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Physiological response of bread wheat (*Triticum aestivum* L.) to high temperature and moisture stresses

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Abstract

Water scarcity and temperature variability are major constraints of wheat productivity and food security in the context of climate change. The impact of temperature and water variability at anthesis of spring wheat was studied in field experiments conducted during 2008-09 & 2009-10. Five wheat cultivars *viz*; Chakwal-50, Wafaq-2001, GA-2002, NARC-2009 (NR-268 line in 2008) and Tatara were sown in a randomized complete block design with three replications. Physiological parameters *i.e.* net photosynthesis (A_n), transpiration rate (E), stomatal conductance (g_s), intercellular carbon dioxide concentration (C_i) and stomatal resistance (r_s) were recorded. The results indicate a reduction in A_n, g_s, C_i and r_s and an increase in E due to high temperature and moisture stress. Among genotypes, NARC-2009 produced highest grain yield and exhibited maximum photosynthetic rate which was positively related to g_s, C_i and inversely related to r_s and E. Rise in temperature and moisture stress at anthesis led to the reduction in photosynthesis, thereby, reducing biomass and grain yield. Therefore, genotypes having better physiological performance under abiotic stresses need to be considered for cultivation under changing environmental conditions. In our study, NARC-2009 performed best and we recommend its cultivation for areas having high temperature and moisture stresses. The values of all physiological attributes (A_n, E, g_s, C_i and r_s) were higher during the first year (2008-09) as compared to the second (2009-10) which was mainly due to the relatively low temperature and higher moisture availability during the first year.

Keywords: Climate change; temperature; water stress; photosynthesis; transpiration; anthesis; wheat
Abbreviations: A_n, net photosynthesis; E, transpiration rate; g_s, stomatal conductance; C_i, intercellular carbondioxide concentration; r_s stomatal resistance; NARC, National Agricultural Research Centre; IPCC, Intergovernmental panel on climate change

Introduction

Wheat is the major staple food crop and is being cultivated under diverse climatic regions of the world. In Pakistan, its contribution towards agriculture and GDP is 14.4 % and 3.1 %, respectively. It was cultivated on an area of 9.04 M ha with production of 24 M tons (GOP, 2011). The annual average increase of 0.3°C in world temperature may alter water availability and usage, hence, can affect cereals production to a greater extent (IPCC, 2001). Temperature fluctuations and variations in moisture availability during the crop growth period can, potentially, alter overall growth and development by affecting vital physiological processes such as photosynthesis, nutrient and water uptake. Photosynthesis is considered to be the most important physiological process controlling plant growth and, consequently, yield (Ali et al. 2010) and a positive correlation has been reported between grain yield and photosynthesis in wheat (Arfan et al., 2007). Rise in temperature along with moisture stress reduces photosynthesis by decreasing stomatal conductance to control evaporative water loss through transpiration. Under such conditions, plants face problems like inability to take CO_2 and reduced leaf cooling due to minimum transpiration that results in a rise of temperature (5-6°C) near leaves leading to the formation of reactive oxygen species (ROS) (Athar and Ashraf, 2009). This situation creates a considerable decrease in photosynthetic activities and crop productivity. However, the degree of decrease in photosynthesis depends on the severity and duration of moisture stress, prevailing temperature, type of species and cultivars (Athar and Ashraf, 2009). Few wheat genotypes with enhanced moisture and temperature tolerance have already been identified, but there is dire need to develop new cultivars/genotypes in food crops tolerant to these abiotic stresses to feed the ever increasing world population and these cultivars should exhibit various physiological and biological mechanisms to cope with the effect of temperature and moisture stresses at different growth stages (Rontein et al., 2002). Asim et al. (2006) are of the view that evapotranspiration and crop coefficients (Kc) might have a significant relationship with crop growth and productivity. Physiological attributes like gas exchange characteristics have been reported to be of prime importance in screening crops for temperature and moisture stress tolerance at different growth stages (Athar and Ashraf, 2009). It has been observed that variability in temperature and moisture may be induced for a crop by planting it under different sowing windows or years (Ahmed et al., 2010). Thus, a crop sown at different timings or climatic conditions (years) would face variable moisture and temperature at different phenological stages which may affect photosynthetic machinery significantly. The current study was undertaken with the objective of evaluating and selecting a suitable genotype having efficient physiological functions and adaptability under stress conditions so that it can be recommended for sowing in rainfed regions of Pakistan where there are no sources of supplemental irrigation and where it can be efficiently used in future breeding programs.

