The Journal of Animal & Plant Sciences, 22(3): 2012, Page: 773-780
ISSN: 1018-7081

WHEAT YIELD RESPONSE TO PHYSIOLOGICAL LIMITATIONS UNDER WATER STRESS CONDITION

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ABSTRACT

The objective of this research was to determine the response of wheat varieties (Damani, Hashim-8, Gomal-8, DN-73, Zam-04 and Dera-98) under irrigated (100% field capacity) and drought stress (35% field capacity). Analysis of variance revealed significant effect of water stress on chlorophyll fluorescence, chlorophyll content, stomatal conductance, stomatal dimension, stomatal density, leaf fresh weight, leaf dry weight, leaf area, specific leaf area (SLA), relative water content (RWC) and grain yield per plant. Although all six varieties behaved independently but significantly for mentioned physiological and yield traits, however Hashim-8, Zam-04 and Damani showed best candidates for rainfed regions, recording minimum percent reduction when grown under 35% field capacity (65% drought) in all above-mentioned traits. The same rainfed varieties also retained higher level of stomatal conductance and RWC under water stress condition and minimum percent reduction in stomatal dimension and stomatal density, which reflect their adoptability under drought condition.

Key words: Wheat, *Triticum aestivum*, Stomata, Chlorophyll content, Drought, Water stress, Yield

INTRODUCTION

In arid/semi-arid farming regions the major constraint limiting wheat production is inadequate rainfall reducing average yield up to 50% and over (Wang *et al.*, 2003). However, soil and atmospheric water deficiency occur during plant's life cycle even outside the mentioned regions such as in temperate (Wilson e*t al.*, 2001) or tropical regions (Grace, 1999). Water limitation in latter regions is the emerging future scenario of expanding arid climate due to global warming (Fischer *et al.*, 2001). The response of plants to water shortage is very complex which is either adoptive or detrimental. Plants manage drought stress through stress avoidance and tolerance strategies that vary with genotype. Plants under drought stress condition struggle to revise their metabolic and structural capabilities mediated by modified gene expression which assists to improve their potential under stress environment (Bohnert and Sheveleva, 1998).

Stimuli are generated in the leaf or elsewhere (roots) to make physiological and biochemical alterations in plants to survive under adverse environment such as carbon assimilation is highly affected under stress condition and plant adopt an integrated strategy with the help of these stimuli to allocate photo-assimilates to other plant parts (Pereira and Chaves, 1993). However, some acclamatory physiological changes also occur in plants under stress environment such as modification in root shoot ratio or temporary storage of reserves in stem (Rodrigues *et al.*, 1995). Similarly, herbaceous annuals growing under water stress condition promote root elongation (Sharp and Davies, 1989) which is maintained by ABA (Sharp and LeNoble, 2002) to sustain through osmotic adjustment (Saab and Sharp, 1989).

In plants, carbon molecules provide building blocks for biomass production, fuel for energy, and exert signalling roles to shape development and metabolism. Accordingly, plant growth is well correlated with light interception and energy conversion through photosynthesis. Because water scarcity closes stomata and reduces carbon entry, it has been therefore assumed that plants grown under drought condition are under carbon starvation and they grow under carbon limitation, which affect their growth and development (Muller *et al.*, 2011). Due to carbon limitation photosynthesis is highly affected under water stress conditions and it is recognized that sucrose and other sugars regulate the expression of many genes involved in this process. It is also well established that the emission of chlorophyll *a* fluorescence provides an indicator of the primary photochemistry of photosynthesis. It is therefore, used for detecting plant tolerance to water stress. Fluorescence may also provide information on the carbon reduction cycle. In leaves affecting from drought stress, the slow phase of fluorescence induction is altered (Ogren and Oquist, 1985; Toivonen and Vidaver, 1988; Ogren, 1990). In these studies it was concluded that, beside stomatal closure, the primary effect of drought stress is impairment of the carbon assimilation. In another study, a sharp increase in leaf chlorophyll fluorescence is occurred above a critical temperature in Lupin however no such response was observed in Solanaceae plants

(Chaves *et al.,* 2002). Therefore, it was assumed that membrane stability was increased in dehydrated leaf tissues (Havaux, 1992). The above findings raise the possibility of using fluorescence as an indicator for drought stress. Such an approach must cope with the complex nature and the great variability of the fluorescence signal.

