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HERITABILITY AND CORRELATION STUDIES OF MORPHO-PHYSIOLOGICALTRAITS FOR DROUGHT TOLERANCE IN SPRING WHEAT

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ABSTRACT

Six wheat genotypes were crossed in 6 x 6 half diallel fashion. The parents and 15 F_1 hybrids were evaluated in a randomized complete block design (RCBD) with four replications and two irrigation treatments. The analysis of variance revealed significant effect of water stress on yield and physiological traits which allowed determining the heritability and correlations for such traits. For yield traits, the parents TD-1, Sarsabz, Moomal and SKD-1 gave relatively minimum reductions on individual mean basis in stress conditions, whereas hybrids TD-1 x TJ-83, Kiran x Sarsabz and Kiran x Moomal recorded minimum declines in most of yield traits showing their feasibility for wheat hybrids in water shortage conditions. Similar to physiological traits, parents TD-1, Sarsabz and SKD-1 maintained their higher relative water content, greater leaf area and less stomatal conductance, while hybrids TD-1 x T.J-83, Kiran x Sarsabz and Sarsabz x Moomal expressed maximum RWC%, more leaf area and minimum stomatal conductance under drought conditions. The heritability estimates in broad were high whereas in narrow sense were low, moderate and high for yield and physiological traits, yet these estimates were greater in stressed than in non-stressed conditions. It indicated that the characters studied were predominantly controlled by additive type of genes and the stressed responsive genes were activated due to drought conditions. Thus, selection for such traits would be more effective for drought tolerance. Generally, the correlation coefficients were also greater in stressed than in non-stressed environments. In stressed conditions, the correlations between yield and physiological traits revealed that grains spike^{-1}, seed index, grain yield plant^{-1}, grain yield kg ha^{-1} and harvest index were positively correlated with relative water content, leaf area, spike fertility, root length and root biomass, nevertheless, all the yield traits were negatively correlated with only stomatal conductance.

Keywords: Correlations, F_1 hybrids, Heritability estimates, yield and physiological traits, water stress tolerance, wheat varieties.

INTRODUCTION

Drought stress is a pervasive feature of wheat production in world's major cereal growing regions. To improve the productivity in these areas, the importance of traits associated with tolerance to drought needs to be quantified. Yield is a complex trait and many physiological, morphological and developmental characteristics have been suggested as being important to yield in water limited environments (McDonald *et al.,* 2008). However, yield can be considered in terms of a few fundamental processes like the ability of a crop to use the available moisture for the efficient production of biomass and its partitioning into yield. Consequently, to achieve higher yields in water deficient environments, evolution of new varieties which better survive stressed conditions are the important goals of wheat breeders. Evolution of drought tolerant wheat varieties is a long and complex process when the motive involved is the incorporation of grain yield into a desirable genotype (Munir *et al.,* 2007a).

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Drought is a serious predicament to wheat, barley and other small-grained cereals, however, future progress in improving drought resistance may be helped by focusing on specific traits which could help improve either crop water use, water-use efficiency or harvest index. Rapid early leaf area development not only improves subsequent crop growth rates but also increases competition with weeds for water and nutrients (Quarrie *et al.,* 1999). The rate of leaf area development is closely associated with embryo size therefore, selection for large embryo size could improve early growth rates. Root morphology and leaf water relations are important morpho-physiological traits used for screening crop plants under drought stressed conditions (Amjad *et al*., 2009). Selection for low delta varieties has also resulted in increased yield under drought conditions. Other constitutive and induced traits, such as phenology, leaf xeromorphy, excised-leaf water loss, rooting behavior, leaf senescence and stored assimilates are also considered in relation for improving yields in small-grain crops (Quarrie *et al.,* 1999). Incorporating specific drought resistance traits in breeding programmes will facilitate more rapid improvement in the drought resistance in wheat and other small-grained cereals (Steve *et al.,* 1999).