Results

Soil moisture

Soil moistures of different depths at anthesis stage during both growing environments (2008-09 and 2009-10) were significantly different from each other. During the first growing season (2008-09), higher volumetric water contents were observed at all depths than for the second growing season (Fig. 1a). Other aspects including total porosity (TP), saturation (SAT) and crop lower limit (CLL) remained almost the same during both environments.

Water requirements of wheat

The water available for the crop was measured by deducting water requirement of the crop from amount of rainfall during a particular decade. The positive values demonstrated surplus water while negative values depicted water deficit (Table 1). Water requirement and crop coefficients (Kc) for wheat were higher up to the 2nd 10 day period of February during both growing seasons. From Table 1, it can be depicted that total water required for wheat was 263.57 and 310.06 mm, whereas, 298.78 and 149.28 mm water was available during 2008-09 and 2009-10, respectively. Fluctuation in temperature was also recorded in both growing seasons (Table 2). Higher temperature was recorded during 2009-10 as compared to the first growing environment (2008-09) which affected the crop's physiological functions and, consequently, its yield.

Net photosynthesis (A_n) (µ mole/m^2/second)

Analysis of variance showed a significant variation for A_n among environments and genotypes (Table 4). The results described by scatterplot (GY= -3726.1649 + 299.258 X) revealed that grain yield increases with photosynthetic rate (Fig. 2a) and a linear and positive correlation of grain yield with net photosynthetic rate was observed. The higher photosynthetic rate during 2008-09 resulted in higher grain yield as compared to the second environment, i.e., 2009-10. Genotypes showed significant differences for physiological attributes during two environments. The maximum photosynthesis was recorded in NARC-2009 (29.88 and 27.08 µ mole/m^2/second in 2008-09 and 2009-10, respectively) with highest grain yield while Wafaq-2001 showed the least photosynthetic activity and minimum yield during both environments (Table 4). Positive correlation coefficient (0.8055) was also noticed between grain yield and photosynthesis that elaborated the dependence of yield on A_n (Table 5).

Stomatal conductance (g_s) and Stomatal resistance (r_s) (mole/m^2/second)

Analysis of variance also reflected significant differences for genotypes under two environments (Table 3) for g_s and r_s. The high g_s was observed during 2008-09 as compared to 2009-10. The scatterplot showed an overall trend of grain yield and gs (Fig. 2b). Increase in yield was observed with increase in g_s depicting a linear relationship to stomatal conductance. The cultivar NARC-2009 showed maximum g_s (0.78 mole/m^2/second) and produced higher yield in both years whereas less conductance was recorded for Wafaq-2001 with least yield (Table 4). Positive correlation (0.8006) was observed between grain yield and g_s. Genotypes showed differential responses towards stomatal resistance. Similarly, stomatal resistance showed a significant relationship with grain yield but was inverse to conductance (Table 3). Resistance of stomata was inversely related to grain yield, hence, increase in resistance caused reduction in yield (Fig. 2e). The genotype NARC-2009 depicted less resistance (0.55 in 2008-09 & 0.33 mole/m^2/second in 2009-10) with higher yield while maximum stomatal resistance was observed in Wafaq-2001 (Table 4). Negative correlation coefficient (-0.2405) between stomatal resistance and grain yield was recorded (Table 5).

Transpiration rate (E) (mole/m^2/second)

Negative correlation was observed between grain yield and transpiration rate. Significant variations were also found for genotypes and environments (Table 3). Results showed that temperature and moisture directly affected E, while E was inversely related to yield. A positive relation, found in scatterplot diagram (Fig. 2c), between grain yield and transpiration described an overall impact of E on grain yield. Increasing transpiration rate led to the yield reduction. The higher transpiration was recorded in Wafaq-2001 with least yield while NARC-2009 and Tatara showed less transpiration and higher yield, even under abiotic stresses during 2009-10 (Table 4). The transpiration rate was negatively correlated (-0.84) with grain yield (Table 5).

Intercellular CO_2 concentration (C_i) (m mol CO_2 mol^{-1} air)

The significant differences for genotypes and environment interactions for CO_2 concentration (Table 3) were observed. Grain yield and intercellular CO_2 concentration showed a direct relationship and an increase in CO_2 resulted in high photosynthesis and reduced stomatal closure that increased grain yield during 2008-09, while opposite trends were observed during 2009-10. Overall, the scatterplot diagram shows a positive and linear relation between yield and CO_2 (Fig. 2d). Among genotypes, maximum CO_2 concentration was recorded in NARC-2009 during both growing years along with higher yield compared to the rest of the genotypes, while less intercellular CO_2, found in Wafaq-2001, produced less grain yield (Table 4). Grain yield and CO_2 concentration were positively and linearly significantly correlated (0.7728) (Table 5).

