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Original Article

Drought tolerance screening of wheat varieties by inducing water stress conditions

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Abstract

Plants of six wheat varieties (Damani, Hashim-8, Gomal-8, DN-73, Zam-04, and Dera-98) were grown under three water regimes i.e. 100% Field Capacity (FC), 35% FC and 25% FC. Results of this experiment showed highly significant difference among wheat varieties in all the studied traits and water stress conditions decreased them significantly. The superior variety Hashim-8 which indicated higher relative water content (RWC), mean productivity (MP), geometric mean productivity (GMP) and stress tolerance index (STI) whereas stress susceptibility index (SSI) and tolerance (TOL) was observed at its lowest. These traits are recognized as beneficial drought tolerance indicators for selecting a stress tolerant variety. Similarly, total grain yield per plant, biological yield per plant and harvest index was also higher in the same wheat variety, which put it as a good candidate for selection criteria in wheat breeding program for drought resistance.

Keywords: wheat, water stress, drought tolerance, relative water content, yield.

1. Introduction

The future of the South Asian countries lies with dry-land farming because rain-fed faming fields share about 60-70% of the arable land (Singh and Dhillon, 2004). The agricultural performance level is very low in the dryland farming areas, and it is possible to raise this level through the adoption of dry farming technology. The stress factors especially drought, negatively affect plant growth and development and causes a sharp decrease of plants productivity (Pan *et al.,* 2002). It can have a substantial impact on the agriculture of the affected region as its short intense can cause significant damage and harm the economy. Plant responses to drought is a complex physical-chemical process, in which many biological macromolecules and small molecules are involved, such as nucleic acids (DNA, RNA, microRNA), proteins, carbohydrates, lipids, hormones, ions, free radicals and mineral elements (Ingram and Bartels, 1996). The effects of drought on yield of crops depend on their severity and the stage of plant growth during which they occur. Seed germination is the first stage of growth that is sensitive to water deficit. Under semiarid regions, low moisture is often a limiting factor during germination. The rate and degree of seedling establishment are extremely important factors to determine both yield and time of maturity (Rauf *et al.,* 2007).

Wheat (*Triticum aestivum* L.) is a staple food for more than 35% of the world's population and it is also one of the most important cereal crops in Pakistan. It is usually sown as mono-crop and area under rain-fed wheat is 19% of total area under wheat cultivation. In North West Frontier Province (NWFP) of Pakistan more than 60% of the wheat cultivating area is under rain-fed. Therefore, the average grain yield is the lowest in this province among all other four provinces of the country. Rain-fed regions locally called as 'Daman' areas, which are characterized by low yields and severe water shortage causing larger area of lands to be unproductive. To improve the livelihoods of the farmers of the rain-fed areas it is necessary to introduce new high yielding wheat varieties which are resistant to severe climatic adver-

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sities peculiar to drought, a serious limiting factor in wheat yields. There are three components of successful rain-fed agriculture; retaining precipitation, reducing evaporation and sowing of crops that have drought tolerance characteristics and fit the rainfall pattern (Anonymous, 2007). Farmers in rain-fed areas usually adopt conventional methods and grow traditional wheat varieties suitable for their area. This is because the farmers in such areas are very poor and living in miserable conditions. Wheat varieties grown in these regions are mostly low yielding and susceptible to pests and diseases but are well acclimatized to the local environment and thrive best under adverse climatic conditions. Improvement of wheat yield has traditionally relied on direct selection for this trait (Braun *et al.,* 1992). Development of stress tolerant varieties is always a major objective of many breeding programs but success has been limited by adequate screening techniques and the lack of genotypes that show clear differences in response to various environmental stresses. Therefore, wheat breeders are always looking for means and sources of genetic improvement for grain yield and other agronomic traits. The adoption of new technologies such as molecular markers may help in achieving some of the goals to increase wheat yield. For this, modern plant breeders are doing their best to integrate new plant biotechnology methods with traditional breeding techniques based on classical genetics. Keeping in view the above research findings, the present study was carried out to investigate the physiological bases and their association between traits and yield responses to drought conditions.

2. Materials and Methods

Seeds of five approved bread wheat varieties (Hashim-8, Gomal-8, DN-73, Zam-04, and Dera-98) and one local variety Damani were sown in pots (4 L) in a glasshouse under ambient environment. These pots were filled with the John Innes No. II growing media. At emergence, only three seedlings per pot were left growing while others were thinned out. Plants were exposed to three treatments i.e. T_1 (control, 100% field capacity = 3.20 L total water received), T_2 (35% plant available water = 6.40 L total water received) and T_3 (25% plant available water = 1.32 L total water received). Pot weight plus dried soil was recorded as 2.84 kg, afterward it was irrigated to make it at field capacity (FC) and its weight was increased to 4.07 kg (moisture content was estimated as 1.23 kg/pot). Pots in control treatment (T_1) were irrigated weekly to keep them at FC during the whole growing period. Pots in T_2 treatment were allowed to deplete moisture content up to 35% of the FC and then these pots were re-irrigated up to 100% of the FC. Pots in T_3 treatment were maintained between 25% to 35% moisture content as compared to FC during the whole growing season (Figure 1). This practice was continued until harvesting. There were four replications of each treatment.