Heritability of a quantitative trait such as grain yield directly determines the efficiency of selection for such trait. Traits with high heritability are easier to be improved than those with lower heritability (Saba *et al.,* 2001). Most cultivars in self-pollinated crops such as in wheat are pure lines produced by selection methods following hybridization. Thus, selection is mainly based on the presence of additive genetic variance (Saba *et al.,* 2001). Heritability of traits is largely affected by the environment where plants are grown. Heritability estimates for physiological traits are expected to be higher under stressed conditions may be due to the expression of stressed responsive genes which might be few in numbers with major effect. Schonfeld *et al.* (1988) reported 5.1 and 64.4% heritability estimates for relative water content under well-watered and drought conditions in wheat, respectively. High heritability might be due to simple inheritance of the traits suggesting that fewer major genes are involved in controlling such characters. Consistency in the estimates of heritability across the traits might be due to similar gene action (Malik and Wright, 1995).

In general, it is believed that if a character is governed by non-additive gene action that may give higher heritability but low genetic advance, whereas if the character is governed by additive gene action, both heritability and genetic advance would be high. High genetic advance are based on narrow sense heritability which uses additive portion from the total genotypic variance (Khan *et al*., 2008). Thus, narrow sense heritability is more useful for measuring the effectiveness of selection and the extent to which a character is transmitted from parents to their offsprings (Songsri *et al.,* 2008). Manal (2009) reported that high heritability was accompanied by high genetic advance for spike length and 1000 grain weight in wheat, whereas low heritability with low genetic advance was reported for plant height and number of grains spike^{-1}, yet the heritability was found generally lower under drought stressed conditions (Ahmed *et al*., 2007).

Correlation studies are also useful to understand drought tolerance as physiological and yield traits with high heritability could be used as indirect selection criteria to improve grain yields in water-stressed environments. Gupta *et al.* (2001) observed positive correlations of leaf water potential, plant height, leaf area, tillers, and shoot dry weight with grain yield at both boot and anthesis stages, while negative correlations among the leaf diffusive and leaf canopy temperature and also with grain yield. Present studies were therefore, aimed to determine heritability estimates and correlations between various morpho-physiological traits in bread wheat genotypes under drought conditions.

MATERIALS AND METHODS

Six wheat varieties viz. TD-1, Kiran-95, Sarsabz, Moomal, SKD-1 and TJ-83 possess diverse origin and characters were crossed in 6 x 6 half diallel mating fashion during 2009, thus 15 F_1 hybrids were developed. F_1 hybrids alongwith their respective parents were grown in randomized complete block design with factorial arrangement using two irrigation levels and four replications at Latif Farm, Sindh Agriculture University, Tandojam during 2010. Two irrigation regimes were: non-stressed (control) and water stressed imposed at anthesis. The data were analyzed to determine the significance between treatments and F_1 hybrids according to method suggested by Gomez and Gomez (1984), whereas, broad sense heritability on mean basis was determined from variance components as under:

$$H^2 = \frac{\sigma^2 G}{\sigma^2 p + \sigma^2 e/r}$$

The narrow sense heritability was calculated as the ratio of additive variance over the phenotypic variance with the following formula:

$$h^2 = \frac{\sigma^2 A}{\sigma^2 P} \times 100$$

The correlation between yield and physiological traits were determined according to method of Raghavrao (1983) for the traits; plant height (cm), number of grains spike^{-1}, grain yield plant^{-1} (g) seed index (1000-grains in g), grain yield kg ha^{-1}, harvest index (%), relative water content (%), stomatal conductance (mmol m^{-2} s^{-1}), leaf area (cm^2), spike fertility (%), root length (cm) and root biomass (g).

RESULTS AND DISCUSSION

Analysis of variance for morpho-physiological parameters

Mean squares indicated that the irrigation treatments caused significant impact on plant height, grains spike^{-1}, grain yield plant^{-1}, seed index, grain yield kg ha^{-1}, harvest index, relative water content in leaf, stomatal conductance, leaf area, spike fertility, root length, and root biomass (Table-1). Genotypes also differed significantly in their performance for all the yield and physiological traits. The significant interaction between treatments x varieties for most of the traits, implied that genotypes performed differently under irrigation regimes. These interactions could usefully be used in the sense that those genotypes can be picked-up which perform well in drought stressed conditions.

