Current Research Journal of Biological Sciences 3(5): 487-498, 2011
ISSN: 2041-0778

Submitted: June 20, 2011 Accepted: August 08, 2011 Published: September 10, 2011

Effect of Water Stress in Bread Wheat Hexaploids

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Abstract: The current objective was to identify tolerant and susceptible genotypes of wheat under different irrigation levels and also to find out the most crucial stage of plant with respect to yield traits. The experimental material consisted of eight bread wheat hexaploids namely Kohistan-97, Rawal-87, Chakwal-86, Inqilab-91, Watan, Uqaab-2000 and Sarsabz. Stress was imposed by withholding irrigation at three different growth stages of plant i.e., vegetative, anthesis and vegetative+anthesis. Agronomic data were recorded for each wheat genotype at different growth stages that included days to flowering, number of tillers, plant height, number of spikes, number of spikelets per spike, number of grains, grain yield and 1000-grain weight. Four drought resistance indices include Stress Susceptibility Index (SSI), Yield Stability Index (YSI), Mean Productivity (MP) and Tolerance Index (TOL) was applied on the basis of grain yield in non-irrigated conditions. Among eight hexaploid wheat genotypes Rawal-87, Chakwal-86 and Pak-81 showed less affect on all traits under different water stress conditions so can be considered as tolerant genotypes. On the other hand Kohistan-97, Inqilab-91, Watan and Uqaab-2000 were greatly affected for yield and yield components under different irrigation levels. It may be concluded these genotypes were susceptible to water stress conditions. Tolerant wheat genotypes can be considered promising with respect to yield and yield contributing traits. Based on different stress indices, genotypes Rawal-87, Chakwal-86 and Pak-81 had the best rank under water stress conditions. These traits therefore deserve better attention in future breeding programs for evolving better wheat for stress environments.

Key words: Agronomic traits, hexaploid wheat, resistance indices, tolerant and susceptible genotypes, water stress

INTRODUCTION

Water stress is the most significant environmental stress in agriculture worldwide and improving yield under drought is a major goal of plant breeding (Cattivelli *et al*., 2008). Rainfed areas play an important role in crop production in Pakistan. Nearly one-fifth of the total wheat acreage in Pakistan is under rainfed and this contributes about 10-12% of the total wheat production in the country (Ahmad *et al*., 1996). Among different factors, drought emerges a serious threat to low productivity for the past few years when no rainfall occurs in most part of the year especially during winter (Kazmi *et al*., 2003). All phases of plant growth are not equally vulnerable to water shortage. Whereas some phases can cope-up with water shortage very well, others are more vulnerable to water shortages that may result in serious yield losses. Moisture stress is known to reduce biomass, tillering ability, grains per spike and grain size at any stage when it occurs. So, the over all effect of the moisture stress depends on its intensity and length of stress (Bukhat, 2005). Substantial losses in wheat grain yield have been reported due to water deficiency depending on the developmental stages at which crop plant experiences stress. Water stress at various stages specially before anthesis can reduce number of heads and numbers of kernels per ear (Dencic *et al*., 2000; Guttieri *et al*., 2001). While water stress imposed during later stages might additionally cause a reduction in number of kernels per ear and kernel weight (Baque *et al*., 2006; Saeedipour, 2011). Drought tolerance was defined by Hall, (1993) as the relative yield of a genotype compared to other genotypes, subjected to the same drought stress. The ability of wheat cultivars to perform reasonably well in variable rainfall and water stressed environments is an important trait for stability of production under drought stress conditions (Pirayvatlov, 2001). A basic approach is to asses the drought tolerance indices. Thus, drought indices which provide a measure of drought based on yield under loss under drought conditions in comparison to normal conditions have been used for screening drought tolerant genotypes (Mitra, 2001). Several indices have been utilized to evaluate genotypes for drought tolerance based on grain yield in different environments. Rosielle and Hamblin, (1981) defined stress tolerance (TOL) as the differences in yield between the stress (Ys) and non-stress (Yp) environments and Mean Productivity (MP) as the average yield of Ys and Yp. Fischer and Maurer, (1978) proposed a Stress Susceptibility Index (SSI) for cultivars . Yield Stability

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Index (YSI) (Bouslama and Schapaugh, 1984) have been employed under various conditions. The cultivars with YSI are expected to have high yield under both stress and non-stress conditions. Cultivars with the highest YSI exhibited the least yield under non-stress conditions (Sio-Se Mardeh *et al*., 2006). Guttieri *et al*.(2001) suggested that SSI more and less than 1 indicates above and below-average susceptibility to drought stress, respectively. A larger value of TOL and SSI show relatively more susceptibility to stress, thus a smaller values of TOL and SSI are favored. Several authors noticed that selection based on these two indexes favors genotypes with low yield under non-stress conditions (Golabadi *et al*., 2006). The aim of the current research was to identify the tolerant and susceptible genotypes of wheat under water stress conditions.

MATERIALS AND METHODS

Experimental design: The experiment was carried out in earthen/ceramic pots (40 cm × 40 cm) and kept in the screen house of the Genetics department, University of Karachi, Pakistan. Experiment was arranged in split plot design having three replications with water regimes as main plots and varieties as sub-plots. Seeds of eight bread wheat hexaploids namely Kohistan-97, Rawal-87, Chakwal-86, Pak-81, Inqilab-91, Watan, Uqaab-2000 and Sarsabz were used in this research. Different water stress was imposed at different developmental stages. These were as follows: Vegetative Stress was given from 38 to 58 days after sowing; Anthesis Stress was given from 58 to 78 days after sowing; Vegetative + Anthesis Stress was imposed from 38 to 78 days after sowing while control plants were never allowed to dry out during crop maturation. The experiment was conducted in the year of 2003-2004.

Climatic conditions: Weather data were recorded regularly during growing season. Mean temperature ranged from 17.74-31.26ºC, humidity 49.9% during Nov 2003-April 2004. Moveable plastic sheet cover was used for protecting the plants from rain. Climatic data was provided by Pakistan Meteorological department, Karachi, Pakistan.

Agronomic traits: Data was recorded for ten plants/pot of each wheat genotype. The traits were included days to flowering, number of tillers, plant height, number of spikes, spike length, number of spikelets per spike, number of grains, grain yield and 1000-grain weight.

Statistical analysis: Data was subjected to analysis of variance, differences among means determined by Duncan's multiple range test (DMRT) at 5% level using SPSS version 11.0 (SPSS, Inc., Chicago, IL).

