Agro-physiological performance of wheat genotypes under normal moisture and drought conditions

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Abstract

Scarcity of water for irrigation is an alarming issue of Pakistan and the problem is being magnified rapidly with the passage of time. Shortage of water is thus, a limiting factor in increasing per unit area wheat (*Triticum aestivum L.*) yield that is staple food of most of the people. Eventually, the gap between production and consumption is widening day by day and Pakistan is now suffering from food crisis. Hence, to find out the wheat genotypes having comparatively more drought tolerance, a field experiment was conducted during 2005-06 and 2006-07 on 497 wheat genotypes, which were subjected to drought conditions in addition to growing under normal soil moisture conditions. Screening of the genotypes was done on the basis of some Physiological and Agronomic attributes such as, Stomatal Conductance, Net Photosynthetic Rate, Transpiration Rate, Photo Active Radiation, Plant Height, Productive Tillers, Grains per Spike, 1000-Grain Weight, Biological Yield, Grain Yield per Plant and Harvest Index. Drought stress adversely affected all these parameters, which expressed significant decrease in their values except harvest index, which was significantly increased irrespective of genotypes during both the years of study. The genotypes under study, on the basis of above physiological and agronomic attributes were grouped into high yielding drought sensitive, high yielding drought tolerant, low yielding drought tolerant and low yielding drought sensitive groups, employing cluster analysis. Thus, out of 497 sixteen wheat genotypes were ranked as high yielding drought tolerant which can be successfully grown under drought conditions without substantial decrease in grain yield.

Keywords: drought; genotypes; physiological attributes; *Triticum aestivum L.*; cluster analysis; drought tolerance, grain yeld, Pakistan

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Introduction

Scarcity of irrigation water is a severe threat to the sustainability of crop production in Pakistan despite of having world's largest alluvial canal irrigation system. For silting up has curtailed storage capacity of dams. One of the major reasons is wastage of huge amount of water in the irrigation process. About 142 Million-Acre Feet (MAF) of river water is diverted to canals of which 52% goes waste by seepage, evaporation or drainage (Anonymous, 2003a). In rain-fed areas too, shortage of moisture supply is

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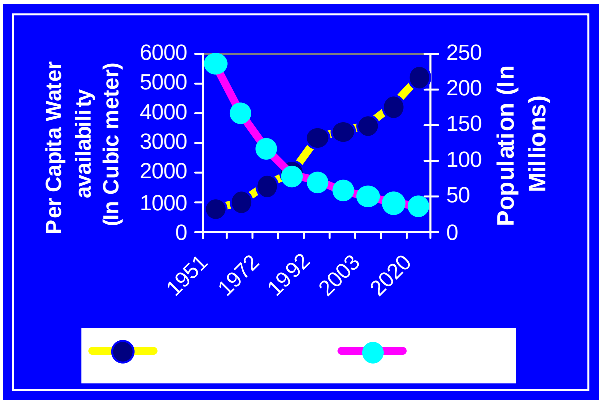

Fig. I. Per capita water availability vs population growth in Pakistan

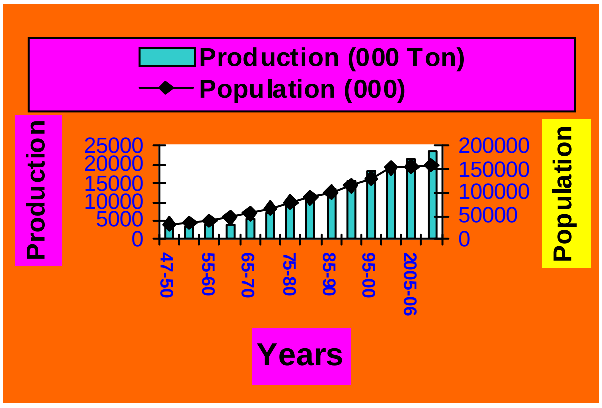

Fig. II. Wheat production and population growth in Pakistan

one of major factors limiting wheat production like other crops (Fig. I).