Mean performance of parents and F_1 hybrids for yield and morpho-physiological traits

The mean performance of parents and their F_1 hybrids for yield traits are presented in Tables 2 & 3. On an average, among the parents, 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 yet, the varieties TD-1, Sarsabz, Moomal and SKD-1 generally performed well by giving minimum reductions in stress conditions for above traits. In plant breeding, it is commonly assumed that when good performing parents are crossed with each other, they are expected to produce better hybrids but this assumption did not always hold true (Baloch and Bhutto, 2003). Generally, among the fifteen F_1 hybrids developed from 6 x 6 half diallel crosses, three hybrids viz. TD-1 x TJ-83, Kiran x Sarsabz and Kiran x Moomal recorded minimum declines in most of yield traits due to water stress conditions. For physiological parameters, on an average over the parents hybrids, the reductions were noted as 62.59% in stomatal conductance and 32.11% in leaf area, while parents TD-1, Sarsabz and SKD-1 maintained their higher relative water content and greater leaf area and also gave less stomatal conductance (Table 3). Regarding the performance of F_1 hybrids, in stress conditions, the hybrids TD-1 x T.J-83, Kiran x Sarsabz and Sarsabz x Moomal recorded maximum RWC (47.00%), more leaf area (24.00cm^2) and minimum stomatal conductance (137.00 mmol m^{-2} s^{-1}). Parent TD-1 also recorded maximum spike fertility (47.50%) followed by SKD-1 of 46.50% (Table-4). Generally, the parents TD-1, SKD-1 and Sarsabz were observed as highly drought tolerant and gave increase in root length (8.95, 9.13 and 8.78cm) and root biomass (9.45, 7.09 and 6.65g) (Table-4), respectively. Whereas, greater spike fertility (89.00%), longer roots (9.50cm) and more root biomass (10.13g) were recoded in hybrid TD-1 x TJ-83.

Table 1. Mean squares for various morpho- physiological traits of parents and F_1 hybrids of wheat grown under water stressed conditions.

Yield traits	Mean squares				
	Replication D.F. =3	Treatment (T) D.F. =1	Genotypes (G) D.F. =20	T x G D.F. =20	Error D.F. = 123
Plant height	25.18	2975.29**	402.66**	20.17**	0.27

Grains spike^{-1}	33.69	13285.92**	152.30**	14.89**	0.43
Grain yield plant^{-1}	135.43	2065.01**	91.27**	23.53**	18.85
Seed index	33.49	3649.33**	64.15**	6.85**	0.40
Grain yield kg ha^{-1}	6261	36309062**	402918**	66056**	6651
Harvest index	0.65	1697.35**	19.20**	2.68*	1.04
Physiological traits					
Relative water content	8.89	82903.71**	76.20**	26.91**	0.36
Stomatal conductance	1.83	3.80*	6.20**	1.87$^{n.s}$	3.24
Leaf area	43.11	628.72**	31.39**	11.93**	0.44
Spike fertility	14.76	3828.59**	21.78**	11.12*	0.36
Root length	16.10	45.05**	14.67**	2.15*	0.44
Root biomass	0.19	27.91**	13.75**	0.82*	0.039

**, * = Significant at 1(P< 0.01) and 5 %(P< 0.05) probability levels, respectively.
n.s = non-significant.

Heritability estimates (broad sense and narrow sense) for morpho-physiological traits

The heritability estimates in broad sense (h^2 b.s) and narrow sense (h^2 n.s) for morphological and physiological traits in non-stressed and in stressed environments are given in Table-5. The yield traits recorded higher heritability estimates in broad sense for plant height (h^2= 99.9%), grains spike^{-1} (h^2= 99.4%), grain yield plant^{-1} (h^2= 98.7%), seed index (h^2 =99.1%), grain yield kg ha^{-1} (h^2=55.8%), and harvest index (h^2= 95.0%) in non-stressed conditions. Whereas, these estimates in water stressed conditions were; h^2= 99.8, 99.5, 98.8, 98.7, 99.9, and 94.3 for plant height, grains spike^{-1}, grain yield plant^{-1}, seed index, grain yield kg ha^{-1}, and harvest index respectively (Table-5). The narrow sense heritability estimates (h^2= n.s) in non-stressed and in water stressed respectively were; 90.4 and 85.4% for plant height; 37.7 and 60.1% for grains spike^{-1}; 46.3 and 66.1% for grain yield plant^{-1}; 60.7 and 68.1% for seed index; 49.7 and 69.1% for grain yield kg ha^{-1}; and 67.4 and 69.7% for harvest index.