Resistance indices: Water stress resistance indices were calculated using the following relationships:

- Stress Susceptibility Index (SSI): [1-(Y_S /Y_P)] / [1-($\overline{Y}_s - \overline{Y}_p$)] (Fischer and Maurer, 1978)

  where;

  Y_S is the yield of cultivar under stress

  Y_P is the yield of cultivar under irrigated conditions

  $\overline{Y}_s$ is the mean yield of all cultivars under stress

  $\overline{Y}_p$ is the mean yield of all cultivars under irrigated conditions

  $1-\left(\overline{Y}_S/\overline{Y}_P\right)$ is the stress intensity

  The relative yield under water stress was calculated as the yield of a specific genotype under stress divided by that of the highest yielding genotype in the population.
- Mean Productivity (MP) = Y_P+Y_S / 2 (Hossain *et al*., 1990)
- Tolerance (TOL) = Y_P-Y_S (Hossain *et al*., 1990)
- Yield Stability Index (YSI) = Y_S/Y_P (Bouslama and Schapaugh, 1984)

RESULTS

Data collected from all eight genotypes at 4 irrigation levels were subjected to statistical test. Analysis of variance was done in split plot design with water regimes as main plot and varieties as sub-plots. The mean squares from the analysis of variance (Table 1) revealed that main effects (genotypes and water stress treatments) and their interactions were significant for spike length, number of spikelets per spike, grain yield and 1000-grain weight. Number of tillers, number of spikes and number of grains showed non-significant differences between varieties and their interactions; however treatments differ significantly. Days to flowering showed non-significant differences between treatments, only. After analysis of variance data was subjected to Duncan's multiple range test to evaluate significance of mean comparison (p<0.05).

Vegetative traits:

Days to flowering: Table 2 demonstrates the mean comparison of days to flowering, number of tillers and plant height. Under normal irrigation the average value of days to flowering was 70.12 and range was 69 to 72 days. Duncan's multiple range tests showed that Chakwal-86 differ significantly from other genotypes. Under vegetative stress, the average days to flowering were 70.20 and it ranged from 69-77 days.More days were required to begin flowering under stress with an increase of 0.11% though this increase was not signifi cant under waterstress. Means for days to flowering at anthesis stress are mentioned in Table 2, the average value was 69.87 days with a range of 63 to 77 days.

Table 1. Mean squares for agronomic traits of bread wheat hexaploids under irrigated and non-irrigated conditions

Sources of Variation	df	days to flowering	no. of tillers	Plant height	no. of spikes	Spike length	no. of spikelets spike^{-1}	no. of grains	grain yield	1000-grain weight
Treatments(T)	3	1.121	28.504*	3074.368**	29.808**	62.407**	152.413**	500074.854***	223.158**	1399.468**
Error (a)	6	5.178	1.223	22.728	1.826	0.688	6.514	9453.145	3.917	31.662
Genotypes(G)	7	44.230**	8.952	307.990**	7.217	6.124**	9.156**	9829.914	13.739*	390.895**
G×T	21	9.485**	9.050	38.350	9.062	2.587**	3.882**	12794.667	9.946*	175.758**
Error (b)	56	3.338	7.130	36.966	7.133	0.656	1.582	8970.106	5.123	35.221

* and **: significant at 5% and 1% level of probability, respectively

Table 2: Mean values for days to flowering, number of tillers and plant height in bread wheat hexaploids under irrigated and non-irrigated conditions

Varieties	Control	Vegetative	Anthesis	V + A
Days to flowering				
Kohistan-97	70.00^{ab} ± 1.00	71.00^{b} ± 1.00	70.00^{b} ± 1.00	72.00^{b} ± 0.00
Rawal-87	69.00^{b} ± 0.00	69.00^{b} ± 0.00	70.00^{b} ± 1.00	71.00^{ab}± 1.00
Chakwal-86	72.00^{a} ± 0.00	76.67^{a} ± 2.33	77.00^{a} ± 2.00	73.33^{a} ± 2.96
Pak-8	171.00^{ab}± 1.00	69.00^{b} ± 0.00	71.00^{b} ± 1.00	69.00^{b} ± 0.00
Inqilab-91	70.00^{ab} ± 1.00	69.00^{b} ± 0.00	63.00^{c} ± 3.00	71.00^{ab}± 1.00
Watan	70.00^{ab} ± 1.00	69.00^{b} ± 0.00	70.00^{b} ± 1.00	69.00^{b} ± 0.00
Uqaab-2000	70.00^{ab} ± 1.00	69.00^{b} ± 0.00	69.00^{b} ± 0.00	69.00^{b} ± 0.00
Sarsabz	69.00^{b} ± 0.00	69.00^{b} ± 0.00	69.00^{b} ± 0.00	69.00^{b} ± 0.00
Average	70.12	70.20	69.87	70.41
% reduction /promotion		0.11	-0.35	0.41
Number of tillers				
Kohistan	18.00^{a}±4.72	9.33^{c} ±0.33	14.00^{a} ±1.52	11.67^{a}±1.15
Rawal-87	10.67^{a}±0.33	10.33^{bc}±0.88	11.00^{abc}±1.00	11.67^{a}±0.57
Chakwal-86	12.67^{a}±1.76	9.00^{c} ±0.57	13.50^{ab} ±0.50	11.00 ±1.00
Pak-8	10.00^{a}±0.57	9.67^{bc} ±0.88	10.33^{bc} ±1.45	12.00^{a}±2.00
Inqilab-91	13.33^{a}±1.66	10.00^{bc}±0.00	10.67^{bc} ±0.33	10.67^{a}±0.57
Watan	15.00^{a}±2.64	13.67^{a} ±1.33	9.00^{c} ±0.57	11.33^{a}±1.52
Uqaab-2000	11.67^{a}±2.33	12.67^{ab}±1.33	10.67^{bc} ±0.33	10.33^{a}±1.52
Sarsabz	13.33^{a}±2.96	10.00^{bc}±1.15	10.67^{bc} ±0.88	10.67^{a}±1.15
Average	13.08	10.58	11.23	11.16
% reduction/promotion		-19.11	-14.14	-14.67
Plant height				
Kohistan	68.10^{cd} ±4.35	51.26^{a}±4.45	56.66^{c}	±3.37 47.36^{bc}±4.19
Rawal-87	62.03^{cd} ±1.93	50.06^{a}±0.23	62.60^{abc}	±3.85 43.40^{c} ±1.13
Chakwal-86	71.73^{bcd} ±3.60	53.06^{a}±8.01	57.45^{bc}	±0.65 46.23^{bc}±5.13
Pak-8	77.33^{abc} ±4.20	56.16^{a}±2.76	66.83^{abc}	±2.79 49.83^{bc}±5.62
Inqilab-91	81.40^{ab} ±0.55	56.50^{a}±2.65	74.10^{a}	±3.74 51.33^{abc}±3.72
Watan	72.70^{bcd} ±3.68	47.96^{a}±3.88	60.63^{abc}	±5.07 52.20^{ab}±2.95
Uqaab-2000	81.33^{ab} ±3.65	56.10^{a}±1.20	71.10^{ab}	±2.95 58.70^{a} ±6.49
Sarsabz	87.50^{a} ±2.75	57.00^{a}±2.19	68.00^{abc}	±5.71 54.36^{ab}±4.92
Average	75.26	53.51	64.67	50.42
% reduction/promotion		-28.89	-14.07	-33.00

