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GROWTH AND YIELD RESPONSE OF WHEAT VARIETIES TO WATER STRESS AT BOOTING AND ANTHESIS STAGES OF DEVELOPMENT

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Abstract

Plants of 6 bread wheat varieties (Damani, Hashim-8, Gomal-8, DN-73, Zam-04 and Dera-98) were subjected to 2 treatments i.e., control treatment (100% field capacity) and stressed treatment (20 days water stress was given during booting stage and 20 days water stress after anthesis). The findings revealed highly significant differences among means of wheat varieties in all physiological and yield traits. Almost all varieties showed their best adaptation under stressed environment however Hashim-8 and Zam-04 behaved exclusively and 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 estimated at its lowest, as these traits are recognised beneficial drought tolerance indicators for selection of a stress tolerant variety. Similarly, total grain yield per plant, biological yield per plant and harvest index was also higher in the same wheat varieties that put them as good candidates for selection criteria in wheat breeding program for drought resistant.

Introduction

Drought is not merely a physical phenomenon that can be defined by the weather (a shortage of rainfall) rather it is defined by the delicate balance between water supply and demand. Whenever human demands for water exceed the natural availability of water, the result is drought. However, it can be caused by too little precipitation (rain and snow) over an extended period. It is understandable that the world population is increasing very fast particularly in developing countries and much of the future food needed by the increasing numbers of people will have to come from rain-fed areas because the possibilities for increasing the area under irrigation are limited (Botterill & Fisher, 2003). Due to global warming the weather patterns are changing all over the world making rainy seasons unpredictable which generally affect not only the total amount of rainfall in a particular season, but also the frequency, duration and severity of water stress in the plants at different stages of growth (Kijne *et al.,* 2003). The stress factors especially drought negatively affects plant growth and development and causes a sharp decrease of plants productivity (Pan *et al.,* 2002). Although droughts can persist for several years, even a short, intense drought can cause significant damage and harm the local economy. However, plant response to drought is a complex physico-chemical process, in which many biological macro and micro molecules are involved (Ingram & Bartels, 1996).

The future of the South Asian countries lies with dryland farming because rain-fed farming shares about 60 to 70% of the arable land (Singh & 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 cropped area of Pakistan consists of 20.9mha, of which 4.8mha (24%) is rain-fed. Wheat (*Triticum aestivum* L.) is a staple food for more than 35% of the world population and it is also the first cereal crop in Pakistan which is usually sown as mono-crop and 19% area of wheat is under rain-fed region. In North West Frontier Province of Pakistan, wheat is cultivated on more than 60% of the rain-fed area (Anon., 2007). Rain-fed regions called as 'Daman' 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 this area it is necessary to introduce new high yielding wheat varieties resistant to severe climatic adversities peculiar to drought, a serious limiting factor in wheat yields.

The effects of drought on yield of crops depend on their severity and the stages of plant growth during which they occur. Crop yield is reduced mostly when drought stress occurs during the heading or flowering stages. Drought stress during maturity resulted in about 10% decrease in yield however moderate stress during the early vegetative growth has mainly no effect on yield (Bauder, 2001). However, seed germination is the first stage of growth that is sensitive to water deficit. Therefore, seed germination, vigour and coleoptile length are fundamentals for the establishment of crop plants. The rate and degree of seedling establishment are extremely important factors to determine both yield and time of maturity (Rauf *et al.,* 2007). Keeping in these points, present study was carried out to quantify association between various physiological traits and yield response when water stress was given 20 days at booting stage and 20 days after anthesis stage.

Materials and Methods

Seeds of 6 bread wheat varieties viz., Damani, Hashim-8, Gomal-8, DN-73, Zam-04 and Dera-98 were sown in pots (4L) in a glasshouse situated in the University of Reading under ambient environment. At emergence, three seedlings per pot were left growing while others were thinned out. Plants were exposed to two treatments i.e., T_1 (control, 100% field capacity) and T_2 (20 days water stress was given during booting stage and 20 days water stress after anthesis). There were four replications in each treatment.

