-1 × TJ-83, Kiran × Sarsabz, Kiran × Moomal and Sarsabz × Moomal are the choice cross combinations to be grown in water stress conditions for obtaining higher yields and selection could be exercised in segregating generations for developing drought tolerant genotypes.

Table 1. Mean squares for yield and physiological traits of wheat parental cultivars and their F_1 hybrids grown under non-stress and water stress conditions.

Traits	Non-stress			Stress at anthesis		
	Replications D.F. = 3	Genotypes D.F. = 20	Error D.F. = 60	Replications D.F. = 3	Genotypes D.F. = 20	Error D.F. = 60
Yield traits						
Grains spike^{-1}	16.10	57.20**	0.33	19.66	109.67**	0.94
Grain yield plant^{-1}	12.26	29.23**	0.35	19.58	43.61**	0.47
Seed index	19.46	32.84**	0.28	15.31	38.52**	0.47
Harvest index	1.78	10.88**	0.54	6.08	13.49**	0.76
Physiological traits						
Relative water content	3.11	9.83**	0.54	5.88	26.97**	0.66
Stomatal conductance	117.36	1994.93**	6.54	110.93	2919**	19.29
Leaf area	7.63	10.16**	0.26	7.15	22.45**	0.46

** = Significant at $p \leq 0.01$.

Table 2. Mean performance of parental cultivars and their F_1 hybrids for yield traits of wheat grown under non-stress and water stress conditions.

Parental cultivars and F_1 hybrids	Grains spike^{-1} (#)		Grain yield plant^{-1} (g)		Seed index (g)		Harvest index (%)	
	Non-stress	Stress	Non-Stress	Stress	Non-stress	Stress	Non-stress	Stress
Parental cultivars								
TD-1	66.75	50.50	26.25	23.50	48.00	39.50	54.26	46.75
Kiran	66.00	45.50	25.50	16.50	47.00	34.50	50.01	45.85
Sarsabz	61.75	50.75	23.00	20.50	43.00	38.00	50.00	43.50
Moomal	60.00	40.75	24.00	15.75	44.75	32.00	49.75	41.75
SKD-1	67.50	48.50	23.50	20.75	42.00	36.50	50.75	44.57
T.J-83	61.00	43.50	24.50	16.50	44.00	33.50	50.00	41.75
F_1 hybrids								
TD-1 × Kiran	67.00	50.50	26.00	20.00	47.50	39.00	50.76	46.16
TD-1 × Sarsabz	66.00	49.50	26.00	20.50	47.50	38.00	49.96	43.82
TD-1 × Moomal	59.500	40.00	20.75	12.75	40.75	30.75	49.99	43.84
TD-1 × SKD-1	67.50	51.00	25.75	20.50	47.50	38.50	49.41	44.75
TD-1 × T.J-83	75.00	58.50	30.25	24.50	50.75	41.00	52.05	49.95
Kiran × Sarsabz	71.00	56.00	28.75	23.50	49.25	40.50	50.55	46.00
Kiran × Moomal	67.00	48.50	25.50	19.50	46.50	37.00	49.02	44.25
Kiran × SKD-1	67.50	50.50	27.00	20.50	47.50	36.50	50.00	45.10
Kiran × T.J-83	66.00	47.75	26.00	19.50	46.50	36.50	48.98	43.85
Sarsabz × Moomal	70.00	56.00	28.25	22.00	48.00	39.50	50.59	45.45
Sarsabz × SKD-1	66.75	47.00	26.00	19.50	46.50	37.00	49.03	43.44
Sarsabz × T.J-83	66.50	49.50	27.00	20.50	47.25	37.00	49.75	43.79
Moomal × SKD-1	67.75	47.50	24.50	16.75	44.75	37.50	44.49	42.75
Moomal × T.J-83	64.50	40.75	20.75	14.00	41.50	31.75	50.00	42.75
SKD-1 × T.J-83	60.50	39.50	19.00	13.50	40.50	30.75	50.17	43.91
Mean	65.98	48.19	25.15	19.10	45.76	36.44	49.98	44.48
R.D.%	-26.96		-24.06		-20.37		-11.00	
$LSD_{0.05}$ (T)	0.20		1.33		0.19		0.31	
$LSD_{0.05}$ (G)	0.66		4.30		0.63		1.01	
$LSD_{0.05}$ (T × G)	0.93		6.08		0.89		1.43	

R.D. % = Relative decrease in percentage due to water stress

Table 3. Mean performance of parental cultivars and their F_1 hybrids for physiological traits of wheat grown under non-stress and water stress conditions.