Plant stomata are the gate between plant and atmosphere and play a vital role in plant responses to environmental conditions (Nilson and Assmann, 2007). Similarly, measurements of stomatal conductance, dimension and density, leaf or soil water potential or plant relative water content (RWC) provide meaningful quantitative data and are necessary in a detailed physiological analysis of drought response characteristics (Woo *et al.,* 2008). It is reported that moderate water stress had positive effects on stomatal density in *Leymus chinensis*, but more severe stress led to a reduction. However, stomatal dimension decreased with water deficit but stomatal density was positively correlated with stomatal conductance, net CO_2 assimilation rate, and water use efficiency. A significantly negative correlation of SLA with stomatal density was also observed, suggesting that the balance between leaf area and its matter may be associated with the guard cell number (Xu and Zhou, 2008). Keeping in view the above findings an experiment was design to observe the response of six wheat varieties to stomatal and chlorophyll limitations under water stressed and non-stressed conditions.

MATERIALS AND METHODS

Seeds of five approved bread wheat varieties viz. Hashim-8 (ICW91), Gomal-8 (CM85836), DN-73 (CMSS96T03253T), Zam-04 (CRG732), Dera-98 (CM76688) and one local variety Damani were sown in 4L pots during 2009 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 two treatments i.e. T_1 (control, 100% field capacity) and T_2 (35% field capacity or 65% Drought) Pot weight plus dried soil was recorded as 2.84kg, afterward it was irrigated to make it at field capacity (FC) and its weight was increased to 4.07kg (moisture content was estimated as 1.23kg/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 (Fig. 1). This practice was continued until harvesting. There were four replications of each treatment.

Chlorophyll content was recorded using chlorophyll metre and reading was taken on the second expanded leaf from the top of two plants from each pot at final tillering stage on (62 DAS). Chlorophyll fluorescence (Fv/Fm=variable fluorescence/maximum fluorescence) was recorded by Handy PEA (Hansa Tech., Industries Ltd, England). The reading was taken on the upper most fully expanded leaf from the top of two plants from each pot at final tillering stage (70 DAS). Stomatal conductance was recorded by Delta-T porometer AP4 (Delta-T Devices Ltd., Burwell, Cambs., UK). The reading was taken 61 days after sowing (DAS) on the second expanded leaf from the top of two plants from each pot at final tillering stage. Stomatal density (mm^2) was estimated using first flag leaves of secondary tillers (99 DAS). Colourless nail polish was pasted on the adaxil side of green leaf on $1cm^2$. After 5-minutes the nail polish was peeled off and a slide was made using the peeled material. These slides were put under microscope having a prescribed magnification of 160 times and photographs were taken using photomicroscope (Leitz Dialux-20, Sony Digital Camera, DSC-F717, Germany) and stomata were counted from one mm^2 area. Stomatal dimension was defined as the length in micrometers between the junctions of the guard cells at each end of the stoma, and is considered the maximum opening potential of the stomatal pore, but not the aperture opening that actually occurs (Maherali *et al*., 2002). Stomatal density and size reported are averages of nine microscopic field views.

Leaf fresh weight of individual plant was determined using Sartorius analytical balance at harvest. Leaves of each plant were placed in labelled envelopes and put in the oven at 65°C for 72 hours for dry weight purpose. All dry leaves were re-weigh separately using Sartorius analytical balance to estimate leaf dry weight. Leaf area (LA) was measured in square centimeters using an automatic leaf area meter (Delta-T Devices Ltd., Burwell, Cambs., UK) which was used to estimate specific leaf area (leaf area in cm^2/leaf dry weight in g). Relative water content (RWC) was recorded 88 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 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:

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

Total grain yield per plant (g) was measured at harvest from main spike and tillers using Sartorius analytical balance. A Completely Randomised Design was applied for ANOVA using the Genstat version 11 (Lawes Agricultural Trust, Rothamsted Experimental Station, UK). Same statistical software was used to estimate correlation coefficient between different attributes.