Leaf area (LA) was measured in square centimeters using an automatic leaf area meter (Delta-T Devices Ltd., Burwell Cambs, UK) whereas days taken to 50% heading (DT50%H) was determined after 50% of the crop produced spikes. Relative water content (RWC) was recorded 76 days after sowing (DAS) at booting stage following to Schonfeld *et al.*, (1988), where fresh weight from three youngest fully expanded leaves (flag leaves) were determined within 2 h after excision. Turgid weight was obtained after soaking the leaves for 16 to 18 h 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 72h at 70°C. Relative water content was calculated from the following equation:

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

Plant height (PH), yield and the parameters related to it were taken at harvest (140 DAS). Main spikes grain yield per plant (MSGY/P) and tillers grains yield per plant (TiGY/P) were taken separately in both treatments. Total grain yield per plant (ToGY/P) was calculated by combining the MSGY/P and TiGY/P, whereas biological yield per plant (BioY/P) was estimated by adding up tillers dry weight, main spike dry weight and straw dry weight together. Harvest index (HI) were estimated as (ToGY/P / BioY/P)*100. Two factorial randomised complete block design was used for ANOVA using the Genstat version 11 (Lawes Agricultural Trust, Rothamsted Experimental Station, UK). The same software was used to estimate simple correlation coefficient between different traits. The significance of correlation was tested against the value of t-tabulated. For estimating the tolerance and susceptibility of varieties the following indices were used:

Stress Susceptibility Index (Fischer & Maurer, 1978):
$SSI = 1 - (Y_S / Y_P) / 1 - (\ _S / \ _P)$

Tolerance (Rosielle & Hamblin, 1981):
$TOL = Y_P - Y_S$

Mean Productivity (Rosielle & Hamblin, 1981):
$MP = (Y_P + Y_S) / 2$

Geometric Mean Productivity (Rosielle & Hamblin, 1981):
$GMP = SQRT\ of\ (Y_S \times Y_P)$

Stress Tolerance Index (Fermandez, 1992):
$STI = (Y_P \times Y_S) / (\ _P)^2$

where Y_P is mean yield of the variety under non-stress condition, Y_S is mean yield of the variety under stress condition, $\ _P$ mean yield of all varieties under non-stress condition and $\ _S$ mean yield of all varieties under stress condition.

Results

Maximum leaf area (Table 1) was observed in control treatment of all wheat varieties such as Damani (22.50cm^2), Hashim-8 (23.23cm^2), Gomal-8 (21.22cm^2), DN-73 (21.82cm^2), Zam-04 (24.53cm^2) and Dera-98 (22.83cm^2). Leaf area was decreased when 20 days water stress was given during booting stage and 20 days water stress after anthesis in all varieties such as Damani (22cm^2), Hashim-8 (22.28cm^2), Gomal-8 (20.40cm^2), DN-73 (21.82cm^2), Zam-04 (18.88cm^2) and Dera-98 (22.58cm^2). It is also noticeable that maximum decrease in leaf area was observed in Zam-04 (23%) and minimum in Hashim-8 (4%) when received water stress. However, the difference among means was non-significant statistically because the stress was given after completion of juvenile phase. RWC of all varieties was significantly ($p<0.05$) decreased when subjected to water stress condition as compared to control (Table 1). However, wheat variety Hashim-8 had higher RWC as compared to other varieties in stress condition. RWC was decreased up to 2.52% in Hashim-8 when 20 days water stress was given during booting stage and 20 days water stress after anthesis. Other varieties such as Damani (7.59%), Gomal-8 (6.76%), DN-73 (10.04%), Zam-04 (12.12%) and Dera-98 (9.97%) have also shown a decrease in RWC when 20 days water stress was given during booting stage and 20 days water stress after anthesis. Days taken to 50% heading (Table 1) was not significantly affected by two treatments and six varieties. However, wheat varieties Hashim-8 took minimum time (74 days) to 50% heading when 20 days water stress was given during booting stage and 20 days water stress after anthesis followed by Damani (75 days), Gomal-8 and Zam-04 (76 days), DN-73 and Dera-98 (78 days). Plants grown under control environment delayed 50% heading from zero to two days only. Similarly, plant height was also deceased significantly ($p<0.05$) in all varieties when 20 days water stress was given during booting stage and 20 days water stress after anthesis (Table 1). Plants of variety Damani were 28% smaller as compared to plants in control treatment followed by Hashim-8 (23%), Zam-04 (19%), Gomal-8 (18%), Dera-98 (17%) and DN-73 (11%).