Germination percentage (GER) was recorded after two weeks whereas days taken to 50% heading (DT50%H) was determined after 50% of the crop produced spikes. Relative water content (RWC) was recorded 88 days after sowing (DAS) at booting stage according to Schonfeld *et al.* (1988), where fresh weight from three youngest fully expanded leaves (flag leaves) were determined within 2 hrs after excision. Turgid weight was obtained after soaking the leaves for 16 to 18 hrs in distilled water. After soaking, leaves were quickly and carefully blotted dry with tissue paper prior to determine of turgid weight. Dry weight was obtained after drying the leaves sample for 72 hrs at 70°C. Relative water content was calculated from the following equation:

$$\text{RWC} = [(\text{fresh weight} - \text{dry weight}) / (\text{turgid weight} - \text{dry weight})] \times 100$$

Leaf area (LA), plant height (PH), yield and the parameters related to it were taken at harvest (137 DAS). Main spikes grain yield per plant (MSGY/P) and tillers grains yield per plant (TiGY/P) were taken separately in all treatments, however in T_3 (highly stressed treatment) there were only main spikes in all four replications. In the second treatment (T_2) though plants produced tillers but few seeds were set in the spike which limits the grain yield of tillers as compared to the main spike within same treatment. A spilt plot design was used for ANOVA using the Genstat version 11 (Lawes Agricultural Trust, Rothamsted Experimental Station, UK). Water stress treatments were arranged as CRD (Completely Randomized Design) in main plots whereas varieties were in subplots. The same software was used to estimate simple correlation coefficient between different traits. For estimating the tolerance and susceptibility of varieties the following indices were used:

Stress Susceptibility Index (Fischer and Maurer, 1978):

$$\text{SSI} = 1 - (Y_S \div Y_P) \div 1 - (\bar{Y}_S \div \bar{Y}_P)$$

Tolerance (Rosielle and Hamblin, 1981):

$$\text{TOL} = Y_P - Y_S$$

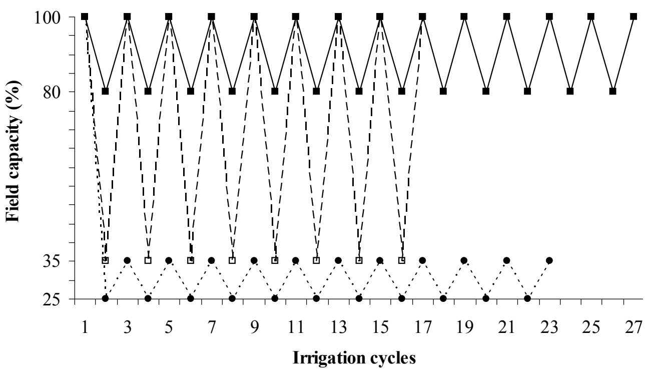

Figure 1. Schematic representation of irrigation cycles and their field capacity of T_1 (■ 100% FC), T_2 (□ 100-35% FC) and T_3 (● 100-25-35-25% FC).

Mean Productivity (Rosielle and Hamblin, 1981):

$$MP = (Y_P + Y_S) \div 2$$

Geometric Mean Productivity (Rosielle and Hamblin, 1981):

$$GMP = \sqrt{(Y_S \times Y_P)}$$

Stress Tolerance Index (Fernandez, 1992):

$$STI = (Y_P \times Y_S) \div (\bar{Y}_P)^2$$

Where Y_P is mean yield of the variety under non-stress condition, Y_S is mean yield of the variety under stress condition, $\bar{Y}_P$ mean yield of all varieties under non-stress condition and $\bar{Y}_S$ mean yield of all varieties under stress condition.

3. Results

Table 1 indicated non-significant differences among wheat varieties and stress treatments regarding seed germination percentage of wheat varieties i.e. seed germination percentage was 92 to 100% when these varieties were raised in 25 and 35% FC pots. A significant ($P<0.05$) varietal difference was observed in days to 50% heading such as Damani and Hashim-8 took minimum time (76 days) to 50% heading followed by Gomal-8 (78 days), Zam-04 and Dera-98 (81 days) and DN-73 (82 days). However, same varieties grown under different stress environments did not show any significant difference in this trait. RWC of all varieties was significantly decreased when subjected to stress conditions as compared to control. Wheat variety Hashim-8 had higher RWC as compared to other varieties in both stress conditions. RWC decreased 3.74% and 33.17% in Hashim-8 in 35% FC and 25% FC treatments, respectively. Other varieties such as Damani (9.41 and 45.52%), Gomal-8 (5.46 and 34.44%), DN-73 (7.48 and 44.13%), Zam-04 (14.21 and 36.29%) and Dera-98 (11.90 and 38.72%) have also shown a decrease in RWC at 35 and 25% FC treatments, respectively. Leaf area of all varieties decreased significantly in both drought conditions. Leaf area of plants grown under 35% FC deceased 21-42% and decreased 44-64% when these varieties were grown under 25% FC. Similarly, plant height was also deceased significantly in all varieties when grown under 25% FC drought treatment. Plants of variety Damani were 40% smaller as compared to plants in control treatment followed by DN-73 (38%), Gomal-8 and Zam-04 (37%), Hashim-8 (35%) and Dera-98 (30%). Apart from Zam-04 and Dera-98 which produced almost same stem height as control ones all other varieties such as Hashim-8 (15%), DN-73 (9%), Damani (7%) and Gomal-8 (4%) significantly reduced plant height when