Parental cultivars and F_1 hybrids	Relative water content (%)		Stomatal conductance (mmol $m^{-2} s^{-1}$)		Leaf area (cm^2)	
	Non-stress	Stress	Non-Stress	Stress	Non-Stress	Stress
Parental cultivars						
TD-1	89.25	44.75	473.25	139.00	30.25	24.25
Kiran	87.75	38.00	448.5	142.75	31.00	16.25
Sarsabz	88.25	44.75	419.25	158.50	28.25	22.25
Moomal	87.25	37.75	400.75	159.75	30.50	20.25
SKD-1	88.50	41.75	414.50	140.25	29.50	23.25
T.J-83	84.50	38.50	433.50	158.75	26.25	18.25
F_1 hybrids						
TD-1 × Kiran	90.50	44.00	466.75	169.50	31.00	21.00
TD-1 × Sarsabz	89.80	44.50	471.50	180.25	29.50	20.50
TD-1 × Moomal	88.50	43.00	460.00	220.25	30.00	20.25
TD-1 × SKD-1	88.90	45.00	473.00	169.00	29.00	19.25
TD-1 × T.J-83	92.20	47.00	476.25	128.50	32.50	24.00
Kiran × Sarsabz	88.50	45.80	474.00	136.25	31.00	23.50
Kiran × Moomal	88.20	43.00	430.00	200.00	29.00	17.75
Kiran × SKD-1	88.74	44.00	445.00	166.00	28.00	18.75
Kiran × T.J-83	88.00	43.00	450.00	188.25	30.00	18.00
Sarsabz × Moomal	87.88	44.75	471.50	137.00	31.00	23.25
Sarsabz × SKD-1	88.41	42.50	465.00	168.50	26.50	17.75
Sarsabz × T.J-83	88.00	44.00	470.50	178.75	29.50	19.75
Moomal × SKD-1	88.54	43.00	465.00	186.50	29.00	18.75
Moomal × T.J-83	86.00	40.00	435.00	210.00	32.00	17.75
SKD-1 × T.J-83	87.00	40.00	453.75	214.75	30.75	19.25
Mean	88.32	42.81	452.24	169.17	29.74	20.19
R.D.%	-51.53		-62.59		-32.11	
$LSD_{0.05}$ (T)	0.19		0.76		0.18	
$LSD_{0.05}$ (G)	0.60		2.47		0.60	
$LSD_{0.05}$ (T × G)	0.85		3.49		0.84	

R.D. % = Relative decrease in percentage due to water stress.

Table 4. Heterotic effects of F_1 hybrids for grains per spike of wheat grown under non-stress and water stress conditions.

F_1 hybrids	Grains $spike^{-1}$			
	Non-stress		Stress at anthesis	
	R.H. (%)	B.P. (%)	R.H. (%)	B.P. (%)
TD-1 × Kiran	0.93	0.37	4.95	0.00
TD-1 × Sarsabz	2.65	-1.14	-2.27	-2.53
TD-1 × Moomal	-6.51	-12.18	-14.06	-26.25
TD-1 × SKD-1	0.56	0.00	2.94	0.98
TD-1 × T.J-83	14.83	11.00	19.66	13.68
Kiran × Sarsabz	10.04	7.04	14.06	9.38
Kiran × Moomal	5.97	1.49	11.08	6.19
Kiran × SKD-1	1.11	0.00	6.93	3.96
Kiran × T.J-83	3.79	0.00	6.81	4.71
Sarsabz × Moomal	13.04	11.79	18.30	9.38
Sarsabz × SKD-1	3.18	-1.12	-5.59	-7.98
Sarsabz × T.J-83	7.71	7.14	4.80	-2.53
Moomal × SKD-1	5.90	0.37	6.05	-2.11
Moomal × T.J-83	6.20	5.43	-3.37	-6.75
SKD-1 × T.J-83	-6.20	-11.57	-16.46	-22.78

R.H. = Relative heterosis, B.H. = Better parent heterosis.

Table 5. Heterotic effects of F_1 hybrids for grain yield per plant of wheat grown under non-stress and water stress conditions.