RESULTS AND DISCUSSION

It is well documented that photosynthesis is one of the primary physiological processes affected by water stress and the emission of chlorophyll fluorescence provides an indicator of the primary photochemistry of photosynthesis. In present study, chlorophyll fluorescence (Table-1) of rainfed varieties (Damani, Hashim-8 and Zam-04) was reduced 16-18% under water stressed condition whereas in irrigated approved varieties it was reduced to 27 (DN-73 and Dera-98) and 32% (Gomal-8) under same treatment. However, rainfed varieties retained significantly ($P<0.05$) maximum chlorophyll fluorescence as compared to irrigated ones. Sayar *et al.* (2008) observed that chlorophyll fluorescence extinction measurement seems to be the most reliable test enabling the discrimination of wheat varieties according to their drought tolerance such as all wheat tolerant varieties in group 5 showed an average of 16% decrease in chlorophyll fluorescence which was significantly lower than the varieties in other groups which were drought susceptible. Similar results were obtained in drought susceptible variety of bean (Dobrudjanski ran) where a significant higher decrease in chlorophyll fluorescence was recorded, however drought tolerant variety Prelom showed a slight tendency to decrease (Zlatev and Yordanov, 2004). It is also reported that decrease of chlorophyll fluorescence under drought stress seems to indicate the occurrence of chronic photoinhibition due to photoinactivation of photosystem II centers, possibly attributable to D1 protein damage which usually limit photosynthetic activity (Zlatev, 2004). Similarly, a minimal decrease (1%) in chlorophyll content (Table-1) was observed in the local Damani variety which was non-significant to its counterpart Hashim-8 (4%). Zam-04 reduced chlorophyll content up to 9% followed by DN-73 (10%), Gomal-8 (14%) and Dera-98 (23%). However, all three rainfed varieties (Damani, Hashim-8 and Zam-04) had significantly ($P<0.05$) maximum chlorophyll content as compared to approved irrigated varieties (Gomal-8, DN-73 and Dera-98). Christopher *et al.* (2004) observed that chlorophyll content was similar for both drought susceptible and resistant varieties until grain filling. However, leaves of drought susceptible varieties lost chlorophyll content earlier than those of drought resistant lines. This showed that the leaves of irrigated varieties (drought susceptible) senesced earlier than those of rainfed ones (drought resistant). This implies that differences in the rate of carbon acquisition before the onset of leaves senescence were not responsible for grain yield of rainfed varieties. This also suggests that the ability of rainfed varieties to maintain leaf chlorophyll content, and most probably to continue carbon acquisition for longer during grain filling as it is observed in sorghum ‘stay green’ line, is likely to be more important in contributing to the increased yield.

Plants growing in water stress condition show alteration in cell carbon metabolism which is possibly mediated with low CO_2 availability due to stomatal closure (Meyer and Genty, 1999; Lawlor, 2002). Data (Table-1) revealed significant ($P<0.05$) differences between water stress conditions and wheat varieties regarding stomatal conductance, stomatal dimensions and stomatal density traits. In optimum (non-stress) condition, the average stomatal conductance was quite higher which was decreased up to 8 (Zam-04), 10 (Hashim-8) and 15% (Damani) in rainfed varieties whereas in irrigated varieties (Dera-98, DN-73 and Gomal-8) it was reduced to 37, 47 and 48% respectively in drought stress condition. There is a strong link between stomatal conductance and photosynthesis in which leaf dehydration can lead to turgor loss of guard cells causing passive stomatal closure which reduce stomatal conductance and consequently the supply of CO_2 to fixation site is reduced (Ahmadi and Siosemardeh, 2005). However, the ability of stomata to remain open in the rainfed varieties was closely linked to their greater capacity for osmotic adjustment as compared with irrigated varieties. Similar results were reported by El-Hafid *et al.* (1998). However, some previous studies showed different relationships between RWC and photosynthetic rate and changes in metabolism in different species. Findings of one of the studies showed that there is good correspondence between the onset of drought-induced inhibition of different photosynthetic sub-processes and stomatal conductance. Contents of ribulose bisphosphate (RuBP) and adenosine triphosphate (ATP) decrease early during drought at still relatively high stomatal conductance. This suggests that RuBP regeneration and ATP synthesis are impaired. Decreased photochemistry and Rubisco activity typically occur at lower stomatal conductance, whereas permanent photoinhibition is only occasional. This study suggests that stomatal closure is the earliest response to drought and the dominant limitation to photosynthesis at mild to moderate drought. However, in parallel, progressive down-regulation or inhibition of metabolic processes leads to decreased RuBP content, which becomes the dominant limitation at severe drought (almost complete stomatal closure), and thereby inhibits photosynthetic CO_2 assimilation (Flexas and Medrano, 2002). However, it is also believed that stomatal responses are often more closely linked to soil moisture content than to leaf water status. This suggests that stomata are responding to chemical signals (e.g. ABA) produced by dehydrating roots, whilst leaf water status is kept constant (Davies and Zhang, 1991; Chaves *et al.*, 2002).