Table 1. Response of six wheat varieties to different levels of water field capacities regarding germination %-age, days to 50% heading, relative water content, leaf area and plant height parameters.

Drought stress treatments	Wheat varieties	GER (%)	DT50%H (days)	RWC (%)	LA (cm^2)	PH (cm)
T_1 (100% FC)	Damani	100±0.00	75.75±1.31	95.32±6.48	27.98±4.21	68.50±3.75
T_1 (100% FC)	Hashim-8	96±0.25	76.25±1.44	96.87±3.68	32.73±2.40	64.58±3.50
T_1 (100% FC)	Gomal-8	100±0.00	79.00±0.41	93.41±1.69	32.27±1.81	65.58±3.21
T_1 (100% FC)	DN-73	83±0.41	84.00±0.91	93.86±2.30	41.49±2.28	65.75±4.80
T_1 (100% FC)	Zam-04	100±0.00	81.25±0.63	92.67±2.99	32.68±2.28	71.17±4.00
T_1 (100% FC)	Dera-98	100±0.00	82.50±1.04	93.17±0.89	38.40±3.12	62.00±3.73
T_2 (35% FC)	Damani	96±0.25	75.50±1.19	86.35±2.20	16.30±2.30	63.67±2.56
T_2 (35% FC)	Hashim-8	96±0.25	76.25±0.63	93.25±4.34	23.07±2.62	55.08±3.21
T_2 (35% FC)	Gomal-8	96±0.25	77.25±0.63	88.31±4.02	21.86±1.09	62.83±0.87
T_2 (35% FC)	DN-73	96±0.25	82.25±0.63	86.84±2.80	28.44±2.00	60.17±2.81
T_2 (35% FC)	Zam-04	100±0.00	80.25±0.75	79.50±2.69	25.90±1.93	71.00±2.69
T_2 (35% FC)	Dera-98	92±0.00	78.75±0.48	82.08±2.11	28.73±0.92	62.08±2.45
T_3 (25% FC)	Damani	100±0.00	75.50±0.48	51.93±2.11	15.72±0.92	41.08±2.45
T_3 (25% FC)	Hashim-8	100±0.00	76.00±0.96	64.74±5.44	15.95±1.05	42.00±2.23
T_3 (25% FC)	Gomal-8	92±0.50	77.25±0.91	61.24±5.80	14.13±1.15	41.25±1.53
T_3 (25% FC)	DN-73	92±0.29	81.25±0.25	52.44±8.06	14.93±1.40	40.50±0.69
T_3 (25% FC)	Zam-04	100±0.00	81.00±1.47	59.04±3.86	12.48±1.54	44.75±1.75
T_3 (25% FC)	Dera-98	96±0.25	80.50±0.96	57.09±2.05	21.22±3.77	43.42±1.75
SED	Treatments	0.16^{NS}	0.79^{NS}	5.01**	1.52**	2.22**
	Varieties	0.19^{NS}	0.47**	3.52^{NS}	1.54**	1.71**
	Interaction	0.34^{NS}	1.09^{NS}	7.49^{NS}	2.87*	3.50^{NS}

Values showing * and ** stand for significance at 0.05 and 0.01 probability level, respectively, whereas ^{NS} represents a non-significant value. SED stands for standard error of difference between varietal means.

grown under 35% FC condition.

As compared to varieties in control treatment, water stress caused significant percent reductions in grains per spike, tillers per plant, 1,000-grain weight, main spike grain yield per plant, tillers grain yield per plant, total grain yield per plant, biological yield per plant and harvest index (Table 2). Variety Hashim-8 showed promising traits when subjected to stress conditions in all parameters and showed a potential variety for dryland farming areas. Table 3 showed the correlation among various traits under water stress and was found positive and significant. Particularly, the RWC was positively and significantly correlated with leaf area (0.78), plant height (0.90), grains per spike (0.77), tillers per plant (0.83), 1,000-grain weight (0.71), main spike grain yield per plant (0.84), tiller grain yield per plant (0.43), total grain yield per plant (0.94) and biological yield per plant (0.97). It is revealed that varieties with higher RWC under stress conditions are more drought tolerant and gave higher yield than others.