F_1 hybrids	Grain yield plant^{-1}			
	Non-stress		Stress at anthesis	
	R.H. (%)	B.P. (%)	R.H. (%)	B.P. (%)
TD-1 × Kiran	0.48	-0.96	0.00	-17.50
TD-1 × Sarsabz	5.29	-0.96	-7.32	-14.63
TD-1 × Moomal	-21.08	-26.51	-53.92	-84.31
TD-1 × SKD-1	3.40	-1.94	-7.93	-14.63
TD-1 × T.J-83	16.12	13.22	18.37	4.08
Kiran × Sarsabz	15.65	11.30	21.28	12.77
Kiran × Moomal	2.94	0.00	17.31	15.38
Kiran × SKD-1	9.26	5.56	9.15	-1.22
Kiran × T.J-83	3.85	1.92	15.38	15.38
Sarsabz × Moomal	16.81	15.04	17.61	6.82
Sarsabz × SKD-1	10.58	9.62	-5.77	-6.41
Sarsabz × T.J-83	12.04	9.26	9.76	0.00
Moomal × SKD-1	3.06	2.04	-8.96	-23.88
Moomal × T.J-83	-16.87	-18.07	-15.18	-17.86
SKD-1 × T.J-83	-26.32	-28.95	-37.96	-53.70

R.H. = Relative heterosis, B.H. = Better parent heterosis.

Table 6. Heterotic effects of F_1 hybrids for seed index of wheat grown under non-stress and water stress conditions.

F_1 hybrids	Seed index			
	Non-stress		Stress at anthesis	
	R.H. (%)	B.P. (%)	R.H. (%)	B.P. (%)
TD-1 × Kiran	0.00	-1.05	5.13	-1.28
TD-1 × Sarsabz	4.21	-1.05	-1.97	-3.95
TD-1 × Moomal	-13.80	-17.79	-16.26	-28.46
TD-1 × SKD-1	5.26	-1.05	1.30	-2.60
TD-1 × T.J-83	9.36	5.42	10.98	3.66
Kiran × Sarsabz	8.63	4.57	10.49	6.17
Kiran × Moomal	1.34	-1.08	10.14	6.76
Kiran × SKD-1	6.32	1.05	2.74	0.00
Kiran × T.J-83	2.15	-1.08	6.85	5.48
Sarsabz × Moomal	8.59	6.77	11.39	3.80
Sarsabz × SKD-1	8.60	7.53	-0.68	-2.70
Sarsabz × T.J-83	7.94	6.88	3.38	-2.70
Moomal × SKD-1	3.07	0.00	8.67	2.67
Moomal × T.J-83	-6.93	-7.83	-3.15	-5.51
SKD-1 × T.J-83	-6.17	-8.64	-13.82	-18.70

R.H. = Relative heterosis, B.H. = Better parent heterosis.

Table 7. Heterotic effects of F_1 hybrids for harvest index of wheat grown under non-stress and water stress conditions.

F_1 hybrids	Harvest index			
	Non-stress		Stress at anthesis	
	R.H. (%)	B.P. (%)	R.H. (%)	B.P. (%)
TD-1 × Kiran	-2.71	-6.90	-0.44	-1.56
TD-1 × Sarsabz	-4.31	-8.61	-3.30	-6.98
TD-1 × Moomal	-3.62	-8.54	-0.86	-6.93
TD-1 × SKD-1	-5.60	-9.82	-2.20	-4.78
TD-1 × T.J-83	-0.15	-4.25	11.28	6.15
Kiran × Sarsabz	1.11	1.07	2.74	0.35
Kiran × Moomal	-1.34	-2.02	1.22	-3.64
Kiran × SKD-1	-0.10	-0.18	-0.22	-1.64
Kiran × T.J-83	-2.09	-2.10	0.09	-4.58
Sarsabz × Moomal	1.85	1.23	6.27	3.96
Sarsabz × SKD-1	-2.04	-2.16	-1.54	-2.60
Sarsabz × T.J-83	-1.16	-1.19	2.49	0.32
Moomal × SKD-1	-11.74	-12.59	-0.28	-3.80
Moomal × T.J-83	0.66	0.00	2.44	2.20
SKD-1 × T.J-83	0.25	0.34	1.71	-1.50

R.H. = Relative heterosis, B.H. = Better parent heterosis.

Table 8. Heterotic effects of F_1 hybrids for relative water content in leaf of wheat grown under non-stress and water stress conditions.