Discussions

The yield of any crop depends on its photosynthetic efficiency. In C3 cereals, such as wheat, grain filling is sustained by photosynthesis at anthesis (Tambussi et al., 2007), hence, photosynthesis and grain yield showed a direct relationship in this study. Fluctuations in climatic factors like temperature and moisture at critical growth stages (particularly at anthesis) can affect wheat yield to a greater extent. Increase or decrease in temperature and water availability can also reduce the photosynthetic efficiency and, ultimately, wheat productivity (Wang et al., 2008). In the present study, genotypes NARC-2009 and Tatara have shown adaptability characteristics to resist stress conditions. Previous studies on drought resistant cultivars showed that maintenance of photosynthesis was related to drought

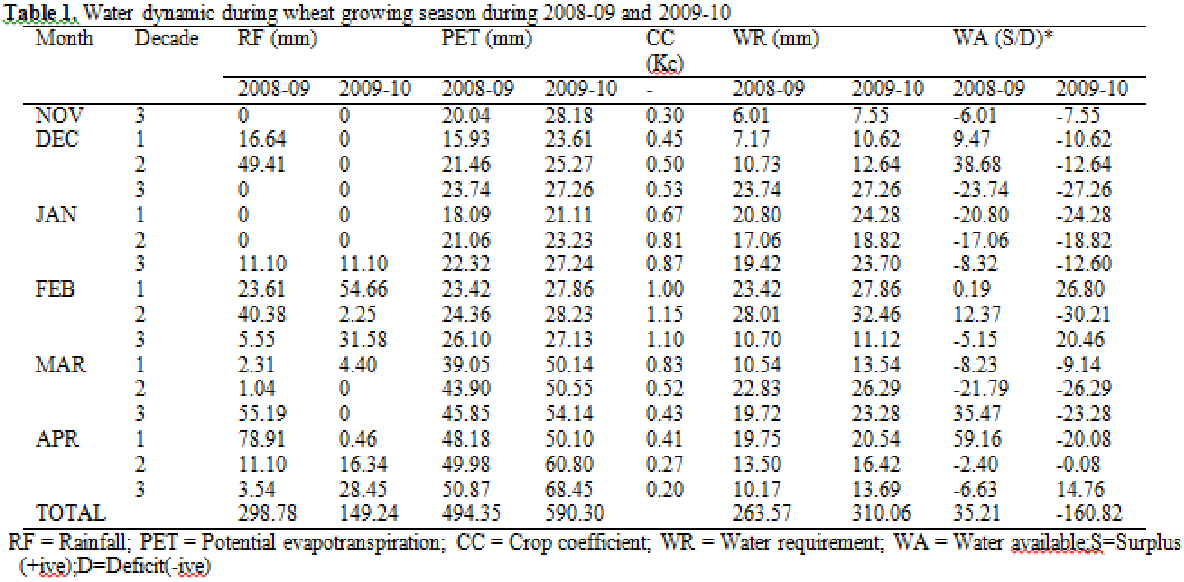

Table 1. Water dynamic during wheat growing season during 2008-09 and 2009-10

Month	Decade	RF (mm)		PET (mm)		CC (Kc)	WR (mm)		WA (S/D)*	
		2008-09	2009-10	2008-09	2009-10	-	2008-09	2009-10	2008-09	2009-10
NOV	3	0	0	20.04	28.18	0.30	6.01	7.55	-6.01	-7.55
DEC	1	16.64	0	15.93	23.61	0.45	7.17	10.62	9.47	-10.62
	2	49.41	0	21.46	25.27	0.50	10.73	12.64	38.68	-12.64
	3	0	0	23.74	27.26	0.53	23.74	27.26	-23.74	-27.26
JAN	1	0	0	18.09	21.11	0.67	20.80	24.28	-20.80	-24.28
	2	0	0	21.06	23.23	0.81	17.06	18.82	-17.06	-18.82
	3	11.10	11.10	22.32	27.24	0.87	19.42	23.70	-8.32	-12.60
FEB	1	23.61	54.66	23.42	27.86	1.00	23.42	27.86	0.19	26.80
	2	40.38	2.25	24.36	28.23	1.15	28.01	32.46	12.37	-30.21
	3	5.55	31.58	26.10	27.13	1.10	10.70	11.12	-5.15	20.46
MAR	1	2.31	4.40	39.05	50.14	0.83	10.54	13.54	-8.23	-9.14
	2	1.04	0	43.90	50.55	0.52	22.83	26.29	-21.79	-26.29
	3	55.19	0	45.85	54.14	0.43	19.72	23.28	35.47	-23.28
APR	1	78.91	0.46	48.18	50.10	0.41	19.75	20.54	59.16	-20.08
	2	11.10	16.34	49.98	60.80	0.27	13.50	16.42	-2.40	-0.08
	3	3.54	28.45	50.87	68.45	0.20	10.17	13.69	-6.63	14.76
TOTAL		298.78	149.24	494.35	590.30		263.57	310.06	35.21	-160.82