The derived parameters such as MP, GMP and STI were large in variety Hashim-8 accompanied with low values of SSI and TOL indicated a greater drought tolerance in this variety (Table 4). The results indicated that MP, GMP, STI, SSI and TOL ranged from 2.22-3.29, 2.15-3.28, 0.54-1.31, 0.57-1.33 and 0.46-1.09 under 35% FC treatments followed by 1.49-2.13, 1.04-1.69, 0.14-0.34, 0.93-1.06 and 1.79-2.55 under 25% FC treatments, respectively. The grain yield of six wheat varieties under both stress conditions showed positive and highly significant correlation with MP, GMP, and STI and a significant negative correlation with SSI (Table 5). Similarly, the grain yield of all varieties under control condition (Y_P) showed positive and highly significant correlations with TOL, MP, GMP and STI under both drought conditions but was not correlated with SSI. It is observed from Table 3 that MP, GMP and STI were better predictors of Y_P and Y_S than other indices under both water stressed conditions. Overall, STI was a better predictor of Y_P and Y_S under both stressed conditions. Fractional yield of main spike and tillers is shown in Figure 2A and B, which revealed a balanced contribution of main spike (Figure 2A) and tillers (Figure 2B) towards the total yield per plant of varieties Damani and Hashim-8. However, in other varieties (DN-73, Gomal-8, Zam-04 and Dera-98) main spike contributed more than the tillers to increase total yield of plant.

4. Discussion

In a laboratory experiment, same six wheat varieties were treated with 15% polyethylene glycol (PEG) solution indicated a significant response regarding seed germination percentage, coleoptile, shoot and root length, fresh shoot and root weight however Hashim-8 was the most promising one

Table 2. Response of six wheat varieties to different levels of water field capacities regarding yield and yield components parameters.

Drought stress treatments	Wheat varieties	Grains per spike	Tillers per plant	1,000-grain weight (g) per plant (g)	Main spike grain yield plant (g)	Tillers grain yield per plant (g)	Total grain yield per plant (g)	Biological yield per	Harvest index (%)
T_1 (100% FC)	Damani	20.83±0.52	3.50±0.29	61.94±1.04	1.29±0.04	1.21±0.17	2.50±0.21	7.27±0.37	34.75±3.56
T_1 (100% FC)	Hashim-8	34.92±1.27	2.75±0.16	52.23±1.11	2.82±0.05	1.71±0.32	3.53±0.36	7.97±0.19	46.96±3.59
T_1 (100% FC)	Gomal-8	32.67±0.95	2.67±0.14	59.47±1.53	1.95±0.09	0.93±0.30	2.87±0.29	7.36±0.30	38.75±2.47
T_1 (100% FC)	DN-73	42.75±1.42	3.00±0.27	52.74±2.29	2.25±0.09	0.35±0.17	2.60±0.21	7.48±0.21	34.58±1.93
T_1 (100% FC)	Zam-04	41.25±2.41	2.58±0.08	56.41±0.70	2.33±0.14	1.04±0.27	3.37±0.13	7.89±0.23	42.73±1.63
T_1 (100% FC)	Dera-98	32.17±2.30	3.50±0.40	51.83±2.15	1.65±0.11	1.05±0.08	2.70±0.09	7.29±0.20	37.03±0.43
T_2 (35% FC)	Damani	16.50±2.23	4.33±0.47	56.47±1.46	0.92±0.11	1.00±0.24	1.93±0.34	6.26±0.44	30.73±4.79
T_2 (35% FC)	Hashim-8	28.08±0.83	4.83±0.29	52.75±1.59	1.48±0.07	1.58±0.38	3.06±0.42	7.17±0.37	42.39±4.15
T_2 (35% FC)	Gomal-8	23.75±2.31	3.42±0.21	56.59±1.52	1.34±0.12	0.72±0.34	2.06±0.42	6.29±0.37	31.97±4.49
T_2 (35% FC)	DN-73	31.92±1.48	3.08±0.21	50.81±1.29	1.62±0.09	0.35±0.13	1.97±0.18	6.59±0.41	29.96±2.40
T_2 (35% FC)	Zam-04	32.33±5.13	3.42±0.32	56.74±3.70	1.78±0.22	0.49±0.22	2.28±0.33	7.04±0.31	32.26±4.13
T_2 (35% FC)	Dera-98	30.42±2.57	4.42±0.21	45.81±1.67	1.39±0.11	0.62±0.07	2.01±0.06	6.71±0.33	30.15±1.59
T_3 (25% FC)	Damani	10.00±2.64	0.00	46.01±1.10	0.47±0.13	0.00	0.47±0.13	1.81±0.24	24.57±4.82
T_3 (25% FC)	Hashim-8	15.42±1.32	0.00	47.69±1.82	0.84±0.08	0.00	0.84±0.08	2.22±0.17	46.43±2.02
T_3 (25% FC)	Gomal-8	16.50±1.26	0.00	49.66±2.97	0.81±0.03	0.00	0.81±0.03	2.10±0.17	39.22±3.26
T_3 (25% FC)	DN-73	13.17±2.32	0.00	42.93±3.97	0.59±0.13	0.00	0.59±0.13	1.96±0.13	29.69±6.64
T_3 (25% FC)	Zam-04	15.67±1.64	0.00	52.67±3.23	0.82±0.08	0.00	0.82±0.08	1.95±0.15	42.27±3.43
T_3 (25% FC)	Dera-98	20.58±0.46	0.00	35.11±1.43	0.72±0.03	0.00	0.72±0.04	1.96±0.22	38.91±5.94
SED	Treatments	0.92**	0.15**	0.86**	0.05**	0.17**	0.17**	0.25**	3.31^{NS}
	Varieties	1.68**	0.16**	1.75**	0.08**	0.13**	0.16**	0.16*	2.82**
	Interaction	2.81**	0.30**	2.90^{NS}	0.14**	0.27**	0.31^{NS}	0.35^{NS}	5.56^{NS}