F_1 hybrids	Relative water content (RWC) in leaf			
	Non-stress		Stress at anthesis	
	R.H. (%)	B.P. (%)	R.H. (%)	B.P. (%)
TD-1 × Kiran	2.21	1.38	4.55	-2.27
TD-1 × Sarsabz	1.17	0.61	-2.25	-1.12
TD-1 × Moomal	0.28	-0.85	3.49	-4.65
TD-1 × SKD-1	0.03	-0.39	3.33	0.00
TD-1 × T.J-83	5.78	3.20	10.64	4.26
Kiran × Sarsabz	0.56	0.28	7.21	-0.44
Kiran × Moomal	0.79	0.51	10.47	9.30
Kiran × SKD-1	0.69	0.27	7.95	4.55
Kiran × T.J-83	2.13	0.28	9.30	9.30
Sarsabz × Moomal	0.14	-0.43	2.33	-6.98
Sarsabz × SKD-1	0.04	-0.11	1.12	-3.37
Sarsabz × T.J-83	1.85	-0.28	3.41	-4.55
Moomal × SKD-1	0.75	0.05	6.98	2.33
Moomal × T.J-83	0.15	-1.45	3.75	2.50
SKD-1 × T.J-83	0.57	-1.72	-1.25	-5.00

R.H. = Relative heterosis, B.H. = Better parent heterosis.

Table 9. Heterotic effects of F_1 hybrids for stomatal conductance of wheat grown under non-stress and water stress conditions.

F_1 hybrids	Stomatal conductance			
	Non-stress		Stress at anthesis	
	R.H. (%)	B.P. (%)	R.H. (%)	B.P. (%)
TD-1 × Kiran	1.26	-1.39	16.89	15.78
TD-1 × Sarsabz	5.36	-0.37	17.48	12.07
TD-1 × Moomal	5.00	-2.88	32.18	27.47
TD-1 × SKD-1	6.16	-0.05	17.38	17.01
TD-1 × T.J-83	4.80	0.63	-15.86	-23.54
Kiran × Sarsabz	8.47	5.38	-10.55	-16.33
Kiran × Moomal	1.25	-4.30	24.38	20.13
Kiran × SKD-1	3.03	-0.79	14.76	14.01
Kiran × T.J-83	2.00	0.33	19.92	15.67
Sarsabz × Moomal	13.04	11.08	-16.15	-16.61
Sarsabz × SKD-1	10.35	9.84	11.35	5.93
Sarsabz × T.J-83	9.38	7.86	11.26	11.33
Moomal × SKD-1	12.34	10.86	19.57	14.34
Moomal × T.J-83	4.11	0.34	24.17	23.93
SKD-1 × T.J-83	6.56	4.46	30.38	26.08

R.H. = Relative heterosis, B.H. = Better parent heterosis.

Table 10. Heterotic effects of F_1 hybrids for leaf area of wheat grown under non-stress and water stress conditions.

F_1 hybrids	Leaf area			
	Non-stress		Stress at anthesis	
	R.H. (%)	B.P. (%)	R.H. (%)	B.P. (%)
TD-1 × Kiran	1.21	0.00	3.57	-15.48
TD-1 × Sarsabz	0.85	-2.54	-13.41	-18.29
TD-1 × Moomal	-1.25	-1.67	-9.88	-19.75
TD-1 × SKD-1	-3.02	-4.31	-23.38	-25.97
TD-1 × T.J-83	13.08	6.92	11.46	-1.04
Kiran × Sarsabz	4.44	0.00	18.09	5.32
Kiran × Moomal	-6.03	-6.90	-2.82	-14.08
Kiran × SKD-1	-8.04	-10.71	-5.33	-24.00
Kiran × T.J-83	4.58	-3.33	4.17	-1.39
Sarsabz × Moomal	5.24	1.61	8.60	12.90
Sarsabz × SKD-1	-8.96	-11.32	-28.17	-30.99
Sarsabz × T.J-83	7.63	4.24	-2.53	-12.66
Moomal × SKD-1	-3.45	-5.17	-16.00	-24.00
Moomal × T.J-83	11.33	4.69	-8.45	-14.08
SKD-1 × T.J-83	9.35	4.07	-7.79	-20.78

R.H. = Relative heterosis, B.H. = Better parent heterosis.

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