A statistically significant difference ($p<0.05$) among two treatments and six varieties was observed regarding number of grains per main spike (Table 2). Plants grown under control environment produced maximum number of grains per main spike in all wheat varieties as compared to stressed treatment wherein the number of grain were linearly decreased. Plants of variety Damani produced 59% less number of grains per main spike in stressed condition as compared to control treatment followed by Gomal-8 (57%), Zam-04 (52%), Dera-98 (46%), DN-73 (35%) and Hashim-8 (26%). There was a significant difference ($p<0.05$) among means of two treatments regarding number of tillers per plant parameter was observed however there was a non-significant difference among six varietal means (Table 2). All varieties produced 3 tillers per plant in control treatment except Dera-98 (4 tillers). Plants grown under stressed condition produced 35% less tillers in wheat variety DN-73 followed by Damani (33%), Dera-98 (29%), Zam-04

(28%), Hashim-8 (10%) and Gomal-8 (6%). Data presented in Table 2 revealed that there was a non-significant difference among varietal means and treatment means regarding 1000-grains weight. However, maximum 1000-grains weight (64.99g) was recorded in DN-73 in control treatment which was reduced to 54.34g in stress treatment. Similar trend was observed in other varieties such as Hashim-8, 63.77g (control) and 62.33g (stress), Zam-04, 63.66g (control) and 61.45g (stress), Damani, 6206g (control) and 59.26g (stress), Gomal-8, 59.88g (control) and 58.93g (stress) and Dera-98, 56.33g (control) and 53.04g (stress). However, maximum decline in 1000-grains weight was recorded in variety DN-73 (16%) when 20 days water stress was given during booting stage and 20 days water stress after anthesis. Main spike grain yield per plant was significantly ($p<0.05$) varied between treatments and varieties (Table 2). Wheat variety Hashim-8 produced maximum MSGY/P (2.72g) when grown under control treatment which was 56% reduced when 20 days water stress was given during booting stage and 20 days water stress after anthesis. Similar trend was observed in Damani, Gomal-8, DN-73, Zam-04, Dera-98 where stressed condition reduced MSGY/P up to 57, 58, 57, 50 and 49%, respectively. A significant difference ($p<0.05$) was observed among varietal means regarding tillers grain yield per plant (Table 2). Maximum TiGY/P (2.51g) was recorded in Damani grown in control which was 98% reduced when 20 days water stress was given during booting stage and 20 days water stress after anthesis. Similar trend was observed in other varieties such as Hashim-8, Gomal-8, DN-73, Zam-04, Dera-98 where stressed condition reduced TiGY/P up to 61, 73, 100, 71 and 83%, respectively.

Table 1. Response of six wheat varieties to 20 days drought stress at booting stage and after anthesis stage regarding leaf area, relative water content, days to 50% heading and plant height variables.