Values showing * and ** stand for significant at 0.05 and 0.01 probability level, respectively, whereas ^{NS} represents a non-significant value. SED stands for standard error of difference between varietal means.

Table 3. Correlation coefficient among various traits of wheat varieties.

	DT50%H	RWC	LA	PH	G/S	T/P	1000-GW	MSGY/P	TiGY/P	ToGY/P	BioY/P	HI
GER	-0.31^{NS}	-0.03^{NS}	-0.19^{NS}	0.05^{NS}	-0.22^{NS}	-0.08^{NS}	0.28^{NS}	-0.11^{NS}	0.29^{NS}	0.04^{NS}	-0.03^{NS}	0.14^{NS}
DT50%H		0.07^{NS}	0.47^{*}	0.15^{NS}	0.51^{*}	-0.09^{NS}	-0.16^{NS}	0.42^{*}	-0.47^{*}	0.08^{NS}	0.13^{NS}	0.02^{NS}
RWC			0.78^{**}	0.90^{**}	0.77^{**}	0.83^{**}	0.71^{**}	0.84^{**}	0.43^{*}	0.94^{**}	0.97^{**}	0.26^{NS}
LA				0.75^{**}	0.91^{**}	0.50^{*}	0.33^{NS}	0.88^{**}	0.13^{NS}	0.79^{**}	0.81^{**}	0.21^{NS}
PH					0.78^{**}	0.76^{**}	0.72^{**}	0.85^{**}	0.22^{NS}	0.87^{**}	0.95^{**}	0.11^{NS}
G/S						0.52^{*}	0.36^{NS}	0.97^{**}	0.13^{NS}	0.84^{**}	0.82^{**}	0.35^{NS}
T/P							0.52^{*}	0.55^{*}	0.33^{NS}	0.73^{**}	0.85^{**}	-0.04^{NS}
1000-GW								0.55^{*}	0.32^{NS}	0.64^{**}	0.67^{**}	0.15^{NS}
MSGY/P									0.18^{NS}	0.89^{**}	0.88^{**}	0.35^{NS}
TiGY/P										0.56^{*}	0.34^{NS}	0.71^{**}
ToGY/P											0.95^{**}	0.44^{*}
BioY/P												0.17^{NS}

Values showing * and ** stand for significant at 0.05 and 0.01 probability level, respectively, whereas ^{NS} represents a non-significant value.

Table 4. Mean values of tolerance and susceptibility indices at 35 and 25% FC drought conditions.

Wheat varieties	SSI	TOL	MP	GMP	STI
	Drought tolerance and susceptibility indices at 35% FC treatment				
Damani	0.77	0.58	2.22	2.15	0.54
Hashim-8	0.57	0.46	3.29	3.28	1.31
Gomal-8	1.20	0.82	2.46	2.41	0.72
DN-73	1.00	0.63	2.28	2.26	0.61
Zam-04	1.33	1.09	2.82	2.75	0.89
Dera-98	1.05	0.69	2.35	2.33	0.63
SED	0.55	0.40	0.27	0.29	0.21
	Drought tolerance and susceptibility indices at 25% FC treatment				
Damani	1.06	2.04	1.49	1.04	0.14
Hashim-8	0.93	1.79	2.13	1.69	0.34
Gomal-8	0.96	2.06	1.84	1.52	0.27
DN-73	1.02	2.01	1.59	1.21	0.18
Zam-04	0.99	2.55	2.09	1.66	0.32
Dera-98	0.96	1.98	1.71	1.40	0.23
SED	0.06	0.29	0.17	0.15	0.04

For SSI and TOL, lower values are desirable whereas for MP, GMP and STI, higher values are desirable. SED stands for standard error of difference between varietal means at 0.05 probability level.

among others (data not shown). These varieties were then grown under glasshouse environment to evaluate their drought tolerance suitability. Under *in vivo* stressed conditions all the measured traits of six varieties were decreased remarkably as compared to the control (well-watered) plants. These results coincide with the findings of Bayoumi *et al.* (2008) who observed that drought caused reductions in days to 50% heading, plant height, number of tillers, spike length, 1,000-kernel weight, biological and grain yield and harvest index by 4.78, 14.7, 36.3, 23.7, 16.4, 32.9, 43.2, and 12.7%, respectively. Present results showed that days to 50% heading, RWC, leaf area, plant height, number of grains per main spike, number of tillers per plant, 1,000-grain weight, main spike grain yield per plant, tillers grain yield per plant, total

Table 5. Correlation coefficient between tolerance and susceptibility indices of wheat varieties under 35 and 25% FC drought conditions.