Similarly, stomatal dimension (Table-1) was reduced 13-17% in rainfed varieties (Damani, Hashim-8 and Zam-04) as compared to 28-40% reduction in irrigated ones (Gomal-8, DN-73 and Dera-98) which indicated a strong limitation of these varieties under stress condition. The greater reduction of stomatal size in irrigated varieties affect stomatal conductance which limits the supply of carbon, ultimately the yield is lowered. Stomatal density (Table-1), on the other hand was not significantly affected (0-2% reduction) in rainfed varieties (Damani, Hashim-8 and Zam-04) however number of stomata significantly reduced (9-13%) in irrigated varieties (Gomal-8, DN-73 and Dera-98). These results are at par with other researchers (Moftah *et al.,* 2005; Xu and Zhou, 2008) where reduction in stomatal dimension and stomatal density was found as a result of water stress, indicating this may enhance the adaptation of plant to drought. The ability of a variety to keep its stomata open despite internal water stress has been considered a form of drought resistance trait (Seropian and Planchon, 1984; Johnson *et al.,* 1987). However, one finding revealed that stomatal density increased in drought stress (Ciha and Brun, 1975) whereas Rodiyati *et al.,* (2005) observed that stomatal density did not express strong response to water deficit conditions.

Table-2 indicated that water stress significantly (P<0.05) reduced the yield related parameters such as leaf fresh and dry weight, leaf area, SLA, RWC and grain yield per plant. Leaf fresh weight was reduced 24-26% when rainfed varieties (Damani, Hashim-8 and Zam-04) were raised under stress condition as compared to irrigated varieties (Gomal-8, DN-73 and Dera-98) where leaf fresh weight was decreased to 34-41%. Similar trend was observed in leaf dry weight variable where 15-18% reduction was noticed in rainfed varieties and 32-34% reduction in irrigated varieties. The possible reason for minimum reduction of leaf fresh and dry weights in rainfed varieties under stress environment could be that the accumulated solutes are used as substances for rapid recovery growth when stress is relieved. Similar results were reported by Christopher *et al.* (2004) where differences between drought resistant and susceptible varieties under stressed condition were due to the portioning of resources during development. The drought susceptible lines had a greater thinner leaves which reduced total dry weight. Hence, the results of present study clearly showed that water scarcity affects stomatal behaviour which imbalance photosynthesis that results into minimum assimilates production. An average of 15% leaf area was decreased in rainfed varieties (Damani, Hashim-8 and Zam-04) as compared to 36% decline in irrigated ones (Gomal-8, DN-73 and Dera-98) under water stress condition. However, SLA was negatively reduced under same environment in Damani and Hashim-8 whereas only 1% reduction was noticed in Zam-04. Similarly, SLA was reduced to 2, 4 and 8% in Dera-98, Gomal-8 and DN-73 respectively. The difference between treatments and varieties in both variables was significant (P<0.05) statistically. These results are in line with Xu and Zhou, (2008) who reported that leaf area and SLA were significantly declined in plants grown under stress environment due to the limited availability of assimilates.