Means followed by the same letter within columns are non-significantly different ($p \leq 0.05$) according to DMR test values in last two rows indicate an average and percent reduction/promotion from control

Maximum (77) days were taken by Chakwal-86 whereas Inqilab-91 flowered 63 days after sowing. An average reduction in days to flowering was 0.35%. The average value of days to flowering under vegetative+anthesis stress was 70.41 days and it ranged from 69-73 days. The maximum mean value (73 days) was found in Chakwal-86. Slight promotion (0.41%) was noticed for average days to flowering under water stress.

Number of tillers: Number of tillers in irrigated plants showed non-significant differences between genotypes. Under vegetative stress, DMRT showed significant differences between Chakwal-86 and Watan. An average value of number of tillers in all genotypes was 10.58 and reduction in number of tillers was 19.11% in comparison to irrigated counter part genotypes. Significant differences were found in number of tillers under anthesis stress. The mean value was 11.23 with a reduction of 14.14%. Kohistan-97 produced maximum (14) and Watan produced minimum (9) number of tillers during anthesis stress. At vegetative+anthesis stress, the mean value for number of tillers was 11.23. All genotypes showed non-significant differences.

Plant height: Under normal irrigation all genotypes showed significant differences in plant height with maximum height (87.50 cm) in Sarsabz and least in Rawal-87 (62.03 cm). Non-significant differences were observed for plant height under vegetative stress. An average reduction of 28.89% was recorded. During anthesis stress significant differences were observed between genotypes which were prominent in Kohistan-97

Table 3: Mean values for number of spikes, spike length and number of spikelet spike^{-1} in bread wheat hexaploids under irrigated and non-irrigated conditions

Varieties	Control	Vegetative	Anthesis	V + A
Number of spikes				
Kohistan-97	$18.00^{a}\pm4.72$	$9.33^{bc}\pm0.33$	$12.00^{a}\pm2.08$	$11.00^{a}\pm0.00$
Rawal-87	$10.67^{a}\pm0.33$	$9.67^{bc}\pm0.33$	$11.00^{a}\pm1.00$	$10.33^{a}\pm1.15$
Chakwal-86	$11.33^{a}\pm1.76$	$7.67^{c}\pm1.85$	$12.50^{a}\pm0.50$	$11.00^{a}\pm1.00$
Pak-81	$10.00^{a}\pm0.57$	$9.33^{bc}\pm1.20$	$10.33^{a}\pm1.45$	$12.00^{a}\pm2.00$
Inqilab-91	$13.33^{a}\pm1.66$	$10.00^{abc}\pm0.00$	$10.67^{a}\pm0.33$	$10.67^{a}\pm0.57$
Watan	$14.67^{a}\pm2.40$	$13.33^{a}\pm1.20$	$8.67^{a}\pm0.88$	$11.33^{a}\pm1.52$
Uqaab-2000	$11.67^{a}\pm2.33$	$12.67^{ab}\pm1.33$	$10.33^{a}\pm0.66$	$10.33^{a}\pm1.52$
Sarsabz	$12.67^{a}\pm2.33$	$10.00^{abc}\pm1.15$	$10.67^{a}\pm0.88$	$10.67^{a}\pm1.15$
Average	12.79	10.25	10.77	10.91
% reduction/promotion		-19.85	-15.79	-14.69
Spike length				
Kohistan-97	$15.13^{abc}\pm0.38$	$11.83^{b}\pm0.26$	$16.00^{ab}\pm0.25$	$13.10^{b}\pm0.32$
Rawal-87	$13.93^{c}\pm0.17$	$12.06^{b}\pm0.12$	$14.86^{bc}\pm0.67$	$12.70^{b}\pm0.46$
Chakwal-86	$15.30^{abc}\pm0.45$	$15.66^{a}\pm0.49$	$15.30^{abc}\pm0.30$	$12.33^{b}\pm0.86$
Pak-81	$14.70^{bc}\pm0.46$	$11.63^{b}\pm0.32$	$14.26^{c}\pm0.08$	$11.80^{b}\pm0.32$
Inqilab-91	$16.30^{a}\pm0.40$	$12.83^{b}\pm0.29$	$15.20^{abc}\pm0.55$	$14.80^{a}\pm0.95$
Watan	$9.93^{c}\pm1.03$	$14.53^{bc}\pm0.66$	$11.33^{b}\pm0.14$	$16.67^{ab}\pm0.33$
Uqaab-2000	$15.36^{abc}\pm0.77$	$12.00^{b}\pm0.30$	$16.53^{a}\pm0.14$	$12.70^{b}\pm0.17$
Sarsabz	$15.66^{ab}\pm0.27$	$12.10^{b}\pm0.52$	$15.50^{abc}\pm0.32$	$12.30^{b}\pm0.41$
Average	15.20	12.25	15.27	12.63
% reduction/promotion		-19.40	0.46	-16.90
Number of spikelet spike				
Kohistan-97	$16.33^{ab}\pm0.88$	$11.33^{ab}\pm1.33$	$15.67^{bc}\pm0.33$	$12.00^{a}\pm0.57$
Rawal-87	$16.33^{ab}\pm0.33$	$13.33^{a}\pm0.33$	$17.33^{ab}\pm0.33$	$13.67^{a}\pm0.66$
Chakwal-86	$15.67^{bc}\pm0.33$	$14.00^{a}\pm2.08$	$14.50^{c}\pm0.50$	$12.00^{a}\pm0.57$
Pak-81	$18.00^{a}\pm0.57$	$14.00^{a}\pm0.57$	$18.00^{a}\pm0.57$	$11.67^{a}\pm0.66$
Inqilab-91	$16.67^{ab}\pm0.33$	$12.00^{a}\pm0.00$	$16.00^{bc}\pm0.00$	$13.00^{a}\pm1.00$
Watan	$16.67^{ab}\pm0.33$	$8.00^{bc}\pm1.52$	$15.33^{c}\pm0.88$	$11.33^{a}\pm0.88$
Uqaab-2000	$17.33^{ab}\pm0.66$	$12.00^{a}\pm0.57$	$18.00^{a}\pm0.57$	$14.00^{a}\pm0.57$
Sarsabz	$18.00^{a}\pm0.57$	$11.67^{ab}\pm1.33$	$15.67^{bc}\pm0.82$	$12.00^{a}\pm1.52$
Average	16.87	12.04	16.31	12.45
% reduction/promotion		-28.63	-3.31	-26.20