	Drought tolerance and susceptibility indices at 35% FC treatment					
	Y_S	TOL	MP	GMP	SSI	STI
Y_P	0.87**	0.52*	0.97**	0.96^{**}	-0.22^{NS}	0.94**
Y_S		-0.29^{NS}	0.97**	0.98^{**}	-0.68**	0.99**
TOL			-0.04^{NS}	-0.08^{NS}	0.90**	-0.13^{NS}
MP				1.00^{**}	-0.47*	1.00**
GMP					-0.50*	1.00**
SSI						-0.54*
	Drought tolerance and susceptibility indices at 25% FC treatment					
	Y_S	TOL	MP	GMP	SSI	STI
Y_P	0.69^{**}	0.96^{**}	0.98^{**}	0.89^{**}	-0.02^{NS}	0.91^{**}
Y_S		0.45^{*}	0.81^{**}	0.94^{**}	-0.74^{**}	0.93^{**}
TOL			0.88^{**}	0.72^{**}	0.47^{*}	0.75^{**}
MP				0.96^{**}	-0.21^{NS}	0.97^{**}
GMP					-0.48^{*}	1.00^{**}
SSI						-0.44^{*}

Values showing * and ** stand for significant at 0.05 and 0.01 probability level, respectively, whereas ^{NS} represents a non-significant value.

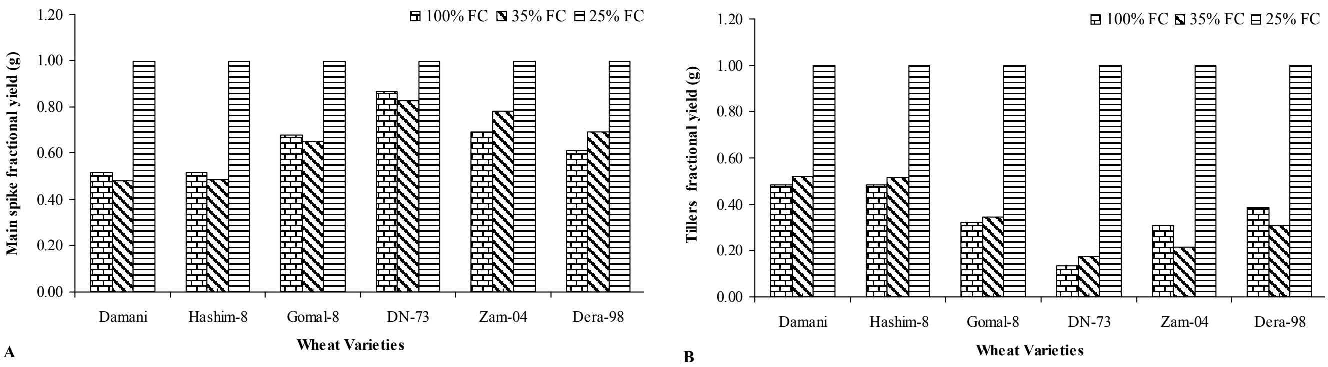

Figure 2. Main spike fractional yield (A) and tillers fractional yield (B) of six wheat varieties at three treatments i.e. 100% FC (bricks bars), 35% FC (diagonal lines bars) and 25% FC (horizontal lines bars). Due to zero tillers in 25% FC treatment the main spike yield was also assumed as tillers yield and was not compared with the rest of two treatments (100% FC and 35% FC).

grain yield per plant and biological yield per plant were decreased under stressed environment which is also reported by Chandler and Singh (2008). They observed that grain yield and biological yield particularly showed maximum sensitivity to moisture stress. Blum and Pnuel (1990) worked on twelve spring wheat varieties and reported that yield and yield components were significantly decreased under minimum annual precipitation. Moreover, fractional yield of main spike and tillers depicted that each variety behaved independently due to the variation in their phenotypes. Main spike and tillers of wheat varieties Damani and Hashim-8 showed equilibrium in total yield production as both contributed equally in enhancing the total yield per plant. However, in varieties DN-73, Gomal-8, Zam-04 and Dera-98 main spike played major role to enhance the total yield per plant as compared to tillers. Plants of all varieties raised in 25% FC did not produce tillers due to sever water stress condition hence only main spike contributed in total yield per plant.