RF = Rainfall; PET = Potential evapotranspiration; CC = Crop coefficient; WR = Water requirement; WA = Water available;S=Surplus (+ive);D=Deficit(-ive)

Table 2. Temperature data of study site (Islamabad).

Month	2008-09			2009-10			30 years average mean temperature (°C)
	Temperature (°C)			Temperature (°C)			
	Max.	Min.	Mean	Max.	Min.	Mean	
October	31	12	21±3.42*	32	13	22±4.24*	22±1.09*
November	25	6	15±2.24*	26	7	16±3.06*	17±0.79*
December	20	6	13±2.45*	21	3	12±2.84*	12±1.17*
January	18	2	10±2.47*	20	2	11±2.44*	10±0.89*
February	19	5	12±1.98*	19	7	15±2.94*	13±1.20*
March	24	10	17±2.07*	27	13	20±3.00*	17±1.79*
April	30	15	23±2.19*	33	16	25±2.96*	23±1.61*

*Represents Mean ±SD of each value.

Table 3. Analysis of variance for net CO_2 assimilation rate ($A_{n)}$), stomatal conductance (g_s), transpiration rate (*E*), internal CO_2 C_i, stomatal resistance, r_s and grain yield (GY) of wheat genotypes during two environments.

Source	DF	P (A_n)	P (g_s)	P (E)	P (Ci)	P (r_s)	P (GY)
Environment (E)	1	0.0007***	0.0001***	0.0002***	0.0538*	0.0000***	0.0000***
Genotype (G)	4	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
G × E	4	0.4958^{ns}	0.2639^{ns}	0.8363^{ns}	0.324^{ns}	0.0036***	0.5315^{ns}

DF=Degree of Freedom, P= Probability of significance at 1, 5 & 10 %, respectively, P(A_n) = Probability of Net CO_2 assimilation rate,P(g_s) = Probability of Stomatal conductance, P(E) = Probability of Transpiration rate, P(C_i) = Probability of Internal CO_2, P(r_s) = Probability of Stomatal resistance, P(GY) = Probability of Grain yield, *** = Highly significant at 1%, ** = Significant at 5% and * = Significant at 10%.

resistance rather than remobilization of pre-anthesis assimilates to grain under drought stress (Wang et al., 2011).

Adequate moisture and relatively low temperature during 2008-09 encouraged growth and development, whereas, 2009-10 was a dry and stressed year with relatively higher temperature, affecting physiological processes of the crop. However, few genotypes adopted certain mechanisms to sustain their growth, including reduced leaf area, shorter growth phases and early maturity (Table 6). We found a rapid decline in photosynthesis, limiting the contribution of assimilates to the grain under temperature and moisture stress. The decrease in A_n under stress is due to stomatal closure with reduced CO_2 diffusion and C_i. Thus, stomatal closure is responsible for stress induced reduction in A_n during 2009-10. Stomata also play an important role in physiological processes of plant as water enters into the plant through stomata. Stomatal conductance is the speed of removal of water from plant parts and is indicative of roots extracting soil water under variable soil and climatic conditions. The higher values of g_s, recorded during the first year of the experiment, can be attributed to favourable environmental conditions like availability of adequate moisture and optimum temperature which promoted growth. Increase in temperature and reduction in available moisture led to low stomatal efficiency and, ultimately, reduced yield which can be enhanced by selecting appropriate genotype and sowing time (Ahmed et al., 2010; Medlyn et al., 2001). During 2009-10, less moisture and relatively higher temperature at anthesis caused a reduction in stomatal conductance and photosynthetic efficiency, consequently, resulting in less grain yield, as water requirement of the crop was not fulfilled due to low rainfall. Kimball et al., (2002) concluded that change in climatic variables alters the microclimate of the crop which can cause 33 to 50 %