About one forth of total cultivated land of Pakistan is drought prone and one third of the total wheat acreages depends entirely on the scarce, erratic and unevenly distributed rainfall (Khan, 2003). Inadequate soil moisture is, thus a stumbling block in raising wheat grain yield in rain fed as well as in irrigated areas of Pakistan; use of tube well water is also not feasible being injurious for soil health (Khan, 2003). The issue of shortage of water is aggravated with the passage of time as shortage of water during the year 2000 was 40.30 MAF, which is apprehended to jump up to 107.80 MAF during the year 2013 (Anonymous, 2003a).

Wheat (*Triticum aestivum L.*) is staple food of majority of populace of Pakistan but its per acre yield is very low in comparison with other countries of the world (Fig. II) because of several reasons including shortage of water supply for irrigation. Therefore, a big portion of national economy has to be spent on the import of wheat to cope with the ever increasing food and feed needs of the country (Anonymous, 2003b) due to population multiplication in arithmetic fashion (Fig. II).

Drought stress is characterized by reduction of water content, diminished leaf water potential, turgor loss, closure of stomata, decrease in cell enlargement and growth (Jaleel et al., 2007). Severe water stress may result in the arrest of photosynthesis, disturbance of metabolism and finally the death of plants (Jaleel et al., 2008). Plant growth is accomplished through cell division, cell enlargement and differentiation, which involve genetic, physiological, ecological and morphological events; sensitive to drought (Taiz and Zeiger, 2006). Water stress reduces plant growth and manifests several morphological, physiological and biochemical alterations leading to massive loss in yield (Farooq et al., 2009). Water shortage at critical growth stages such as crown root initiation, tillering, booting, anthesis and grain filling has deleterious effects on plant growth, development and economic yield of wheat (Khan, 2003; Manikavelu et al., 2006).

Wheat grain yield and yield components such as productive tillers, grains per spike, kernel weight, biological yield and harvest index are the attributes which are adversely affected by soil moisture stress (Akram, 2003; Edward and Wright, 2008; Farooq et al., 2009). The first response of virtually all plants to acute water shortage is the closure of stomata to prevent transpirational water loss (Manisfield and Atinson, 1990), which may result in response to decrease in leaf turgor and water potential (Cornic and Massacci, 1996; Yokota et al., 2002). Water deficit hampers photosynthesis due to reduced synthesis of chlorophyll pigments resulting in declined light harvesting reaction (Jaleel et al., 2009). The other causes of reduction in photosynthetic rate are decrease in leaf expansion, impaired photosynthetic machinery, reduced influx of CO_2 due to low stomatal conductance and premature leaf senescence (Wahid and Rasool, 2005). Water stress lowers water potential, osmotic potential and pressure potential of wheat leaves (Akram, 2003). Water stress mostly reduces leaf growth and in turn leaf area in many plant species (Wullschleger et al., 2005; Farooq et al., 2009).

Tolerance to abiotic stresses is very complex due to intricate interactions between stress factors and various molecular, biochemical, agronomic and physiological phenomenon affecting plant growth and development (Razmjoo et al., 2008). Conventional breeding strategies are based on empirical selection for yield which are far from being optimal without understanding of a physiological and molecular basis which may help target the key traits that limit yield (Cattivelli et al., 2008). Thus, screening and selection of genotypes for drought prone conditions on the basis of physiological traits is indispensable in addition to agronomic attributes (Kirigwi et al., 2007; Venuprasad et al., 2007). Drought stress tolerance is seen in almost all plant species but its extent varies from species to species and even within species due to differences in phonological, morphological, biochemical, physiological and molecular adaptive mechanisms (Nakayama et al., 2007).