Stress treatments	Wheat Varieties	LA (cm^2)	RWC (%)	DT50% H (days)	PH (cm)
T_1	Damani	22.00 ± 1.44	96.01 ± 0.82	74.00 ± 0.00	72.33 ± 0.00
T_1	Hashim-8	23.23 ± 0.74	97.74 ± 4.57	79.50 ± 1.50	66.50 ± 1.03
T_1	Gomal-8	21.22 ± 0.99	94.06 ± 1.09	77.00 ± 0.00	66.00 ± 5.38
T_1	DN-73	31.40 ± 0.13	94.59 ± 1.54	79.50 ± 1.50	68.67 ± 0.41
T_1	Zam-04	24.53 ± 1.14	93.21 ± 1.54	78.00 ± 0.00	75.17 ± 0.62
T_1	Dera-98	22.83 ± 1.57	93.25 ± 3.35	77.50 ± 0.50	70.67 ± 1.24
T_2	Damani	22.50 ± 0.60	90.36 ± 6.57	76.50 ± 0.50	51.83 ± 1.03
T_2	Hashim-8	18.28 ± 0.89	93.31 ± 5.77	74.00 ± 0.00	51.00 ± 4.96
T_2	Gomal-8	20.82 ± 0.59	87.77 ± 4.80	76.50 ± 0.50	53.83 ± 1.45
T_2	DN-73	26.82 ± 1.52	87.19 ± 9.21	78.00 ± 0.00	60.83 ± 3.93
T_2	Zam-04	18.88 ± 0.22	87.01 ± 5.44	77.00 ± 0.00	60.83 ± 1.45
T_2	Dera-98	23.58 ± 0.25	87.01 ± 0.24	77.50 ± 0.50	58.67 ± 2.48
	Treatments	0.16^{NS}	0.79^{**}	5.01^{NS}	1.52^{**}
SED	Varieties	0.19^{NS}	0.47^{**}	3.52^{NS}	1.54^{**}
	Interaction	0.34^{NS}	1.09^{NS}	7.49^{NS}	2.87^{*}

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

Total grain yield per plant was significantly ($p<0.05$) decreased in 6 wheat varieties grown under stressed condition as compared to control treatment (Table 2). Variety Hashim-8 produced maximum ToGY/P (4.61g) when grown under control which was decreased 58% when plants received 20 days water stress during booting stage and 20 days water stress after anthesis. However, this reduction in yield was minimum compared to other varieties such as Zam-04 (59%), Gomal-8 (64%), Dera-98 (65%), DN-73 (67%) and Damani (82% reduction). Data shown in Table 2 regarding biological yield per plant was significantly ($p<0.05$) decreased in six wheat varieties grown under stressed condition. Plants grown in control produced maximum BioY/P in varieties of Damani, Hashim-8 and Dera-98 (9g) followed by Gomal-8, Zam-04, and DN-73 which produced 8g of BioY/P. This was decreased in stressed treatment to 48% (DN-73), 46% (Damani and Hashim-8), 44% (Dera-98), 43% (Zam-04) and 39% (Gomal-8). Harvest index data of all six varieties showed a significant difference ($P<0.05$) between means of two different treatments (Table 2). Maximum harvest index (50.72%) was estimated in variety Hashim-8 when grown under control environment followed by Damani (44.74%), Zam-04 (44.70%), Gomal-8 (42.08%), DN-73 (40.95%) and Dera-98 (39.71%). Plants received 20 days water stress during booting stage and 20 days water stress after anthesis significantly reduced HI in all varieties such as 67% HI was decreased in Damani as compared to control followed by 42% in Gomal-8, 37% in Dera-98, 36% in DN-73, 28% in Zam-04 and 23% in Hashim-8.

Table 2. Response of six wheat varieties to 20 days drought stress at booting stage and after anthesis stage regarding yield and yield components.