Table 2. Mean performance for yield traits of parents and F_1 hybrids of wheat grown under non-stressed and water stressed conditions.

Parents/ F_1 hybrids	Plant height (cm)		Grains spike^{-1}		Grain yield plant^{-1} (g)		Seed index(g)	
	Non-stress	Stressed	Non stress	Stressed	Non stress	Stressed	Non stress	Stressed
TD-1	57.75	55.75	66.75	50.50	26.25	23.50	48.00	39.50
Kiran	80.75	70.50	66.00	45.50	25.50	16.50	47.00	34.50
Sarsabz	85.00	74.00	61.75	50.75	23.00	20.50	43.00	38.00
Moomal	75.00	63.00	60.00	40.75	24.00	15.75	44.75	32.00
SKD-1	61.75	60.75	67.50	48.50	23.50	20.75	42.00	36.50
T.J-83	71.50	66.75	61.00	43.50	24.50	16.50	44.00	33.50
F_1 hybrids								
TD-1 x Kiran	74.75	67.75	67.00	50.50	26.00	20.00	47.50	39.00
TD-1 x Sarsabz	80.75	70.75	66.00	49.50	26.00	20.50	47.50	38.00
TD-1 x Moomal	76.75	70.75	59.500	40.00	20.75	12.75	40.75	30.75
TD-1 x SKD-1	64.00	56.00	67.50	51.00	25.75	20.50	47.50	38.50
TD-1 x T.J-83	62.00	57.00	75.00	58.50	30.25	24.50	50.75	41.00
Kiran x Sarsabz	86.00	78.50	71.00	56.00	28.75	23.50	49.25	40.50
Kiran x Moomal	70.75	60.75	67.00	48.50	25.50	19.50	46.50	37.00
Kiran x SKD-1	71.00	60.00	67.50	50.50	27.00	20.50	47.50	36.50
Kiran x	78.00	67.00	66.00	47.75	26.00	19.50	46.50	36.50

T.J-83								
Sarsabz x Moomal	82.00	74.00	70.00	56.00	28.25	22.00	48.00	39.50
Sarsabz x SKD-1	80.75	69.75	66.75	47.00	26.00	19.50	46.50	37.00
Sarsabz x T.J-83	84.00	72.00	66.50	49.50	27.00	20.50	47.25	37.00
Moomal x SKD-1	78.00	66.75	67.75	47.50	24.50	16.75	44.75	37.50
Moomal x T.J-83	75.00	67.00	64.50	40.75	20.75	14.00	41.50	31.75
SKD-1 x T.J-83	70.75	60.75	60.50	39.50	19.00	13.50	40.50	30.75
Mean	74.58	66.17	65.98	48.19	25.15	19.10	45.76	36.44
R.D.%	-10.70		-26.96		-24.06		-20.37	
LSD 5% (T)	0.16		0.20		1.33		0.19	
LSD 5% (G)	0.52		0.66		4.30		0.63	
LSD 5% (T x G)	0.73		0.93		6.08		0.89	

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

Table 3. Mean performance for yield and physiological traits of parents and F_1 hybrids of wheat grown under non-stressed and water stressed conditions.