(56.66 cm) and Inqilab-91 (74.10 cm). The mean value for plant height was 64.67 cm. All genotypes showed reduction in plant height with an average reduction of 14.07%.The mean value for plant height was 50.42 cm and it ranged from 43.40 to 58.70 cm under vegetative + anthesis stress. All genotypes showed reduction for plant height with an average of 33% as compared to control plants.

Yield components:

Number of spikes: All genotypes differ non-significantly for number of spikes under irrigated condition. Significant differences were observed for number of spikes among all genotypes under vegetative stress (Table 3). Maximum spikes were observed in Watan (13) and minimum in Chakwal-86 (8). Overall mean spikes number was 10.25, which was found reduced (19.85%) when compared with control plants. During anthesis stress, number of spikes showed non-significant differences in all the genotypes. When compared with control average percent reduction of 15.79% was observed. All genotypes differ non-significantly for number of spikes with each other under vegetative + anthesis stress.

Spike length: Under irrigated condition Rawal-87 and Inqilab-91 differ significantly from each other. The mean spike length was 15.20 cm under non-stressed condition. Spike length varied significantly under vegetative stress. Maximum spike length was recorded in Chakwal-86 (15.66 cm) and minimum was in Watan (9.93 cm). Genotypes Pak-81 and Uqaab-2000 showed significant differences under anthesis stress. Spike length was reduced when plants subjected to water stress during vegetative + anthesis stages with an average of 16.90%. All of the genotypes differ non-significantly with each other except Inqilab-91.

Number of spikelets per spike: The mean value for number of spikelets per spike was 16.87 with a range of 16 to 18 in irrigated plants. Comparison revealed mean spikelets per spike was 12.04 that ranged from 8 to 14 under vegetative stress. An average reduction of 28.63% was obtained for number of spikelets per spike as compared to control plants (Table 3).

In case of anthesis stress, highest and lowest number of spikelets was noted in Uqaab-2000 and Chakwal-86 respectively. At vegetative + anthesis stress, the mean value for number of spikelets per spike was 12.45 that ranged from 11 to 14 with an average reduction of 26.20%. Non-significant differences were observed between genotypes for this trait.

Table 4: Mean values for number of grains, grain yield and 1000-grain weight in bread wheat hexaploids under irrigated and non-irrigated conditions

Varieties	Control	Vegetative	Anthesis	V + A
Number of grains				
Kohistan-97	465.33^{a}±118.89	152.33^{a}±39.49	233.00^{ab}±79.95	149.33^{ab}±29.79
Rawal-87	358.67^{a}±14.14	232.00^{a}±8.38	294.00^{ab}±5.56	195.00^{a} ±25.73
Chakwal-86	313.00^{a}±57.07	194.67^{a}±94.69	154.50^{bc}±29.50	105.67^{ab}±52.84
Pak-81	404.00^{a}±12.50	226.00^{a}±51.67	302.33^{ab}±82.46	71.00^{bc} ±7.63
Inqilab-91	583.00^{a}±39.80	148.33^{a}±6.17	343.33^{a} ±35.78	82.33^{ab} ±46.26
Watan	548.33^{a}±108.22	91.33^{a} ±51.33	215.33^{ab}±30.02	70.33^{bc} ±9.40
Uqaab-2000	429.00^{a}±119.37	163.00^{a}±15.50	307.00^{ab}±19.34	157.00^{ab}±47.22
Sarsabz	509.6^{a}±71.5717	6.67^{a} ±27.6626	1.33^{ab} ±22.00	162.00^{ab}±40.87
Average	451.37	173.04	263.85	124.08
% reduction /promotion		-61.66	- 41.54	-72.51
Grain yield				
Kohistan-97	9.29^{ab} ±3.57	2.96^{a}±1.13	3.29^{a}±1.59	2.97^{ab}±0.55
Rawal-87	6.58^{ab} ±0.57	3.37^{a}±0.19	2.73^{a}±0.28	2.95^{ab}±0.40
Chakwal-86	3.87^{bc} ±0.88	2.58^{a}±1.19	2.95^{a}±0.78	1.93^{ab}±1.01
Pak-81	6.77^{ab} ±0.08	4.93^{a}±1.30	5.05^{a}±1.83	1.86^{ab}±0.50
Inqilab-91	12.93^{a}±0.77	5.16^{a}±0.23	4.51^{a}±0.44	1.45^{bc}±0.71
Watan	12.93^{a}±2.65	2.34^{a}±1.18	1.9^{a} ±0.36	3.62^{ab}±0.22
Uqaab-2000	11.28^{a}±3.02	3.83^{a}±0.78	3.44^{a}±0.60	4.63^{a} ±1.37
Sarsabz	11.59^{a}±1.30	3.93^{a}±0.90	2.85^{a}±0.84	4.58^{a} ±1.17
Average	9.40	3.63	3.34	2.99
% reduction/promotion		-61.38	-64.46	-68.19
1000-grain weight				
Kohistan-97	19.89^{bc}±1.53	24.28^{bc} ±12.81	17.61^{ab} ±3.34	23.10^{c}±2.26
Rawal-87	23.20^{b} ±0.14	20.23^{c} ±1.06	3.57^{c} ±0.67	22.95^{c}±6.65
Chakwal-86	15.06^{bc}±0.76	17.99^{c} ±8.59	26.81^{a} ±2.78	32.57^{c}±10.57
Pak-81	20.89^{bc}±3.93	26.73^{abc}±6.3	320.64^{ab}±4.38	29.73^{c}±16.87
Inqilab-91	26.23^{ab}±1.15	35.71^{ab} ±5.69	15.53^{abc} ±0.61	26.24^{c}±5.05
Watan	29.76^{ab}±2.43	38.00^{a} ±21.06	10.62^{bc} ±1.60	60.74^{a}±1.45
Uqaab-2000	31.37^{a} ±3.29	35.40^{ab} ±20.76	15.25^{abc} ±5.31	48.20^{b}±20.40
Sarsabz	28.91^{ab}±1.69	27.17^{abc}±1.18	15.12^{abc} ±7.53	27.33^{c}±10.08
Average	24.41	28.18	15.64	33.85
% reduction/promotion		15.44	-35.92	38.67