Table-2 also revealed that RWC was reduced 8-9% in rainfed varieties whereas there was 16-20% reduction in irrigated ones. Minimal reduction in RWC in rainfed varieties may be attributed to differences in the ability to absorb more water from the soil and or the ability to control water loss through the stomata. Moreover, retaining sufficient RWC in leaves by the rainfed varieties has a significant effect on photosynthesis, which suggests that because of osmotic adjustment rainfed varieties may avoid non-stomatal limitations to photosynthesis. It may also be due to differences in the ability of the tested varieties to accumulate and adjust osmotically to maintain tissue turgor and other physiological activities (Sinclair and Ludlow, 1985) 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 (Korir *et al.,* 2006). On the other hand, a significant decline (31-37%) in grain yield per plant was observed in irrigated varieties, however in rainfed varieties grain yield was declined 6 (Hasim-8), 8 (Damani) and 10% (Zam-04) which indicated that these varieties have full potential to be grown in drought regions. As observed for yield, water stress caused a significant reduction in stomatal and chlorophyll traits which subsequently reduced photosynthesis hence yield was declined across the varieties. It appears to be a possible physiological mechanism by which drought can affect growth and productivity of crops. However, rainfed varieties thrived well under stress condition because of their minimum reduction in the above-mentioned traits. Similar results have been reported by other researchers (Ahmadi and Siosemardeh, 2005; Ratnayaka and Kincaid, 2005).

Table-3 depicted that the correlation coefficients, in general were positive and significantly higher magnitudes across prominent parameters. Such as chlorophyll fluorescence, Stomatal conductance and Stomatal dimension showed significantly positive association among most of the traits except stomatal density and SLA. However, chlorophyll content was significantly and positively correlated with all traits except stomatal density and SLA traits where a significant but negative trend was observed. Positive and significant association of stomatal density was observed with leaf area only and was non-significant with rest of traits. The reason could be the relationship between stomatal/chlorophyll parameters and photosynthesis

Table-1. Mean values of chlorophyll fluorescence, chlorophyll content, stomatal conductance, dimension and density of six wheat varieties to different levels of water field capacities.

Drought Treatments	Wheat Varieties	Chlorophyll fluorescence (ratio)	Chlorophyll content (units)	Stomatal conductance (mmol m^{-2}s^{-1})	Stomatal dimension (micron)	Stomatal density (mm^2)
100% FC	Damani	0.82±0.00	13.86±0.76	215.13±22.03	1647±27.00	32.25±0.63
100% FC	Hashim-8	0.82±0.00	13.80±0.76	260.00±37.31	2178±59.70	41.50±1.19
100% FC	Gomal-8	0.82±0.00	12.08±0.56	267.13±48.86	1256±40.89	62.75±1.11
100% FC	DN-73	0.82±0.01	12.88±0.66	267.88±50.65	1710±70.08	46.00±0.91
100% FC	Zam-04	0.81±0.01	14.64±1.24	220.38±18.64	1826±40.45	46.25±0.25
100% FC	Dera-98	0.82±0.01	13.30±0.68	240.50±38.17	1975±5.00	55.75±1.18
35% FC	Damani	0.68±0.01	13.66±2.10	183.89±30.59	1368±41.09	31.75±1.03
35% FC	Hashim-8	0.68±0.01	13.24±1.23	234.13±60.48	1821±27.07	41.50±1.19
35% FC	Gomal-8	0.56±0.01	10.43±0.11	142.40±4.14	875±25.00	55.25±5.01
35% FC	DN-73	0.60±0.00	11.56±0.27	138.88±13.30	1230±30.00	42.00±1.15
35% FC	Zam-04	0.68±0.01	13.30±0.91	202.13±31.57	1581±45.91	46.00±0.91
35% FC	Dera-98	0.60±0.00	10.25±0.17	151.94±29.72	1179±57.63	48.25±2.32
LSD	Treatment	0.010^{**}	1.08^{**}	32.93^{**}	59.0^{**}	2.22^{**}
	Varieties	0.017^{**}	1.87^{**}	57.04^{*}	102.3^{**}	3.85^{**}
	Interaction	0.024^{**}	2.65^{NS}	80.67^{NS}	144.6^{**}	5.45^{**}
% Reduction in 35% FC						
	Damani	16	1	15	17	2
	Hashim-8	18	4	10	16	0
	Gomal-8	32	14	47	30	12
	DN-73	27	10	48	28	9
	Zam-04	17	9	8	13	1
	Dera-98	27	23	37	40	13

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

Table-2. Mean values of leaf fresh weight, leaf dry weight, leaf area, specific leaf area, RWC and grain yield per plant of six wheat varieties to different levels of water field capacities.