Parents/ F_1 hybrids	Grain yield (kg ha^{-1})		Harvest index (%)		Relative water content (%)		Stomatal conductance (mmol m^{-2} s^{-1})	
	Non-stress	Stressed	Non stress	Stressed	Non stress	Stressed	Non stress	Stressed
TD-1	4563.00	3675.75	54.26	46.75	89.25	44.75	473.25	139.00
Kiran	4401.00	3230.75	50.01	45.85	87.75	38.00	448.5	142.75
Sarsabz	4265.75	3510.00	50.00	43.50	88.25	44.75	419.25	158.50
Moomal	4300.00	3149.50	49.75	41.75	87.25	37.75	400.75	159.75
SKD-1	4280.00	3550.00	50.75	44.57	88.50	41.75	414.50	140.25
T.J-83	4270.00	3010.00	50.00	41.75	84.50	38.50	433.50	158.75
F_1 hybrids								
TD-1 x Kiran	4570.50	3571.50	50.76	46.16	90.50	44.00	466.75	169.50
TD-1 x Sarsabz	4572.75	3481.50	49.96	43.82	89.80	44.50	471.50	180.25
TD-1 x Moomal	4000.75	3003.25	49.99	43.84	88.50	43.00	460.00	220.25
TD-1 x SKD-1	4501.00	3571.50	49.41	44.75	88.90	45.00	473.00	169.00
TD-1 x T.J-83	4750.75	3789.00	52.05	49.95	92.20	47.00	476.25	128.50
Kiran x Sarsabz	4600.75	3701.75	50.55	46.00	88.50	45.80	474.00	136.25
Kiran x Moomal	4514.75	3545.75	49.02	44.25	88.20	43.00	430.00	200.00
Kiran x SKD-1	4573.25	3601.75	50.00	45.10	88.74	44.00	445.00	166.00
Kiran x T.J-83	4494.25	3570.75	48.98	43.85	88.00	43.00	450.00	188.25
Sarsabz x Moomal	4590.75	3701.75	50.59	45.45	87.88	44.75	471.50	137.00
Sarsabz x SKD-1	4398.75	3470.75	49.03	43.44	88.41	42.50	465.00	168.50
Sarsabz x T.J-83	4535.25	3580.75	49.75	43.79	88.00	44.00	470.50	178.75
Moomal x SKD-1	4041.00	3471.50	44.49	42.75	88.54	43.00	465.00	186.50
Moomal x T.J-83	4006.25	3050.00	50.00	42.75	86.00	40.00	435.00	210.00
SKD-1 x	4021.25	3050.00	50.17	43.91	87.00	40.00	453.75	214.75

T.J-83								
Mean	4392.90	3442.26	49.98	44.48	88.32	42.81	452.24	169.17
R.D.%	-21.64		-11.00		-51.53		-62.59	
LSD 5% (T)	24.91		0.31		0.19		0.76	
LSD 5% (G)	80.72		1.01		0.60		2.47	
LSD 5% (T x G)	114.15		1.43		0.85		3.49	

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

Table 4. Mean performance for physiological traits of parents and F_1 hybrids of wheat grown under non-stressed and water stressed conditions.

Parents/F_1 hybrids	Leaf area (cm^2)		Spike fertility (%)		Root length (cm)		Root biomass (g)	
	Non-stress	Stressed	Non stress	Stressed	Non stress	Stressed	Non stress	Stressed
TD-1	30.25	24.25	87.25	47.50	7.45	8.95	7.13	9.45
Kiran	31.00	16.25	86.75	39.50	6.83	7.00	5.56	5.98
Sarsabz	28.25	22.25	83.25	46.50	6.00	8.78	4.98	6.65
Moomal	30.50	20.25	83.50	39.75	5.95	6.23	4.88	5.25
SKD-1	29.50	23.25	84.00	46.50	7.01	9.13	5.58	7.09
T.J-83	26.25	18.25	83.00	39.50	6.95	7.85	5.73	5.25
F_1 hybrids								
TD-1 x Kiran	31.00	21.00	87.50	44.80	7.75	8.45	7.15	7.65
TD-1 x Sarsabz	29.50	20.50	86.75	47.80	7.83	8.25	7.20	7.75
TD-1 x Moomal	30.00	20.25	87.90	45.50	5.45	6.98	6.15	7.83
TD-1 x SKD-1	29.00	19.25	87.80	47.80	7.65	7.75	7.16	7.73
TD-1 x T.J-83	32.50	24.00	89.00	48.00	9.50	11.58	10.13	11.53
Kiran x Sarsabz	31.00	23.50	88.00	47.00	7.68	8.75	7.26	7.73
Kiran x Moomal	29.00	17.75	87.00	41.00	7.55	7.65	7.14	7.93
Kiran x SKD-1	28.00	18.75	86.90	44.00	7.53	7.75	7.15	7.63
Kiran x T.J-83	30.00	18.00	86.00	40.25	7.43	7.83	7.10	7.95
Sarsabz xMoomal	31.00	23.25	87.25	46.00	7.75	8.68	9.21	10.15
Sarsabz x SKD-1	26.50	17.75	85.00	47.00	7.75	7.93	7.14	7.43
Sarsabz x T.J-83	29.50	19.75	84.00	44.00	7.43	7.95	8.10	8.35
Moomal x SKD-1	29.00	18.75	85.00	45.00	7.33	7.85	7.10	7.18
Moomal x T.J-83	32.00	17.75	86.00	39.50	6.33	6.98	6.18	6.70
SKD-1 x T.J-83	30.75	19.25	85.50	41.00	5.45	7.60	6.09	6.70
Mean	29.74	20.19	86.06	44.19	7.17	8.09	6.86	7.61
R.D.%	-32.11		-48.65		+12.83		+10.92	
LSD 5%(T)	0.18		0.36		0.04		0.06	
LSD %(G)	0.60		1.17		0.12		0.20	
LSD 5% (T x G)	0.84		1.65		0.18		0.28	