Number of grains: Mean comparison for the number of grains was non-significant between eight genotypes when plants received normal irrigation. The mean value was 451 with a range of 313 to 583 (Table 4). Number of grains was non-significantly reducedat vegetative stress in all the genotypes. Average reduction of 61.66% was recorded. It ranged from 91 to 232. Under anthesis stress, the mean value for number of grains was 264; it ranged from 155 to 343. All genotypes showed significant differences. During vegetative+anthesis stress, all genotypes showed significant differences for number of grains. Minimum number of grains was noted in Watan (70) and highest number was in Rawal-87 (195). Average reduction was 72.51% for number of grains under both the stresses.

Grain yield: Grain yield showed significant differences in non-stressed plants. The maximum grain yield (12.93 g) was noted in Inqilab-91 and Watan while minimum grain yield (3.87 g) was observed in Chakwal-86 under control condition (Table 4). Non-significant differences were observed for grain yield among all genotypes under vegetative stress. The mean value of grain yield was 3.63 g/plant that ranged from 2.34 to 5.16 g. An average reduction of 61.38% was recorded for grain yield as compared to control. Again non-significant differences has been noticed under anthesis stress, average reduction for grain yield in all genotypes was 64.46% and it ranged from 1.90 to 5.05 g. Grain yield was significantly affected by vegetative+anthesis stress in all genotypes. Significant differences were obtained between Inqilab-91 and Uqaab-2000. The highest grain yield (4.63 g) was calculated in Uqaab-2000 and lowest (1.45 g) was in Inqilab-91.

1000-grain weight: At normal irrigation, comparison of means among all genotypes under study showed significan differences with each other. The highest (31.37 g) 1000-grain weight was noted in Uqaab-2000 and lowest (15.06 g) was in Chakwal-86 (Table 4). DMRT showed highly significant differences among genotypes for 1000-grain weight with a value of 28.18 g that ranged from 17.99 to 38 g under vegetative stress. Anthesis stress reduced 1000-grain weight of all genotypes. The mean value for 1000-grain weight was 15.64 g and average reduction was 35.92%. In case of vegetative+anthesis stress, Rawal-87, Watan and Uqaab-2000 differed significantly with each other and rest of the genotypes differed non-significantly. Average increase of 38.67% for 1000-grain weight was recorded when compared with control.

Table 5. Resistance indices of bread wheat hexaploids under non-irrigated conditions

Varieties	Stresses	SSI	YSI	MP	TOL
Kohistan-97	V	1.11	0.31	6.12	6.33
	A	1.00	0.35	6.29	6.00
	V+A	0.99	0.31	6.13	6.32
Rawal-87	V	0.79	0.51	4.97	3.21
	A	0.91	0.41	4.65	3.85
	V+A	0.80	0.44	4.76	3.63
Chakwal-86	V	0.54	0.66	3.22	1.29
	A	0.36	0.76	3.41	0.92
	V+A	0.73	0.49	2.90	1.94
Pak-81	V	0.44	0.72	5.85	1.84
	A	0.39	0.74	5.91	1.72
	V+A	1.06	0.27	4.31	4.91
Inqilab-91	V	1.15	0.29	8.37	9.12
	A	1.01	0.34	8.72	8.42
	V+A	1.30	0.11	7.19	11.48
Watan	V	1.20	0.25	8.14	9.57
	A	1.32	0.14	7.41	11.03
	V+A	1.05	0.27	8.27	9.31
Uqaab-2000	V	1.07	0.34	7.58	7.40
	A	1.08	0.30	7.36	7.84
	V+A	0.86	0.41	7.95	6.65
Sarsabz	V	1.07	0.33	7.76	7.66
	A	1.17	0.24	7.22	8.74
	V+A	0.88	0.39	8.08	7.01

Abbreviations: SSI: Stress Susceptibility Index; YSI: Yield Stability Index; MP: Mean Productivity; TOL: Tolerance; V: Vegetative; A: Anthesis; V+A: Vegetative + Anthesis stress

Resistance indices: Resistances were calculated on the basis of grain yield of varieties under different stages of water stresses. Under vegetative stress genotypes Pak-81, Chakwal-86 and Rawal-87 showed lowest Stress Susceptibility Index (SSI) values <1 whereas Sarsabz, Uqaab-2000, Kohistan-97, Inqilab-91, Watan, and had SSI values more than 1 (Table 5). Similar results were obtained at anthesis stress. Varieties with a lower SSI were considered to be tolerant varieties.The situation was slightly different under vegetative+anthesis stress Chakwal-86, Rawal-87, Uqaab-2000, Sarsabz and Kohistan-97 showed low SSI whereas Watan, Pak-81 and Inqilab-91 exhibited high SSI values. Varieties with SSI value more than 1 are considered as water susceptible and vice versa are tolerant varieties.

Higher Yield Stability Index (YSI) were noticed in Pak-81, Chakwal-86 and Rawal-87 while the low YSI was found in Watan, Inqilab-91, Kohistan-97, Sarsabz and Uqaab-2000 under vegetative stress. High values of YSI at anthesis stress observed for Chakwal-86, Pak-81 and Rawal-87. However rest of the genotypes i.e. Watan, Sarsabz, Uqaab-2000, Inqilab-91 and Kohistan-97 showed low YSI. Under vegetative + anthesis stress YSI showed high values for Chakwal-86, Rawal-87, Uqaab-2000 and Sarsabz whereas Inqilab-91, Pak-81, Watan and Kohistan-97 had low YSI values.

At vegetative stress high Mean Productivity (MP) values were obtained for Inqilab-91, Watan, Sarsabz, Uqaab-2000 and Kohistan-97 whereas rest of the three genotypes showed low MP values. Under anthesis stress, five out of eight genotypes showed high MP values like Inqilab-91, Watan, Uqaab-2000, Sarsabz and Kohistan-97 however rest of the three exhibited low MP values. Similar results were observed under vegetative + anthesis stress. Varieties with low MP values are considered to be stable under water stress.