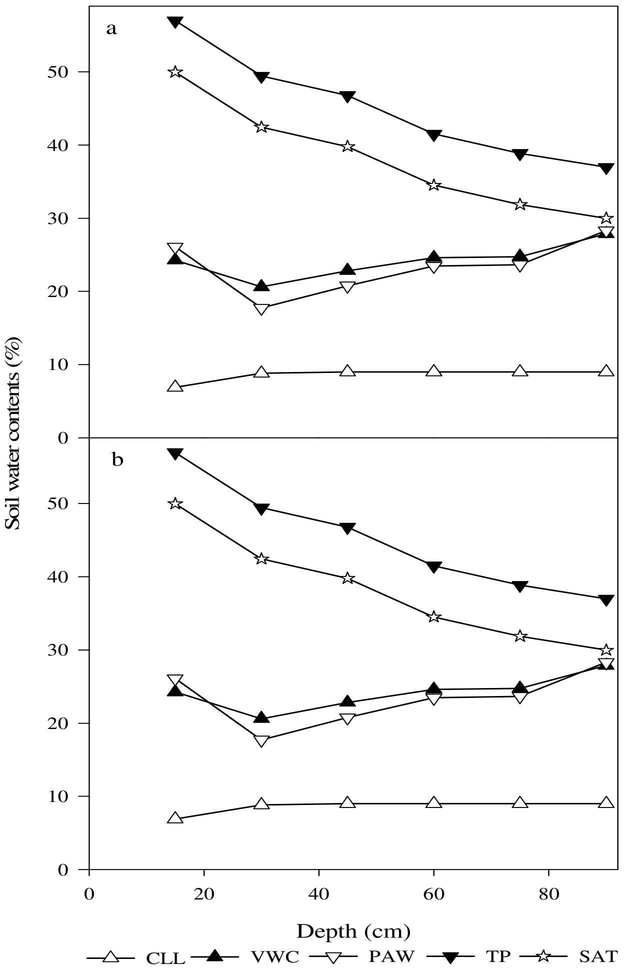

Fig 1. Volumetric soil water contents (%) crop lower limit (CLL), plant available water (PAW), saturation (SAT), volumetric water content (VWC) and total porosity (TP) under different depths at flag leaf stage during 2008-09 (Normal year) (a) and 2009-10 (b).

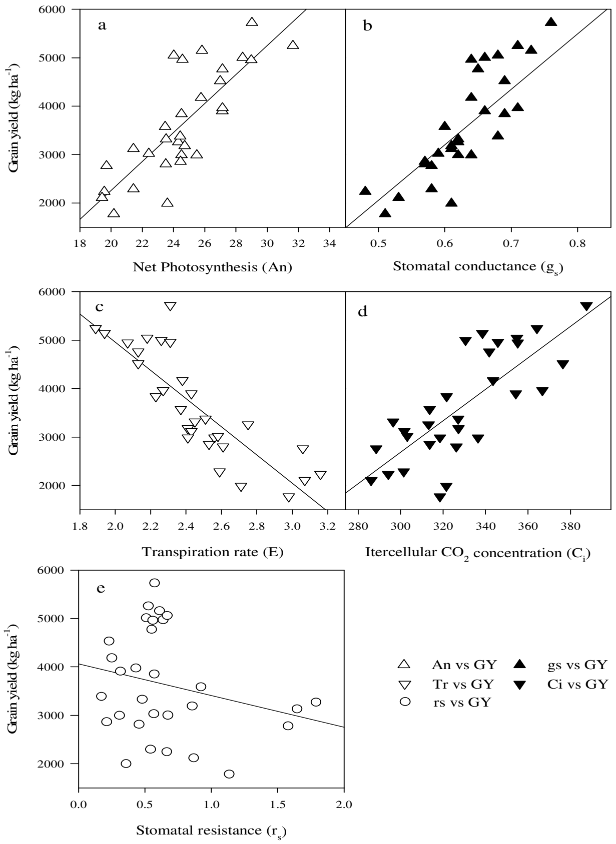

Fig. 2. Scatter plot of grain yield against net photosynthesis (a), stomatal conductance (b), transpiration rate (c), intercellular CO_2 concentration (d) and stomatal resistance (e) for wheat genotypes under two environments 2008-09 and 2009-10.