R.D. % = Relative decrease (-) or increase (-) in percentage due to water stress

The broad sense heritability estimates (h^2 b.s.) for physiological traits such as relative water content was h^2= 94.5% in non-stressed and h^2 = 97.55% in stressed; stomatal conductance h^2 = 99.6% in non-stressed and h^2 = 99.3% in stress; leaf area h^2 = 97.3% in non-stressed and h^2 = 97.94% in stressed; spike fertility h^2 = 98.38% in non-stressed and h^2 = 98.96% in stress; root length h^2 = 99.59% in non-stressed and h^2 = 99.64% in stress; root biomass h^2 =99.65% in non-stressed and h^2 = 99.42% in stressed conditions (Table-5). The narrow sense heritability estimates (h^2 n.s.) in non-stressed and in water stressed, respectively for relative water content in leaf were 75.3 and 73.4%; stomatal conductance 63.2 and 38.8%; leaf area 47.6 and 65.9%; spike fertility 56.5 and 73.9%; root length 14.3 and 62.6 and root biomass 28.4 and 51.9%, respectively (Table-5).

Phenotypic correlations

The combined correlation coefficients (r) worked-out for parents and their F_1 hybrids are presented in Table 3 for yield and physiological traits under both non-stressed and in water stressed conditions. The results of plant height showed both positive and negative but non-significant correlations with relative water content in leaf, stomatal conductance, leaf area, spike fertility, root length and root biomass in non-stressed and in water stressed conditions (Table-3). The grains spike^{-1} recorded highly significant associations with stomatal conductance (r = 0.56), spike fertility (0.57), root length (0.85) and root biomass 0.75), respectively in non-stressed (Table-3) while in stressed environment, grains spike^{-1} showed significantly positive associations with relative water content (r = 0.80), leaf area (r = 0.59), spike fertility (r = 0.79), root length (r = 0.74) and root biomass (r = 0.68) yet grains spike^{-1} expressed significantly negative correlations with stomatal conductance (r = -0.68**) (Table-6). Seed index expressed significant relationship with stomatal conductance (r = 0.59), spike fertility (r = 0.57), root length (r = 0.79) and root biomass (r = 0.63) in non-stressed (Table-6) in stressed conditions, these correlations were; r = 0.80, 0.59, 0.79, 0.74 and 0.68 for relative water content, leaf area, spike fertility, root length and root biomass, respectively (Table-6), however seed index showed significantly negative correlations (r = -0.63) with stomatal conductance. Grain yield plant^{-1} exhibited non-significant correlations with other traits in non-stressed conditions (Table-6) whereas in stressed conditions, grain yield plant^{-1} showed significant associations by r = 0.78, 0.62, 0.83, 0.70 and 0.61 for relative water content, leaf area, spike fertility, root length and root biomass respectively but significantly negative correlation (r = -0.71) with stomatal conductance (Table-6). Harvest index demonstrated significant correlations with relative water content (r = 0.51), stomatal conductance (0.42), leaf area (0.41), spike fertility (0.47), root length (0.47) and root biomass (0.43) in non-stressed conditions (Table-6) and in stressed environment, nevertheless harvest index was significantly but negatively associated with stomatal conductance (r = - 0.41) and non-significantly positive with leaf area (r = 0.28) and spike fertility (r =0.35) (Table-6).

Table 5. Heritability estimates for morpho-physiological parameters of wheat varieties grown under non-stressed and water stressed conditions.