Tolerance (TOL) values at vegetative stress existed high for Watan, Inqilab-91, Sarsabz, Uqaab-2000 and Kohistan-97 while Chakwal-86, Pak-81 and Rawal-87 showed low TOL values. Similar results were obtained for anthesis and vegetative+anthesis stress, high TOL values had been noticed in Watan, Sarsabz, Inqilab-91, Uqaab-2000 and Kohistan-97 however Chakwal-86, Pak-81 and Rawal-87 showed low TOL values.

DISCUSSION

Water stress is one of the major abiotic stresses that drastically affect the development of plant. During current studies effect of water stress imposed at different developmental stages was studied on eight bread wheat hexaploids. Results revealed that wheat varieties under study showed substantially variable response at various levels of irrigation.

Vegetative traits: It has been observed that when plants subjected to water stress at vegetative stage genotypes Kohistan-97 and Chakwal-86 took more time to begin flowering at stress condition as compared to their non-stressed genotypes. However genotypes Pak-81, Inqilab-91, Watan and Uqaab-2000 showed early flowering under stress. At anthesis stress, genotypes Chakwal-86 and Rawal-87 required more days to flower as compared to their respective control. Genotypes Inqilab-91 and Uqaab-

2000 showed early flowering as compared to control. Under both stresses (vegetative+anthesis stress) genotypes Kohistan-97, Rawal-87, Chakwal-86 and Inqilab-91 took more days to flower. Genotypes Pak-81, Watan and Uqaab-2000 showed early flowering as compared to non-stressed condition. The plants strive to complete their life cycle as early as possible to cope with drought stress conditions. Therefore, days required to initiate heading or flowering in wheat are generally decreased due to early start of reproductive stage (Riaz, 2003). An interaction among genotypes and irrigation levels were found to be significant. This might be due to varying response of different genotypes to irrigation at different growth stages.

Stress at vegetative caused significant decline for number of tillers in all genotypes except Uqaab-2000 that showed increased in number of tillers, indicating that this genotype copes with stress and showed tolerance. The number of tillers per plant has direct contribution towards grain yield. It means, as the number of productive tillers increases there will be simultaneous increase in yield. Over the stress treatments, stress imposed at vegetative caused decline of 19.11% in tillers as compared to non-stressed condition. Similar to present findings Kimurto *et al*. (2003) and Baque *et al*. (2006) have reported that water stress at tillering or at booting significantly affected the formation of tillers in wheat. Water stress at anthesis significantly decreased the number of tillers in five wheat genotypes. Whereas three genotypes Rawal-87, Chakwal-86 and Pak-81 showed an increase in number of tillers, it seems that they able to be tolerate to stress at anthesis stage. By comparing all three water stresses, genotypes Rawal-87 and Pak-81 showed an increase in number of tillers, their better performance under water deficit led to suggest that these genotypes are stable. Genotypes Kohistan-97, Inqilab-91, Watan and Sarsabz showed decline in number of tillers at all stresses indicating that they were more sensitive to water deficit conditions. Genotype Uqaab-2000 showed better performance under vegetative stress, however at anthesis and vegetative + anthesis stress this genotype was more sensitive to maturation progression.

Reduction in plant height has been observed in all the genotypes under three irrigation levels as compared to non stress condition though variability was seen. When wheat crop was subjected to water stress throughout reproductive growth, preceded by the crop exposed to water stress during the vegetative development a substantial decrease in plant height was recorded for four wheat varieties (Qadir *et al*., 1999; Saleem, 2003). Substantial decline in plant height has been reported when irrigation was with held at booting stage, however tolerant genotypes attained more plant height (Gupta *et al*., 2001; Saleem, 2003). The decrease in plant height in response to water stress could be due to decrease in relative turgidity and dehydration of protoplasm, which is associated with a loss of turgor and reduced expansion of cell and cell division (Arnon, 1972; El-Kholy and Gaballah, 2005). By comparing all three stresses, genotype Sarsabz showed decreased plant height in all stresses and found to be more sensitive to water deficit. Genotype Uqaab-2000 performed better at vegetative + anthesis stress and poor at vegetative and anthesis stress alone. Genotype Rawal-87 performed better under all three stresses.

Yield components: Under vegetative water stress number of spikes decreased in all genotypes except Uqaab-2000. This genotype produced sterile spikes. Zhong-hu and Rajaram (1994) found spikes to be most sensitive to drought, as stress reduced spike numbers (Garcia-del-Moral *et al*., 2003). At anthesis stress genotypes Rawal-87, Chakwal-86 and Pak-81 showed an increase in number of spikes, while rest of the genotypes had decreased number of spikes. When stress was imposed at vegetative + anthesis stage Pak-81 showed an increase in spike numbers while the rest of seven genotypes had significant decrease in number of spikes as compared to non-stressed genotypes. Severe water deficit around anthesis produced serious effects on wheat yield, reducing the number of spikes and spikelets and therefore causing a decrease in plant fertility (Guinata *et al*., 1993). By comparing all levels of stresses genotype Kohistan-97 found to be most susceptible to all water stress levels. Genotype Pak-81 had stable performance it means that it had a better tolerance ability against water deficit.

At vegetative stress significant decrease in spike length has been observed in all genotypes except Chakwal-86 as compared to their respective control. The decrease in stem height and ear length due to water stress has been reported earlier in wheat (Iqbal *et al*., 1999). At anthesis stress genotypes Kohistan-97, Rawal-87 and Uqaab-2000 had increased while other four genotypes showed a decrease in spike length as compared to control condition. Under both stresses (vegetative + anthesis stress) all genotypes showed reduction in spike length when compared to non-stressed genotypes. Drought stress when imposed to spring wheat at various growth stages greatest adverse effects on ear length during stem elongation and heading stage had been noticed (Saleem, 2003). During current experiment genotypes × treatment interaction was significant which shows that the genotypes responded differently to different treatments. By comparing all three stress levels genotype Watan was found most affected as shown by decrease in spike length. Genotype Rawal-87 showed minimum reduction in spike length at vegetative and vegetative + anthesis stress whereas promotion has been noticed under anthesis stress that indicated its capability of tolerance to water deficit.