Stress treatments	Wheat varieties	Grains per spike	Tillers per plant	1000-grain weight (g)	Main spike grain yield per plant (g)	Tillers grain yield per plant (g)	Total grain yield per plant (g)	Biological yield per plant (g)	Harvest index (%)
T_1 Control	Damani	26.50 ± 0.50	3.00 ± 0.00	59.26 ± 0.74	1.57 ± 0.01	2.51 ± 0.43	4.08 ± 0.42	9.13 ± 0.03	44.76 ± 4.74
T_1 Control	Hashim-8	32.17 ± 3.51	3.33 ± 0.00	53.77 ± 1.81	1.72 ± 0.13	1.89 ± 0.04	3.61 ± 0.09	8.10 ± 0.15	44.67 ± 1.92
T_1 Control	Gomal-8	30.50 ± 2.84	2.83 ± 0.17	59.88 ± 0.72	1.83 ± 0.19	1.44 ± 0.28	3.27 ± 0.09	7.78 ± 0.39	42.24 ± 3.19
T_1 Control	DN-73	40.00 ± 2.34	2.83 ± 0.17	64.99 ± 1.21	2.60 ± 0.10	0.75 ± 0.22	3.35 ± 0.32	8.17 ± 0.28	41.13 ± 5.34
T_1 Control	Zam-04	33.83 ± 0.50	3.00 ± 0.00	61.45 ± 1.16	2.08 ± 0.01	1.42 ± 0.43	3.50 ± 0.42	7.82 ± 0.30	44.56 ± 3.70
T_1 Control	Dera-98	32.17 ± 1.84	3.50 ± 0.17	56.33 ± 1.72	1.82 ± 0.16	1.60 ± 0.86	3.42 ± 0.70	8.61 ± 0.49	39.38 ± 5.87
T_2 Stress	Damani	10.83 ± 1.50	2.00 ± 0.33	62.06 ± 0.44	0.67 ± 0.09	0.05 ± 0.03	0.72 ± 0.06	4.89 ± 0.62	15.17 ± 3.08
T_2 Stress	Hashim-8	23.83 ± 2.84	3.00 ± 1.00	49.32 ± 3.83	1.20 ± 0.37	0.74 ± 0.25	1.95 ± 0.12	4.95 ± 0.27	39.28 ± 0.32
T_2 Stress	Gomal-8	13.17 ± 0.84	2.67 ± 0.00	58.93 ± 1.07	0.78 ± 0.04	0.39 ± 0.26	1.17 ± 0.22	4.77 ± 0.40	24.30 ± 2.65
T_2 Stress	DN-73	20.67 ± 3.01	1.83 ± 0.50	54.34 ± 2.65	1.12 ± 0.11	0.00 ± 0.00	1.12 ± 0.11	4.26 ± 0.04	26.14 ± 2.33
T_2 Stress	Zam-04	16.33 ± 0.67	2.17 ± 0.84	63.66 ± 2.09	1.04 ± 0.01	0.41 ± 0.41	1.45 ± 0.40	4.49 ± 0.49	31.58 ± 5.43
T_2 Stress	Dera-98	17.50 ± 0.50	2.50 ± 0.50	53.04 ± 3.64	0.93 ± 0.09	0.27 ± 0.17	1.20 ± 0.26	4.82 ± 0.23	24.72 ± 4.25
	Treatments	0.92 **	0.15 **	0.86 **	0.05 **	0.17 **	0.17 **	0.25 **	3.31 **
SED	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

The correlation among various traits under water stress and was found positive and significant (Table 3). Particularly, the RWC was positively and significantly correlated with leaf area (0.62), plant height (0.54), grains per spike (0.76), tillers per plant (0.79), 1000-grains weight (0.56), main spike grain yield per plant (0.71), tiller grain yield per plant (0.80), total grain yield per plant (0.84), biological yield per plant (0.87) and harvest index (0.74). It is assumed that varieties with higher RWC under stress conditions have more drought tolerance and gave higher yield than others. The derived parameters such as MP, GMP and STI were larger in varieties Hashim-8 and Zam-04 followed by lower values of SSI and TOL indicated greater drought adoptability in these varieties (Table 4). The results indicated that SSI, TOL, MP, GMP and STI ranged from 1.28-0.72, 3.36-1.67, 2.78-2.22, 2.65-1.72 and 0.56-0.24 under stressed treatment. 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.