Drought treatments	Wheat Varieties	Leaf fresh weight (g)	Leaf dry weight (g)	Leaf area (cm^2)	SLA (cm^2/g)	RWC (%)	Grain yield per plant (g)
100% FC	Damani	0.88±0.03	0.15±0.01	27.98±4.21	178.62±18.67	94.50±1.44	2.64±0.14
100% FC	Hashim-8	0.89±0.04	0.15±0.01	32.73±2.40	224.55±6.53	96.00±0.91	3.78±0.26
100% FC	Gomal-8	0.68±0.05	0.15±0.01	32.27±1.81	219.74±12.65	93.41±1.69	2.87±0.29
100% FC	DN-73	0.82±0.07	0.18±0.02	41.49±2.28	232.02±15.70	93.86±2.30	2.85±0.12
100% FC	Zam-04	0.80±0.01	0.22±0.01	32.68±2.28	150.62±6.91	92.67±2.99	3.37±0.13
100% FC	Dera-98	0.97±0.05	0.20±0.01	41.65±1.65	208.15±6.34	93.17±0.89	2.70±0.09
35% FC	Damani	0.66±0.05	0.13±0.01	23.80±1.70	188.40±16.29	86.06±2.10	2.43±0.09
35% FC	Hashim-8	0.68±0.04	0.12±0.01	27.82±1.60	232.95±13.22	88.50±2.60	3.56±0.27
35% FC	Gomal-8	0.40±0.03	0.10±0.01	20.36±0.97	211.68±14.42	78.42±0.50	1.81±0.20
35% FC	DN-73	0.54±0.03	0.12±0.01	25.94±1.33	212.55±17.17	75.55±1.79	1.89±0.13
35% FC	Zam-04	0.61±0.03	0.18±0.01	27.40±1.56	149.26±9.83	84.26±3.75	3.03±0.11
35% FC	Dera-98	0.62±0.04	0.14±0.01	27.03±1.07	204.24±16.22	77.08±1.20	1.87±0.10
LSD	Treatment	0.05^{**}	0.014^{**}	2.49^{**}	15.99^{*}	2.43^{**}	0.18^{**}
	Varieties	0.09^{**}	0.024^{**}	4.31^{**}	27.69^{**}	4.20^{**}	0.31^{**}
	Interaction	0.13^{NS}	0.034^{NS}	6.09^{**}	39.16^{NS}	5.94^{**}	0.44^{**}
% Reduction in 35% FC							
	Damani	26	18	15	-5	9	8
	Hashim-8	24	18	15	-4	8	6
	Gomal-8	41	34	37	4	16	37
	DN-73	34	32	37	8	20	33
	Zam-04	24	15	16	1	9	10
	Dera-98	37	32	35	2	17	31

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

Table-3. Correlation coefficients between physiological and yield traits - chlorophyll fluorescence (CF), chlorophyll content (CC), stomatal conductance (SC), stomatal dimension (S Dim), stomatal density (S Den), leaf fresh weight (LFW), leaf dry weight (LDW), leaf area (LA), specific leaf area (SLA), relative water content (RWC) and grain yield per plant of wheat cultivars.

Parameters	CC	SC	S Dim	S Den	LFW	LDW	LA	SLA	RWC	Yield
CF	0.72**	0.89**	0.73**	0.02^{NS}	0.89**	0.68**	0.77**	-0.04^{NS}	0.96**	0.67**
CC		0.60**	0.80**	-0.45**	0.71**	0.61**	0.39*	-0.39*	0.76**	0.77**
SC			0.72**	0.16^{NS}	0.74**	0.52**	0.76**	0.23^{NS}	0.92**	0.79**
S Dim				-0.24^{NS}	0.86**	0.61**	0.66**	-0.01^{NS}	0.76**	0.84**
S Den					-0.16^{NS}	0.13^{NS}	0.29*	0.23^{NS}	-0.03^{NS}	-0.12^{NS}
LFW						0.67**	0.78**	-0.01^{NS}	0.85**	0.59**
LDW							0.74**	-0.49*	0.56**	0.45*
LA								0.22^{NS}	0.68**	0.43*
SLA									0.03^{NS}	-0.03^{NS}
RWC										0.76**