A significant decrease in number of spikelets per spike has been noticed in all genotypes. When water stress was imposed at anthesis stage significant decrease in number of spikelets per spike has been observed in six genotypes whereas Rawal-87 and Uqaab-2000 had an increase in number of spikelets. Stress at jointed stage of wheat decreased number of spikelets per head (Musick and Dusek, 1980) whereas drought at crown-root initiation or late tillering stages in wheat caused significant reduction in number of spikelets per spike (Shalaby *et al*., 1988). Under vegetative + anthesis stress number of spikelets exhibited significant decrease in all genotypes. Water stress during vegetative and reproductive development had an equal suppressive effect on number of spikelets per spike in four wheat varieties (Qadir *et al*., 1999). The results of this conform to the findings of Karim *et al.* (2000) and Baque *et al.* (2006) who reported that water stress reduced grain yield by reducing productive tillers per plant, fertile spikelet per plant, number of grains per plant and individual grain weight. An interaction between genotypes and treatment was found to be significant during current work which means that the genotypes behaved differently under 4 levels of irrigation. In current studies for number of spikelets per spike genotype Rawal-87 can be considered as stress tolerant genotype because it performed better under all three stages of water stress as compared to other genotypes whereas performance of Sarsabz was least at all water stress levels.

Significant decrease in number of grains has been noticed in all genotypes. Vegetative stress reduced the number of grains per spike in all genotypes. The contribution of pre-anthesis assimilates to grain may be crucial for maintaining yield. When adverse climatic conditions reduce photosynthesis and water uptake (Saeedipour, 2011). During vegetative+anthesis stress significant decrease was observed for number of grains in all genotypes as compared to non-stressed genotypes. Number of grains per spike has been influenced by different irrigation in wheat cultivars (Khan *et al*., 2002; Khan *et al*., 2004) post anthesis drought being the most sensitive stage for number of grains per spike (Ashraf, 1998). The continuous growth of grains in the absence of current photosynthate would deplete the reserves and grain growth would cease (Westgate and Boyer, 1985). Non-significant interaction of Genotype × Treatment during current research work shows that the genotypes responded similarly to different treatments. The numbers of grains have been mostly found to be negatively affected by water deficit. In the present studies number of grains was reduced greatly by vegetative + anthesis stress. By comparing all three-water stresses genotype Rawal-87 had lowest reduction as compared to other genotypes. Genotype showing stability for this trait is often better tolerant to drought condition (Riaz and Chowdhry, 2003). Genotype Watan had maximum reduction in all stresses; suggestive of being sensitive to all levels of water stresses.

A significant decline in grain yield has been found out under vegetative stress as compared to their respective control during present research. Severe reduction in grain yields of wheat genotype with the reduction of 40% at three irrigation stage to 98% in the post anthesis stage of drought suggests that the sensitivity of grain yield to drought stress depends upon the severity of the stress and the stage when it is imposed (Kazmi *et al*., 2003). At anthesis stage of stress all genotypes showed inhibition in grain yield as compared to control. The extent of yield reduction from water stress depends not only on the magnitude of the deficit but also on the stage of growth. Reduction in average grain yield about 50% under the drought stress condition (Nouri-Ganbalani *et al*., 2009). In the present research, 68% reduction in grain yield was recorded when stress was imposed at vegetative + anthesis stage indicating the necessity of water to all critical stages of plant development. Currently an interaction among the genotypes and irrigation levels was found significant for grain yield. This might be due to varying response of genotypes to irrigation at different growth stages. By comparing all three levels of water stresses the decrease was comparatively less in genotype Chakwal-86 at anthesis and vegetative + anthesis stress than others and considered as adaptable to stress condition. Genotype Pak-81 had lowest reduction in grain yield at vegetative stress, thus less affected, being more water stress tolerant at early stage of water deficit. Genotype Watan showed maximum reduction at vegetative and anthesis stress while genotype Inqilab-91 had greatest reduction under both stresses indicating that these genotypes were more sensitive to water stress.

Six genotypes showed significant increase in 1000-grain weight, genotypes Rawal-87 and Sarsabz showed decreased 1000-grain weight under vegetative stress. Reduction in grain weight due to drought and variable response of the tested wheat genotypes to water stress has been reported (Khan *et al*., 1993). Drought stresses affected the 1000-grain weight in different wheat varieties not in a definite pattern as reported by Majid *et al.* (2007). They also reported an increase in 1000-grain weight under pre, post anthesis and terminal drought stresses differentially of local hexaploid wheat. Under anthesis stress, significant decrease for 1000-grain weight has been observed in all genotypes except Chakwal-86 that showed increase in 1000-grain weight. It may be suggested that this genotype had the ability to cope the stress or is tolerable to water stress. Reduction in 1000-grain weight due to water deficit has been studied by many workers (Dastfal and Ramazanpoor, 2000). This reduction in 1000-grain weight could be attributed to a decrease in the supply of assimilates to the grains which led to curtailing the duration of grain filling phase (Rajiki, 1982; Qadir *et al*., 1999). Except Rawal-87 and Sarsabz all genotypes showed increased 1000-grain weight under vegetative + anthesis stress. An interaction was significant which means that the genotypes behaved differently to different irrigation levels. By comparing all stresses, genotype Chakwal-86 had increased 1000-grain weight at all water stress levels, it might be suggested that it had capability of tolerance against water stress. However genotype Sarsabz had decreased 1000-grain weight indicating that it was prone towards water deficit conditions.

Resistance indices: Wheat breeders have made significant improvements in adaptation of wheat to stress-prone environments (Trethowan *et al*., 2002; Lantican *et al*., 2003). Under vegetative and anthesis stresses, genotypes Rawal-87, Chakwal-86 and Pak-81 showed stress susceptibility index (SSI) less than 1, it indicates that these genotypes could be considered as tolerant against water stress. Whereas Kohistan-97, Inqilab-91, Watan, Uqaab-2000 and Sarsabz had SSI values more than 1 could be considered as susceptible. SSI has been widely used by researchers to identify sensitive and resistant genotypes (Fischer and Maurer, 1978; Winter *et al*., 1988; Clarke *et al.*, 1984, 1992). Drought susceptibility index is a measure of yield stability. However, timing of water stress in relation to the development of different genotypes (Clarke *et al*., 1984) or lack of adaptation to favorable environments (Baker, 1987) could be other possible causes of variation in DSI. The results of the present study are in good agreement with the early findings of Clarke *et al*. (1984), Clarke *et al*. (1992) and Ahmad *et al*. (2003) where they reported considerable variation in DSI values of certain wheat genotypes of both environments.