reduction in conductance, similar to the findings of the present study. However, drought resistance genotypes like NARC-2009 and Tatara have the potential to maintain higher stomatal conductance under stress. Thus, stomatal closure is considered as a primary physiological attribute for crops to cope with stress conditions and is an important trait in stomatal resistance. Fluctuations in climatic variables like temperature and moisture cause changes in stomatal resistance. Results of the present study also describe that low stomatal resistance during 2008-09 was due to adequate moisture availability and optimum temperature during crop growth cycle, whereas, increase in resistance during 2009-10 reduced grain yield. It has been reported that non-stomatal and stomatal factors had significant impacts on photosynthetic rate under severe water stressed conditions(Shangguan et al., 1999). Transpiration is an important process to maintain leaf temperature by providing a cooling effect. Since transpiration is significantly affected by biotic stresses, genotypes having higher transpiration efficiency (the ratio of dry matter to transpiration) can be considered best for stress conditions. In this study, adequate moisture resulted in an optimum transpirational rate during 2008-09 which can be attributed to the presence of less moisture and high temperature. Increase in temperature and reduction in humidity enhances the transpiration rate that led to less water availability for photosynthesis in plant tissues, causing yield reduction during 2009-10. Our results are in agreement with the findings of Li et al. (2003), who conclude that reduced transpiration rate can reduce stomatal conductance, causing increase in CO_2 concentration. However, adaptation of genotypes to sustain their growth under stress conditions, including reduced leaf surface area and developing waxy material on leaf surface, mimic water loss by transpiration. Our findings are in the line with those of Medlyn et al. (2001), who reported that enhancement of carbon dioxide concentration can lead to stomata closure and, ultimately, affect the transpiration and grain yield. Intercellular CO_2 (C_i) regulates many processes including photosynthesis, stomatal activity and transpiration rate in plants. A two times increase in carbon dioxide concentration limits the evapotranspiration rate of agricultural crops (Kang et al., 2002). During 2008-09, higher CO_2 recorded in plant cells boosted yield and, on the other hand, less CO_2 during 2009-10 lowered grain production. Therefore, under drought

Table 4. Means of A_n, g_s, E, C_i, r_s and grain yield for wheat genotypes during two environments.

Environments	Genotypes	A_n	g_s	E	C_i	r_s	GY (kg ha^{-1})
E1 (2008-09)	Chakwal-50	25.83±1.33* bc	0.66±0.08* bc	2.26±0.89* de	332.70±9.16* bc	0.57±0.08* d	4600±1046.05* bc
	Wafaq-2001	21.81±1.21* f	0.60±0.09*de	2.74± 0.69*b	301.20±9.07* d	1.67±0.09* a	3048±1264.06* e
	GA-2002	24.23±1.39* cde	0.61±0.08* cde	2.44±0.74* cd	319.87± 9.02*cd	0.82±0.08* bc	3248±872.54* e
	NR-268	29.88±1.40* a	0.78±0.08* a	2.09±0.84* e	368.97±9.18* a	0.55± 0.05*d	5305±1150.20* a
	Tatara	25.65±1.36* bc	0.68±0.08* b	2.08±0.88* e	345.03±9.20* b	0.61± 0.07*cd	4985± 1044.34*ab
E2 (2009-10)	Chakwal-50	23.46± 1.22*def	0.59±0.77* e	2.52±0.85* bcd	304.47± 7.48*d	0.42±0.07* de	3063± 1025.31*e
	Wafaq-2001	19.72± 1.11*g	0.50±0.08* f	3.07±0.73* a	299.63± 7.34*d	0.89±0.08* b	2038±651.69* f
	GA-2002	22.85± 1.28*ef	0.58±0.07* e	2.63± 0.77* bc	316.47± 7.30* cd	0.45±0.07* de	2357±644.25* f
	NARC-2009	27.08± 1.29*b	0.68±0.78* b	2.27± 0.66*de	365.82± 7.51*a	0.33±0.08* e	4125±1065.23* cd
	Tatara	25.22± 1.27*bcd	0.65±0.78* bcd	2.43± 0.78*cd	335.73± 7.66*bc	0.24±0.08*e	3512± 967.33*de

A_n= Net CO_2 assimilation rate, g_s= Stomatal conductance, *E*= Transpiration rate, C_i= Internal CO_2, r_s= Stomatal resistance, GY= Grain yield, *Represents Mean ±SD of each value, Different alphabets represented significant difference among means using LSD test.