The decrease in 1,000-grains weight may be due to disturbed nutrient uptake efficiency and photosynthetic translocation within the plant (Iqbal *et al.,* 1999) that produced shrivelled grains due to hastened maturity. This is likely due to the shortage of moistures which forces plant to complete its grain formation in relatively lesser time (Riaz and

Chowdhrv, 2003). Under drought conditions the availability of current assimilates for extending seed filling will often be severely reduced. In such circumstances, a variety that can mobilize reserves of carbohydrates in the stem will be able to maintain better seed filling. It is important to note that varieties Damani, Hashim-8, Zam-04, Dera-98 and Gomal-8, which we believe have resistant to water deficit, had a feature of developmental plasticity (the ability of plant to produce flowers with minimum of vegetative structure) and this enables them to produce seed on a limited supply of water which otherwise is coupled with the abundant of water (Quarrie *et al.,* 1999).

There was a non-significant effect of stress environments on days to 50% heading of wheat varieties. These results are endorsed by Majer *et al.* (2008) who observed that sensitive genotypes responded with earlier heading and therefore shortened life cycle to stress whereas tolerant varieties had no significant differences in the time of heading. Hence, registering the time of heading proved to be a useful tool to characterize varieties. Wheat varieties which flowered and matured earlier may have been favored by partial escape from drought and have an ability to complete their life before dehydrated by high summer temperatures.

All varieties particularly variety Hashim-8 retained maximum RWC when grown under stress conditions. Similar results were obtained by Tahara *et al.* (1990) in winter wheat varieties as the high-yield selections maintained a significantly higher RWC than the low-yield selections. Sinclair and Ludlow (1985) proposed that RWC was better measure for plant's water status than thermodynamic state variable (water potential, turgor potential and solute potential). In present study, RWC was determined to give indication on the plant water status under drought condition. RWC decreased with water stress in all the varieties however Hashim-8 retained maximum RWC in all treatments. Similar observations have been reported in common bean (Korir *et al.,* 2006). This deviation in RWC may be attributed to differences in the ability of the variation to absorb more water from the soil and or the ability to control water loss through the stomata's. These findings are in agreement with those reported by Sinclair and Ludlow (1985). It may also be due to differences in the ability of the tested varieties to accumulate and adjust osmotically to maintain tissue turgor and hence physiological activities. Varietals differences in RWC may also be a result of their varied genetic ability to absorb water in the existing rooting zone and or extending rooting depth to increase water reserve for crops. At the cellular level, plants attempts to alleviate the damaging effects of stress by altering their metabolism to cope with stress (Schonfeld *et al.,* 1988; Siddique *et al.,* 2000).

In rain-fed wheat growing areas, harvest index is one of the important components of identity for screening the drought resistance varieties using conventional breeding techniques (Passioura, 1977). Presents findings showed higher harvest index (42.39% and 46.43%) of Hashim-8 in stressed (35% FC) and sever stressed (25% FC) conditions, respectively and revealed it a promising variety for dryland farming as it is suggested that high harvest index may be due to improved resistance to drought by making the plants much shorter along with enhancing the supply of nutrient substances (assimilates) to the young spike (Austin, 1994).

The two factors that feature most prominently to achieve the yield improvement are early flowering in spring wheat (Siddique *et al.,* 1990; Richards, 1991) and plant height (Butler *et al.,* 2005). Earlier flowering is important is drier areas as it provides a better balance between pre-anthesis and post-anthesis water use so that conditions during grain filling are more favorable. This may have come about with the acceptance of greater frost risk. The semi-dwarfing genes have conferred benefits in both favorable and unfavorable environments (Butler *et al.,* 2005). The main reason for their advantage is that more assimilates are available for growing spikes (as less is used for stem growth) and hence leads to greater floret fertility and more grain set (Fischer and Stockman, 1986; Richards, 1992). Present results also indicated a decline in plants height in all varieties under stressed condition. The decrease in plant height in all varieties in response to drought stress in both experiments may 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).

References

Anonymous 2007. Agricultural Statistics of Pakistan. Ministry of Food, Agriculture and Livestock, Government of Pakistan, Islamabad.

Arnon. I. 1972. Crop Production in Dry Regions, Background and Principles. N. Polunin, editor. Leonard Hill Book, London, Vol. 1, pp. 203-211.

Austin, R.B. 1994. Plant breeding opportunities. In Physiology and Determination of Crop Yield. K.J. Boote, editor. CSSA, Madison, Wisconsin, USA. The American Society of Agronomy. pp. 567-586.

Bayoumi, T.Y., Eid, M.H. and Metwali, E.M. 2008. Application of physiological and biochemical indices as a screening technique for drought tolerance in wheat genotypes. African Journal of Biotechnology. 7(14), 2341-2352.

Blum, A. and Pnuel, Y. 1990. Physiological attributes associated with drought resistance on wheat cultivars in a Mediterranean environment. Australian Journal of Agricultural Research. 41, 799-810.

Braun H.J., Pfeiffer, W.H. and Pollmer, W.G. 1992. Environments for selecting widely adapted spring wheat. Crop Science. 32, 1420-1427.