The situation was slightly different under vegetative +anthesis stress, genotypes Kohistan-97, Rawal-87, Chakwal-86, Uqaab-2000 and Sarsabz showed low SSI values, this observations indicates that they are tolerant however Pak-81, Inqilab-91 and Watan considered as susceptible varieties under both stress condition. Genotypes with low SSI are presumed to be stress resistant or tolerant because they exhibit smaller reductions in yield in rainfed condition as compared to irrigated conditions than the mean of all genotypes. However, the low DSI values may not necessarily give a good indication of drought resistance of a genotype. Low DSI values of a variety could be due to lack of yield production under well-watered conditions rather than an indication of its ability to water stress. The DSI has sometime been represented as providing a measure of genotypic yield potential under water stress conditions (Bruckner and Frohberg, 1987). However, DSI does not account for differences in yield potential among genotypes (Clarke *et al*., 1992). DSI actually provide a measure of yield stability based on minimization of yield loss under stressed compared to non-stressed conditions rather than on yield level under dry conditions per se (Clarke *et al*., 1984).Therefore, a stress tolerant genotype as defined by DSI, need necessarily not to have a high yield potential. The effectiveness of selection indices depends on the stress severity supporting the idea that only under moderate stress condition, potential yield greatly influences yield under stress (Blum, 1996; Panthuwan *et al*., 2002; Sio-Se Mardeh *et al*., 2006). It is concluded from the results of current study that water stress imposed at vegetative + anthesis stage reduced wheat yield in all varieties. The differential response of varieties to imposed water stress condition indicates the tolerance ability of wheat varieties, Rawal-87 and Chakwal-86 showed high yield potential and stability. Higher Yield Stability Index (YSI) were noticed in the genotypes Pak-81, Chakwal-86 and Rawal-87 while the low YSI was found in Watan, Inqilab-91, Kohistan-97, Sarsabz and Uqaab-2000 under vegetative and anthesis stress. At vegetative + anthesis stress high values of YSI were obtained for Chakwal-86, Rawal-87, Uqaab-2000 and Sarsabz while Inqilab-91, Pak-81, Watan and Kohistan-97 had lesser YSI values. Bouslama and Schapaugh (1984) stated that evaluating the yield under stress of a cultivar relative to its non-stress yield, could be an indicator of drought resistant genetic materials. Cultivars with the highest YSI exhibited the least yield under non-stress conditions and the highest yield under stress conditions (Sio-Se Mardeh *et al*., 2006). The current results showed that the genotypes Rawal-87, Chakwal-86 and Pak-81 had high YSI under all water retention stresses indicated that these varieties had stable performance, and produced a better yield under water deficit.

At vegetative, anthesis and vegetative+anthesis stress, Mean Productivity (MP) values obtained were high for Inqilab-91, Watan, Sarsabz, Uqaab-2000 and Kohistan-97 however low MP values were found in Chakwal-86, Rawal-87 and Pak-81. MP is mean production under both stress and non-stress conditions (Rosielle and Hamblin, 1981). In current results genotypes Inqilab-91, Watan, Sarsabz, Uqaab-2000 and Kohistan-97 with relatively low yields under water stress conditions, exhibited high MP values. Hossain *et al*. (1990) used MP as a resistance criterion for wheat cultivars in moderate stress conditions. The current results showed that genotypes Rawal-87, Chakwal-86 and Pak-81 had low MP values and identified as tolerant however Inqilab-91, Watan, Sarsabz, Uqaab-2000 and Kohistan-97 with the highest MP were considered as susceptible.

Tolerance (TOL) values at vegetative, anthesis and vegetative + anthesis stress were high for Watan, Inqilab-91, Sarsabz, Uqaab-2000 and Kohistan-97 while Chakwal-86, Pak-81 and Rawal-87 showed low TOL values. Greater the TOL value, the larger the yield reduction under stress condition and the higher the stress sensitivity (Sio-Se Mardeh *et al*., 2006). Among the stress tolerance indicators, a larger of TOL and SSI represent relatively more sensitivity to stress, thus a smaller value of TOL and SSI are favored. Selection based on these two criteria favors genotypes with low yield potential under non stress conditions and yield under stress conditions (Fernandez, 1992). In current material genotypes Rawal-87, Chakwal-86 and Pak-81 had low values and they were more stable and showed high tolerance over water stresses. Similar results were reported by Fernandez (1992), Zeinali *et al*. (2004), Sio-Se Mardeh (2006), Talebi (2009), Sanjari and Yazdansepas (2008), Nouri *et al*. (2011), Mohammadi *et al*. (2010), Karimizadeh and Mohammadi (2011) and Mohammadi *et al*. (2011). All of whom found these resistance indices to be suitable for discriminating the best genotypes under stress and irrigated conditions.

CONCLUSION

For growth parameters like tillers/plant, plant height, number of spikes, spike length and number of spikelets per spike considerable declines were observed when stress was imposed at vegetative stage, nonetheless, maximum reduction in number of grains, grain yield and plant height occurred when stress was imposed at vegetative+anthesis stage. Among hexaploid wheat, Rawal-87 performed well as it attained a short stature, showed lesser reduction of tillers and yield components like spike length, number of spikelets per spike and number of grains under all water stresses. Similarly Chakwal-86 and Pak-81 were less affected under three levels of water stresses with respect to all agronomic traits. These can be considered as tolerant genotypes under water stress. On the other hand, performance of Kohistan-97, Inqilab-91, Watan and Uqaab-2000 was not up to the mark at different irrigation levels. It was also greatly affected agronomically i.e. maximum reduction in plant height, grains number and grain yield. It indicated that these genotypes are most sensitive to different irrigation stress levels and could be considered as susceptible varieties against water stress. Considering the result of this study, it was observed that Rawal-87, Chakwal-86 and Pak-81 at all water stresses in comparison with other genotypes had best ranks regarding yield. They were also desirable in terms of SSI, YSI, MP and TOL indices. They showed considerable potential germplasm to improve water stress tolerance in wheat breeding programs. So, they were identified as suitable genotypes for both stress and non-stress conditions.

ABBREVIATIONS

SSI : Stress Susceptibility Index
YSI : Yield Stability Index
MP : Mean Productivity
TOL : Tolerance Index

ACKNOWLEDGMENT

This work has been presented as poster in The 2nd International Conference on Integrated Approaches to Improve Crop Production under Drought Prone Environments, Italy, September 2005, funded by the USAID. The authors wish to acknowledge the institutes that provided germplasm which included the Department of Agronomy, University of Agriculture, Faisalabad and Tandojam, Sindh, Pakistan.

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