One of the ways to compensate the losses due to water deficit in yield partially is introduction of genotypes having high range of adaptability, more osmo-regulation efficacy and better photosynthetic efficiency. Hence, in view of the above the study was contemplated to find out the genotypes having better tolerance against water stress.

Materials and Methods

Site description

The experiment was carried out at the Agronomic Research Area, Ayub Agriculture Research Institute, Faisalabad, Pakistan. (31.25 N, 73.09 E and 183m a.s.l.) during the years 2005-06 and 2006-07. Soil of the experimental area was well drained, sandy clay loam with PH 7.9, 0.31 m S cm^{-1} total exchangeable salts and 0.76% organic matter belonging to Lyallpur soil series being aridisol-fine-silty, mixed, hyperthermic Ustalfic, Haplarged in USDA and Haplic Yermosols in FAO classification.

Fig. III. An overview of wheat field

Experimental Details

The Bread wheat germplasm comprising of 497 entries was used along with five checks viz, Bahawal Pur 2000, Bhakhar 2000, Inqlab-91, Pak-81 and Uqab-2000 as experimental material. The experiment was laid out in split plot design with plant size of 0.60 x 2.5 m^2 having three replication. Water regimes were kept in main blocks and wheat genotypes were randomized in sub plots. One main block was given three irrigations at crown root initiation, booting and grain filling in addition to 158.4, 43.1 and 133.9 mm rain fall during 2005-06 and 2006-07, respectively; whereas no irrigation was applied to the other main block.

Crop husbandry

As the experiment was sown after harvesting mung bean, the field was prepared by cultivating twice in addition to disc harrowing once each following by planting (Fig. III). Sowing was done during first week of November each year using dibbler with inter and intra row spacing of 30 cm and 7.5cm, respectively @ two seeds per hole. Two weeks after emergence, thinning was done to maintain single plant per hole. Nitrogen, Phosphorus and Potassium were applied at 150,100 and 50kg ha^{-1} using Urea, diammonium phosphate and sulphate of potash, respectively. All the phosphorus, potash and nitrogen were applied at sowing. Manual hoeing was used as tool for weeds control and all other agronomic practices were kept uniform during the entire growth period.

Measurements

Data of different parameters were recorded from the five guarded plants in the middle of each row. Thus, leaf stomatal conductance was recorded with PP System PMR-5 (EGM-4) Steady State Porometer (SG5-1RT, UK) whereas, net photosynthetic rate, transpiration rate and photoactive radiation were recorded with Infra Red Gas Analyzer (Model C 340, Inc. United Kingdome) from flag leaf area at anthesis stage. Data pertaining to plant height, productive tillers, kernels per spike, 1000- kernel weight, biological yield and grain yield per plant were recorded at maturity.

Statistical analysis

The raw data was complied by taking the means of all the five guarded plants from each replication for different traits in the experiment. The means were subjected to statistical analysis. All statistical parameters, viz., mean standard error, variance and coefficient of variation were analyzed statistically using the software package Systat (Wilkinson et al., 1996). Correlation analysis was performed to determine the relationships between physiological, morphological and agronomic traits under drought and moisture stress conditions in accordance with Johnson et al., (1955). Among the genotypes broad genetic divergence was calculated by using the non-hierarchical Euclidian cluster analysis (Sachan et al., 2004).

Table 1
Distribution of rainfall, temperature regimes and drought stress during 2005-06

Period	Rainfall (mm)	Temp. °C		Stress duration (days)	Growth Stages
		Min	Max		
Nov.	-	10.2	27.5	30	Germination
Dec.	-	2.3	22.3	31	CRI, Tillering
Jan.	6.8	3.7	19.9	29(2)*	Tillering, Jointing
Feb.	11.7	10.2	26.5	25(3)	Booting, Anthesis
March	24.7	12.7	27	26(5)	Anthesis, Grain Filling
April	-	19	36.2	30	Dough, Maturity
Total	43.1			171(10)	

*Values in parenthesis indicate number of rainy days.