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

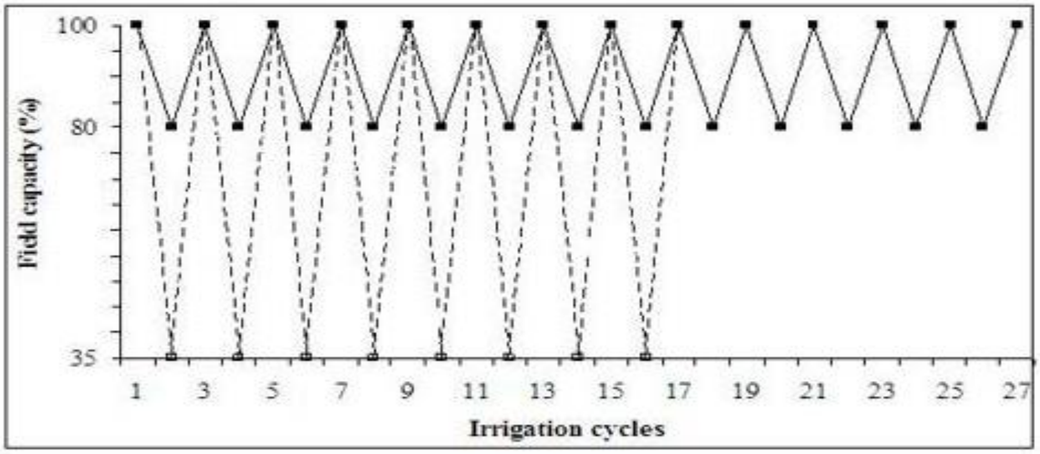

Fig. 1. Schematic representation of irrigation cycles and their field capacity of T1 (■ 100% FC i.e. 14 times irrigations until harvest) and T2 (☐ 35%FC or 65% drought stress i.e. 9 times irrigations until harvest).

which significantly affected net assimilates (Zlatev, 2004; Ahmadi and Siosemardeh, 2005). Leaf fresh weight was positively and significantly correlated to all traits except SLA while leaf dry weight was positively and significantly associated with all traits studied. Leaf area showed significantly positive association among all traits except SLA which was non-significant with almost all traits except leaf dry weight and chlorophyll content however these two traits were negatively correlated to SLA. Positive and significant correlation was observed in RWC and grain yield per plant with almost all parameter except stomatal density and SLA traits where a non-significant negative association was noticed. Similar results were reposted by Attarbashi *et al.* (2002), Subhani and Chowdhry (2000) and Munir *et al.* (2007) which showed that most of the physiological traits significantly affected the grain yield in wheat crop.

Conclusion: Wheat yield was significantly affected by stomatal, non-stomatal and leaf water status parameters when grown in drought condition. Present results indicated that stomatal and non-stomatal parameters were changed in response to water status, which may be closely associated with photosynthesis and water use efficiency that reduced wheat yield under water stress condition. However, stomatal and non-stomatal inhibition to photosynthesis under stress condition varied in susceptible (irrigated) and resistant (rain fed) wheat varieties. Minimum reduction in chlorophyll content and fluorescence, stomatal size and conductance and RWC could be some adaptive strategies in resistant varieties which appear to be involved in drought resistance. Therefore, three wheat varieties, Damani, Hashim-8 and Zam-04 are emerged as drought resistant varieties for rainfed regions. However, variety Damani is already under cultivation in local rain fed area of D. I. Khan which has tolerance against drought but its yield is highly reduced in stress condition. Therefore, Hashim-8 and Zam-04 can be approved as the most suitable candidates to replace low yielding local variety and can be introduced in other rainfed regions.

Acknowledgement: Authors are highly indebted to the Higher Education Commission of Pakistan for providing a post-doctorate scholarship to Dr. A. A. Khakwani which makes this research a success.

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