Yield traits	Heritability % (h^2 b.s)		Heritability % (h^2 n.s)	
	Non-stress	Stressed at anthesis	Non-stress	Stressed at anthesis
Plant height	99.9	99.8	90.4	85.4
Grains spike^{-1}	99.4	99.5	37.7	60.1
Grain yield plant^{-1}	98.7	98.8	46.3	66.1
Seed index	99.1	98.7	60.7	68.1
Grain yield kg ha^{-1}	55.8	99.9	49.7	69.1
Harvest index	95.0	94.3	67.4	69.7
Physiological traits				
Relative water content	94.5	97.5	75.3	73.4
Stomatal conductance	99.6	99.3	63.2	38.8
Leaf area	97.3	97.9	47.6	65.9
Spike fertility	98.3	98.9	56.5	73.9
Root length	99.5	99.6	14.3	62.6
Root biomass	99.6	99.4	28.4	51.9

Table 6. Correlations coefficient (r) among morpho-physiological traits of wheat genotypes in non-stressed and water stressed condition.

Characters	Relative water content in leaf		Stomatal conductance		Leaf area	
	Non-stress	Water stress	Non-stress	Water stress	Non-stress	Water stress
Plant height	-0.11	0.16	0.007	-0.003	-0.05	0.001
Grains spike^{-1}	0.21	0.80**	0.56**	-0.68**	0.33	0.59* *

Seed index	0.28	0.80**	0.59**	-0.63**	0.21	0.55**
Grain yield plant^{-1}	0.30	0.78**	0.25	-0.71**	0.19	0.62**
Grain yield kg ha^{-1}	0.36	0.78**	0.43*	-0.61**	0.11	0.53**
Harvest index	0.51**	0.40*	0.42*	-0.41*	0.41*	0.28
Character	Spike fertility		Root length		Root biomass	
	Non-stress	Water stress	Non-stress	Water stress	Non-stress	Water stress
Plant height	-0.18	-0.02	-0.20	-0.17	-0.09	-0.18
Grains spike^{-1}	0.57**	0.79**	0.85**	0.74**	0.75**	0.68**
Seed index	0.57**	0.78**	0.79**	0.68**	0.63**	0.61**
Grain yield plant^{-1}	0.29	0.83**	0.30	0.70**	0.20	0.61**
Grain yield kg ha^{-1}	0.60**	0.75**	0.70**	0.71**	0.55**	0.63**
Harvest index	0.47**	0.35	0.47**	0.59**	0.43*	0.61**

**, * = Significant at 1(P< 0.01) and 5 %(P< 0.05) probability levels, respectively.

Mean performance of parents and F_1 hybrids for yield and morpho-physiological traits

The mean performance of parents and their F_1 hybrids for yield traits revealed that, on an average, declines of 24.06% in grain yield plant^{-1}, 26.96% in grains spike^{-1}, 20.37% in seed index and 11.00% in harvest index occurred yet, parents TD-1, Sarsabz, Moomal and SKD-1 gave relatively minimum reductions in stress conditions for above traits. Generally, hybrids such as TD-1 x TJ-83, Kiran x Sarsabz and Kiran x Moomal recorded minimum declines in most of yield traits due to water stress conditions, hence were considered as drought tolerant. It may be inferred from the results that if hybrid crop is feasible in wheat, then above hybrids may be grown in water shortage conditions.

For physiological parameters, on an average, the reductions of 62.59% in stomatal conductance and 32.11% in leaf area occurred due to stress, while parents TD-1, Sarsabz and SKD-1 maintained their higher relative water content and greater leaf area with less stomatal conductance. Rucker *et al*. (1995) found that reduction in leaf area (LA) by water stress reduced crop yield through reduction in photosynthesis, while Adjei and Kirkham (1980) observed that drought resistant cultivars possess higher stomatal resistance than drought sensitive cultivars. In stress condition, hybrids TD-1 x T.J-83, Kiran x Sarsabz and Sarsabz x Moomal expressed maximum RWC%, more leaf area and minimum stomatal conductance. Parent TD-1 recorded maximum spike fertility followed by SKD-1. By and large, the parents TD-1, SKD-1 and Sarsabz were observed as highly drought tolerant and gave increase in root length and root biomass. Whereas hybrid TD-1 x TJ-83 gave greater spike fertility, longer roots and more root biomass.