Butler, J.D., Byrne, P.F., Mohammadi, V., Chapman P.L. and Haley, S.D. 2005. Agronomic performance of *Rht* Alleles in a spring wheat population across a range of moisture levels. Crop Science. 45, 939-947.

Chandler, S.S. and Singh, T.K. 2008. Selection criteria for drought tolerance in spring wheat (*Triticum aestivum*

L.). Series: Coping with wheat in a changing environment abiotic stresses. Proceedings of the 11th International Wheat Genetics Symposium. R. Appels, R. Eastwood, E. Lagudah, P. Langridge and M. Mackay Lynne, editors. Sydney University Press, Australia, pp. 1-3.

Fernandez, G.C.J. 1992. Effective Selection Criteria for Assessing Plant Stress Tolerance. In Proceedings of the International Symposium on Adaptation of Vegetative and other Food Crops in Temperature and Water Stress. Taiwan. 13. pp. 257-270.

Fischer R.A. and Maurer, R. 1978. Drought resistance in spring wheat cultivars. Australian Journal of Agricultural Research. 29, 897-912.

Fischer, R.A. and Stockman, Y.M. 1986. Increased kernel number in Norin 10-derived dwarf wheat: evaluation of the cause. Australian Journal of Plant Physiology. 13, 767-784.

Ingram J. and Bartels, D. 1996. The Molecular basis of dehydration tolerance in plants. Annual Review of Plant Physiology and Plant Molecular Biology. 47, 337-403.

Iqbal, M., Ahmed, K. Ahmed, I., Sadiq, M. and Ashraf, M. 1999. Yield and yield components of durum wheat as influenced by water stress at various growth stages. Pakistan Journal of Biological Sciences. 2, 11-14.

Korir, P., Nyabundi, J. and Kimurto, P. 2006. Genotypic response of common bean (*Phaseolus vulgaris* L). to moisture stress condition in Kenya. Asian Journal of Plant Sciences. 5, 24-32.

Majer, P., Sass, L., Lelley, T., Cseuz, L., Vass, I., Dudits, D. and Pauk, J. 2008. Testing drought tolerance of wheat by a complex stress diagnostic system installed in greenhouse. Acta Biologica Szegediensis. 52(1), 97-100.

Pan X.Y., Wang, Y.F., Wang, G.X., Cao, Q.D. and Wang, J. 2002. Relationship between growth redundancy and size inequality in spring wheat populations mulched with clear plastic film. Acta Phytoecology Sinica. 26, 177-184.

Passioura, J.B. 1977. Grain yield, harvest index, and water use of wheat. Journal of the Australian Institute of Agricultural Science. 43, 117-120.

Quarrie, S.A., Stojanovic, J. and Pekic, S. 1999. Improving drought resistance in small-grained cereals: A case study, progress and prospects. Plant growth Regulators. 29, 1-21.

Rauf, M., Munir, M., Ul-Hassan, M., Ahmed, M. and Afzai, M. 2007. Performance of wheat genotypes under osmotic stress at germination and early seedling growth stage. African Journal of Biotechnology. 8, 971-975.

Riaz, R. and Chowdhrv, M. 2003. Genetic analysis of some economic traits of wheat under drought condition. Asian Journal of Plant Sciences. 2, 790-796.

Richards, R.A. 1991. Crop improvement for temperate Australia: future opportunities. Field Crop Research. 26, 141-169.

Richards, R.A. 1992. The effect of dwarfing genes in spring wheat in dry environment: I. Agronomic characteristics. Australian Journal of Agricultural Research. 43, 517-527.

Rosielle, A.A. and Hamblin, J. 1981. Theoretical aspects of selection for yield in stress and non stress environments. Crop Science. 21, 943- 946.

Schonfeld, M.A., Johnson, R.C., Carver, B.F. and Mornhinweg, D.W. 1988. Water relations in winter wheat as drought resistance indicators. Crop Science. 28, 526-531.

Siddique, K.H.M., Tennant, D., Perry, M.W. and Belford, R.K. 1990. Water use and water use efficiency of old and modern wheat cultivars in a Mediterranean-type environment. Australian Journal of Agricultural Research. 41, 431-447.

Siddique, M.R.B., Hamid, A. and Aslam, M.S. 2000. Drought stress effects on water relations of wheat. Botanical Bulletin of Academia Sinica. 41, 35-39.

Sinclair, T. and Ludlow, M. 1985. Who taught plants thermodynamics? The unfulfilled potential of plant water potential. Australian Journal of Plant Physiology. 12, 213-217.

Singh, J. and Dhillon, S.S. 2004. Agricultural Geography. Tata McGraw-Hill Publishing Co. Ltd., New Delhi, India. pp: 412.

Tahara, M., Carver, B.F., Johnson, R.C. and Smith, E.L. 1990. Relationship between relative water content during reproductive development and winter wheat grain yield. Euphytica. 49(3), 255-262.