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

	LA	RWC	DT 50% H	PH	G/S	T/P	1000-GW	MSGY/P	TiGY/P	ToGY/P	BioY/P
RWC	0.62**										
DT50 % H	-0.06^{NS}	-0.13^{NS}									
PH	0.45*	0.54*	0.53*								
G/S	0.56*	0.76**	0.27^{NS}	0.81**							
T/P	0.56*	0.79**	-0.12^{NS}	0.53*	0.75**						
1000-GW	0.13^{NS}	0.56*	-0.15^{NS}	0.31^{NS}	0.45*	0.40*					
MSGY/P	0.47*	0.71**	0.23^{NS}	0.74**	0.91**	0.67**	0.60**				
TiGY/P	0.47*	0.80**	-0.10^{NS}	0.73**	0.73**	0.79**	0.45*	0.64**			
ToGY/P	0.52*	0.84**	0.05^{NS}	0.81**	0.89**	0.81**	0.57*	0.89**	0.92**		
BioY/P	0.54*	0.87**	0.13^{NS}	0.83**	0.85**	0.79**	0.49*	0.84**	0.90**	0.97**	
HI	0.41*	0.74**	0.06^{NS}	0.74**	0.91**	0.79**	0.62**	0.83**	0.84**	0.92**	0.82**

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 water stressed condition.

Wheat varieties	SSI	TOL	MP	GMP	STI
Damani	1.28	3.36	2.40	1.72	0.24
Hashim-8	0.72	1.67	2.78	2.65	0.56
Gomal-8	1.00	2.10	2.22	1.94	0.30
DN-73	1.03	2.23	2.23	1.92	0.30
Zam-04	0.88	2.05	2.47	2.20	0.39
Dera-98	0.96	2.22	2.31	1.98	0.31
SED	0.10**	0.41**	0.13**	0.10**	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. Values showing ** stand for highly significant at 0.01 probability level

Table 5. Correlation coefficient between tolerance and susceptibility indices of wheat varieties under water stressed condition.

	Y_P	Y_S	SSI	TOL	MP	GMP
Y_S	0.93**					
SSI	0.17^{NS}	-0.20^{NS}				
TOL	0.97**	0.80**	0.42*			
MP	0.99**	0.97**	0.06^{NS}	0.93**		
GMP	0.98**	0.98**	-0.01^{NS}	0.90**	0.99**	
STI	0.99**	0.97**	0.04 ^{NS}	0.92**	0.99**	0.99**

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

Discussion

Seeds of Damani, Hashim-8, Gomal-8, DN-73, Zam-04 and Dera-98 were treated with 15% polyethylene glycol (PEG) solution under laboratory condition showed promising response regarding germination percentage, coleoptile, shoot and root length, fresh shoot and root weight, however varieties Hashim-8 and Zam-04 showed most adoptive drought tolerant traits than others (Khakwani *et al.*, 2011). These varieties were then grown under glasshouse environment to evaluate their drought tolerance suitability at 100, 25 and 35% water field capacity. Under *in vivo* water scarce conditions all the measured traits of six varieties were decreased remarkably under water stressed conditions as compared to the control (well-watered) plants. Approved rainfed variety Hashim-8 again showed significantly noticeable survival and yield producing traits under adverse stressed environment (data not shown). After these two experiments a third experiment (present one) was designed to evaluate same varieties by giving them 20 days water stress during booting stage and 20 days water stress after anthesis.