Table 5. Correlation coefficient of A_n, g_s, E, C_i, r_s and GY for wheat genotypes.

	En	G	An	g_s	E	Ci	r_s	GY
En								
G	0							
An	-0.3103	0.4491						
g_s	-0.4162	0.4864	0.8052					
E	0.4157	-0.4488	-0.8292	-0.8023				
Ci	-0.1764	0.6044	0.8332	0.7413	-0.7191			
r_s	-0.4721	-0.3455	-0.4521	-0.2835	0.3966	-0.4456		
GY	-0.5600	0.3908	0.8055	0.8006	-0.8379	0.7728	-0.2405	

En = Environment, G = Genotypes, A_n= Net CO_2 assimilation rate, g_s= Stomatal conductance, *E*= Transpiration rate, C_i= Internal CO_2, r_s= Stomatal resistance, GY= Grain yield.

Table 6. Means of Fresh weight, dry weight, 1000 grain weight and grain yield per plant for wheat genotypes during two environments.

Environments	Genotypes	Fresh weight at Anthesis (Kg ha^{-1})	Dry Weight at Anthesis (Kg ha^{-1})	1000 Grain Weight (g)	GY (Kg ha^{-1})
E1 (2008-09)	Chakwal-50	18805±5011* cd	13156± 4863*d	33.1± 8.09*bcd	2570±1046*b
	Wafaq-2001	17136±5627* e	10396±3445* g	31.4±8.82* cd	1820±1264* e
	GA-2002	18446±4598* d	11258±6676* f	32.2±8.92* bcd	1990±872* d
	NR-268	21879±7066* a	16731±6562* a	37.4±9.50* a	2940±1210* a
	Tatara	21329±7212* a	14160±4965* c	34.6± 9.25*ab	2670±1120* b
E2 (2009-10)	Chakwal-50	17532±5689* e	12079±2725* e	32.2±7.85* bcd	2020±1025* d
	Wafaq-2001	15863±4987* f	9319±1498* h	27.9± 8.99*e	1140±651* g
	GA-2002	17173±5692* e	10181±2416* g	30.4±8.57*de	1450±644* f
	NARC-2009	20606±6521* b	15066± 4969*b	33.7± 9.75*bc	2250±1038* c
	Tatara	19052±6451* c	13083± 4867*d	33.1±9.22* bcd	2070±1012* d

*Represents Mean ±SD of each value, Different alphabets represented significant difference among means using LSD test.

stress, the decreased concentration of C_i in leaves might be due to stomatal activity, resulting in reduced photosynthesis and grain yield. Thus, genotypes that can sustain stress should be recommended for sowing under varying climatic stresses to obtain grain yield on a sustainable basis.

Materials and methods

Study site

The field experiments were conducted at National Agricultural Research Centre (NARC), Islamabad, Pakistan during 2008-09 & 2009-10. Climate of the study area is subtropical with average annual rainfall of more than 1150 mm, having an altitude of 45° above horizon, Latitude 33° 40' North and Longitude 73° 08' East.

USDA soil characteristics

Soil series of the experimental site at Islamabad is Rajar with great groups Ustorthents and soil order is Entisol. The physiochemical characteristics of the study site are presented in Table 7. Soil samples from different layers of 15 cm each were taken till the depth of 90 cm by using tubes for soil moisture at anthesis stage where crop physiological data was collected.

Climatic parameters

Weather data regarding temperature and rainfall were collected from the meteorological station located inside the research area. The potential evapotranspiration, crop water requirement and available moisture were also calculated at ten day intervals to determine water requirement of crop

Table 7. Physiochemical characteristics of soil at Islamabad during 2008-09 and 2009-10.