Heritability estimates of yield and physiological traits

Heritability determines the extent of transmissibility of traits from parents to the offspring, thus traits with high heritability estimates are easier to manipulate (Saba *et al.,* 2001). For general yield traits, heritability estimates ranged from 55.8 to 99.7% in non-stressed and 86.7 to 99.9% in water stressed conditions for plant height, grains spike^{-1}, grain yield plant^{-1}, seed index, grain yield kg ha^{-1} and harvest index. These results indicated that the above yield traits are primarily under the control of additive genes. Ayoub and Chowdhry (2000); Yadav *et al.* (2003); Farshadfar *et al.* (2000) also obtained high estimates of narrow sense heritability for days to heading, plant height, spike length and 1000-grain weight, harvest index and grain yield under both irrigated and rainfed conditions. The heritability estimates in narrow sense (h^2 = n.s) for yield traits were generally higher in stressed as compared to non-stressed conditions, however heritability estimates in non-stressed were moderate for grain yield plant^{-1}, seed index and grain yield kg ha^{-1}, yet high for plant height and harvest index. In stressed conditions, yield traits gave moderate to high heritability estimates (Table-5).

Moderate to high heritability estimates for yield traits in present studies indicated that the ratio of additive variance/genes were greater than non-additive genes in stressed conditions and were less affected by the environmental factors. Present results are in accordance with those of Razia and Aslam (2003) and Munir *et al.* (2007b) reported high narrow sense heritability estimates for grains spike^{-1}, seed index and grain yield plant^{-1} under drought conditions. The broad sense heritability estimates for physiological traits like relative water content, stomatal conductance, leaf area, spike fertility, root length and root biomass were high in non-stressed (94.5 to 99.6%) and in stressed conditions also (94.2 to 99.7%). Heritability estimates were moderate to low for relative water content, stomatal conductance, leaf area, spike fertility, root length and root biomass in both non-stressed and in stressed conditions (Table-5). These results suggested that physiological traits can be used as selection criteria to improve drought tolerance in wheat. Efisue *et al.* (2009) determined heritability estimates based on variance ratios that ranged from 47% for leaf area.

Phenotypic correlation among morpho-physiological traits

Plant height showed no correlations with any of the physiological traits in both non-stressed and in stressed conditions. We expected such type of results because water stress was imposed after anthesis, where plant height attained almost its maximum height. The grains spike^{-1} was significantly correlated with stomatal conductance, spike fertility (SF), root length (RL) and root biomass (RB) in non-stressed while grains spike^{-1} showed significant association with RWC, LA, SF, RL and RB in stressed conditions. The increase in grains spike^{-1} in stressed may be due to increased RWC, LA, RL and RB. Seed index exhibited significant relationship with stomatal conductance, SF, RL and RB in non-stressed and in stress, yet it was negatively correlated with stomatal conductance. The negative correlations between stomatal conductance and seed index indicated that in stress, the genotypes with less stomatal conductance being stress tolerant gave increased seed index. However, grain yield plant^{-1} demonstrated significantly positive association with RWC, LA, SF, RL and RB in stressed conditions, while grain yield plant^{-1} showed negative correlation with stomatal conductance. Gupta *et al.* (2001) observed significant correlations of leaf area with grain yield and biological yield, whereas Munir *et al.* (2006) found that stomatal frequency, stomatal size, days to maturity, grain spike^{-1} and 1000-grain weight were positively correlated with grain yield.

CONCLUSION

On an average, parents TD-1, Sarsabz, Moomal and SKD-1 and hybrids TD-1 x TJ-83, Kiran x Sarsabz and Kiran x Moomal gave relatively minimum reductions in yield traits in stressed conditions, hence showing their feasibility in water shortage conditions. For physiological parameters, parents TD-1, Sarsabz and SKD-1 and hybrids TD-1 x T.J-83, Kiran x Sarsabz and Sarsabz x Moomal maintained their higher relative water content and greater leaf area with less stomatal under drought conditions. The heritability estimates in broad and narrow sense for yield and physiological traits were moderate to high, yet these were greater in stressed than in non-stressed conditions which indicated that the characters studied were predominantly controlled by additive type of gene action, thus selection for such traits would be effective in segregating populations. Generally, the correlation of yield and physiological traits were positive and greater in stressed than in non-stressed environments, nevertheless, all the yield traits were negatively correlated with only stomatal conductance.

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