Six wheat varieties grown under water stressed condition decreased remarkably all the measured traits (leaf area, relative water content, days to 50% heading, plant height, grains/spike, tillers/plant, 1000-garins weight, main spike grain yield/plant, tillers grain yield/plant, total grain yield/plant, Biological yield/plant and harvest index) as compared to the control plants. These results are in agreement with the findings of Bayoumi *et al.,* (2008) who observed that drought caused reduction in days to 50% heading, plant height, number of effective tillers, spike length, 1000-kernel weight, biological and grain yield as well as harvest index by 4.78, 14.7, 36.3, 23.7, 16.4, 32.9, 43.2 and 12.7%, respectively. In a field study, Blum and Pnuel (1990) reported that yield and yield components of twelve spring wheat varieties were significantly decreased when they received minimum annual precipitation. Present results showed that number of grains per main spike, 1000-grain weight, number of tillers per plant, biological yield per plant and grain yield per plant were decreased under stressed environment which is also reported by Chandler and Singh (2008) who reported that grain yield and biological yield particularly showed maximum sensitivity to moisture stress. It is also envisaged from present research that not only the drought but timing of drought is also important for some traits in wheat and other cereal crops (Richards, 2006), such as yield was significantly decreased when 20 days stress was given at booting stage and 20 days stress after anthesis stage. The reason for lower grain yield under stressed condition was mainly due to reduction in the number of spikes/plant, number of grains/spike and number of tillers/plant. These results depicted that the number of grains per main spike contributed more in enhancing the total yield per plant as compared to number of tillers.

The decrease in 1000-grains weight under stressed condition 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 possible due to the shortage of moistures which forces plant to complete its grain formation in relatively lesser time (Riaz & Chowdhrv, 2003). Under drought conditions the availability of current assimilates for extending seed filling will often be severely reduced. In such circumstances, the 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 Hashim-8 and Zam-04, which we believe are resistant to water deficit, having 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).

None of the wheat varieties were significantly affected by stressed treatment regarding days to 50% heading. The results are certified by Majer *et al.,* (2008) who observed that drought sensitive genotypes responded with earlier heading and therefore shortened life cycle to stress whereas tolerant varieties had no significant difference in the heading time. Hence, registering the time of heading proved to be a useful tool to characterise varieties. Wheat varieties which flowered and matured earlier may have been favoured by partial escape from drought and have an ability to complete their life before dehydrated by high summer temperatures. Harvest index, as long as the source of assimilates and their supply to spike was 43.82% for non-stress and 26.98% for stressed treatment. Austin (1994) 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 to young spike. In dry wheat growing areas, harvest index is the main component of identity that has improved yield as a result of conventional wheat breeding (Passioura, 1977).

The two factors that feature most prominently to achieve 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 in rainfed regions as it provides a better balance between pre-anthesis and post-anthesis water use so that conditions during grain filling are more favourable. This may have come about with the acceptance of greater frost risk. The semi-dwarfing genes have conferred benefits in both favourable and unfavourable 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 & 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 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).

Variety Hashim-8 retained maximum RWC in non-stress and stress treatments. 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 under stressed condition. 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. 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 (Schonfeld *et al.,* 1988; Siddique *et al.,* 2000). At the cellular level, plants attempts to alleviate the damaging effects of stress by altering their metabolism to cope with stress. Apart from higher level of RWC under stressed condition, the same variety also has higher estimations of mean productivity, geometric mean productivity and stress tolerance index whereas lower values of stress susceptibility index and tolerance indicated it a potential variety for drought affected regions.

Conclusion

It can be concluded from the findings of present research that although all varieties survived and established well when they received 20 days water stress during booting stage and 20 days water stress after anthesis. However, approved wheat varieties Hashim-8 and Zam-04 achieved most of the yield related traits and consequently produced highest total yield under water stress environment as compared to others. Damani, which is the local wheat variety and commonly cultivated in the rainfed region of Daman, D.I. Khan could not prove as prominent as Hashim-8 and Zam-04. Although, wheat varieties Gomal-8, Dera-98 and DN-73 sustained well against stress treatment but their yield was significantly dropped which did not show their significance in rainfed regions. Hence, approved varieties Hashim-8 and Zam-04 are recommended for rainfed areas to obtain better yield. Moreover, the drought tolerance traits of these varieties can be incorporated in to other high yielding varieties to get maximum plant population and yield.

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