Determinations (2008-09)	Units	0-15	15-30	30-45	45-60	60-75	75-90
pH	1:1	7.5	7.6	8.3	8.2	8.4	8.4
EC	dSm^{-1}	0.24	0.2	0.21	0.21	0.22	0.21
Nitrogen	%	0.04	0.04	0.03	0.030	0.02	0.02
Nitrate-N	mg Kg^{-1}	7.86	7.28	6.50	6.20	5.24	5.00
AV.P	mg kg^{-1}	3.64	3.39	3.90	3.72	2.72	2.54
K	mg kg^{-1}	160	180	210	220	210	240
Organic Carbon	%	0.91	0.87	0.63	0.6	0.44	0.41
Silt	%	33	33	33	33	33	33
Sand	%	35	35	35	35	35	35
Clay	%	32	33	34	35	35	35
Texture		Loam	Loam	Loam	loam	Loam	Loam
B.Density	gcm^{-3}	1.24	1.42	1.46	1.52	1.59	1.65
SLL	$mmmm^{-1}$	0.07	0.09	0.09	0.09	0.09	0.09
SDUL	$mmmm^{-1}$	0.34	0.24	0.25	0.26	0.23	0.23
Saturated SW	$mmmm^{-1}$	0.48	0.40	0.38	0.36	0.33	0.31
Soil Albedo	0.13						
Determinations (2009-10)	**Units**	**0-15**	**15-30**	**30-45**	**45-60**	**60-75**	**75-90**
pH		7.4	7.5	7.9	8.2	8.4	8.4
EC	dSm^{-1}	0.23	0.2	0.2	0.21	0.22	0.21
Nitrogen	%	0.039	0.037	0.027	0.026	0.019	0.017
Nitrate-N	mg Kg^{-1}	6.4	5.9	5.3	5.0	4.2	4.1
AV.P	mg kg^{-1}	3.1	2.9	3.3	3.2	2.3	2.2
K	mg kg^{-1}	120	135	159	165	158	180
Organic Carbon	%	0.72	0.69	0.50	0.47	0.35	0.32
Silt	%	33	33	33	33	33	33
Sand	%	35	35	35	35	35	35
Clay	%	32	32	32	32	32	32
Texture		loam	Loam	loam	loam	loam	loam
B.Density	gcm^{-3}	1.22	1.40	1.44	1.50	1.57	1.63
SLL	$mmmm^{-1}$	0.07	0.09	0.09	0.09	0.09	0.09
SDUL	$mmmm^{-1}$	0.34	0.24	0.25	0.26	0.23	0.23
Saturated SW	$mmmm^{-1}$	0.46	0.39	0.38	0.36	0.33	0.31
Soil Albedo	0.13						

EC= Electrical conductivity, AV.P = Available phosphorus, B.Density = Bulk density, SLL = Soil lower limit, SDUL = Soil drain upper limit.

during its life cycle, as described by Doorenbos and Pruitt (1977).

Field preparation

A summer fallow field was prepared, before sowing, with disc followed by cultivator and the surface was planked for final seed bed preparation.

Plant material and experimental design

The experimental material comprised of five genotypes *viz*., Chakwal-50, Wafaq-2001, GA-2002, NARC-2009 (NR-268 line in 2008-09) and Tatara. The experiment was sown with hand drill replicated thrice in randomized complete block design (RCBD) in 5 m x 3 m plots with row spacing of 25 cm. Nitrogen and Phosphorus (as Urea & DAP, respectively) were applied at the rate of 100 kg ha^{-1} of N and P at the time of sowing. Sowing was performed on 19th November during both years using 120 kg ha^{-1} seed rate. Weeds were controlled manually, as and when needed.

Physiological attributes

At anthesis stage (Zadok's scale, 1974), flag leaves of all cultivars were used to collect data regarding net photosynthesis (A_n), stomatal conductance (g_s), transpiration rate (E), intercellular CO_2 concentration (C_i) and stomatal resistance (r_s) by infrared gas analyzer (IRGA, LCA-4, ADC, Hoddesdon UK) (Long & Bernacchi, 2003). The instruments internal gas flow rate was 250 $\mu mols^{-1}$, with ambient gas pressure (1000 Kpa) and RH (65%) while leaf area was $6.25cm^2$ with 1300 $\mu molm^{-2}s^{-1}$ PAR and 28.4^oC temperature. The 100 grain weight (g), yield per plant (g) and grain yield (kg ha^{-1}) were recorded after harvesting at maturity during both growing seasons.

Statistical analysis of data

The data collected were subjected to analysis of variance (ANOVA) following Steel et al., (1997). Regressions between various parameters were drawn using STATISTICA 9 (Statsoft, Inc. 2010).

Conclusion

Increase in temperature and reduction in moisture affected photosynthetic rate, stomatal conductance, transpiration rate, carbon dioxide concentration and stomatal resistance, hence, final yield. However, stable behaviour/performance of a particular genotype under different climatic conditions demonstrated that it has the potential to adapt itself under varying stress conditions. Thus, it is suggested that farmers should select a genotype having better yield stability and enhanced efficiency of physiological attributes.

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