Table 2
Distribution of rainfall, temperature regimes and drought stress during 2006-07

Period	Rainfall (mm)	Temp. °C		Stress duration (days)	Growth Stages
		Min	Max		
Nov.	7.0	11.8	27.4	29(1)*	Germination
Dec.	15.4	7	22.1	29(2)	CRI,Tillering
Jan.	16.8	4.3	18.1	27(4)	Tillering, Jointing
Feb.	43.7	8.1	19.2	20(8)	Booting, Anthesis
March	66.5	14.3	26.6	23(8)	Anthesis, Grain Filling
April	9.0	17.0	34	28(2)	DoughStage, Maturity
Total	158.4			156(25)	

*Values in parenthesis indicate number of rainy days

Results

On the basic of non-hierarchical Euclidian cluster analysis genetic pool of 497 wheat genotypes was grouped into six clusters (Tables 1-3). Cluster I, II, III, IV, V and VI comprised of 16, 32, 124, 103, 108, and 114 genotypes, respectively. Taking into account grain yield per plant under normal soil moisture and per cent yield reduction due to water deficit cluster, cluster I was found to be high yielding and

Table 3
Cluster mean values obtained by K-means Non-Hierarchical clustering for various traits.

Characters	**Clusters**								
		I			II			III	
Genotypes		16			32			124	
Moisture conditions	N	D	% R	N	D	% R	N	D	% R
Photosynthetic rate (µ mole m^{-2} s^{-1})	85.80	78.00	7.23	81.96	49.18	40.00	73.03	60.39	17.31
Transpiration rate (m mole m^{-2} s^{-1})	9.97	6.23	37.51	9.99	5.88	41.14	8.78	5.49	37.47
Stomatal conductance (m mole m^{-2} s^{-1})	24.89	10.74	56.85	22.91	11.29	50.72	21.42	11.67	45.52
Photoactive radiation (m mole m^{-2} s^{-1})	1107	1067	3.61	1096	998	8.94	1071	974	9.06
Plant height (cm)	58.42	46.24	20.85	57.52	41.95	27.07	54.86	38.95	29.00
Productive tillers $plant^{-1}$	6.09	5.68	6.73	5.87	4.98	15.16	5.66	4.85	14.31
Grains $spike^{-1}$	56.20	47.50	15.48	55.81	46.72	16.29	55.57	46.29	16.70
1000-Grain weight (g)	44.09	39.07	11.39	42.97	39.80	7.38	43.02	39.55	8.07
Biological yield (g)	83.33	65.42	21.49	52.38	32.07	38.77	52.08	31.88	38.79
Grain yield $plant^{-1}$ (g)	19.6	16.4	16.33	17.00	9.00	47.05	17.0	9.8	42.35
Harvest index	23.52	25.07	+6.59	32.45	23.68	27.03	32.69	31.25	4.41

Characters	**Clusters**								
	IV	V	VI	IV	V	VI	IV	V	VI
Genotypes	103	108	114	103	108	114	103	108	114
Moisture conditions	N	D	% R	N	D	% R	N	D	% R
Photosynthetic rate (µ mole m^{-2} s^{-1})	62.19	51.12	17.80	62.19	51.12	17.80	62.19	51.12	17.80
Transpiration rate (m mole m^{-2} s^{-1})	7.57	4.95	34.61	7.57	4.95	34.61	7.57	4.95	34.61
Stomatal conductance (m mole m^{-2} s^{-1})	20.02	10.93	45.41	20.02	10.93	45.41	20.02	10.93	45.41
Photoactive radiation (m mole m^{-2} s^{-1})	986	821	16.73	986	821	16.73	986	821	16.73
Plant height (cm)	56.75	41.35	27.14	56.75	41.35	27.14	56.75	41.35	27.14
Productive tillers $plant^{-1}$	5.87	5.26	10.39	5.87	5.26	10.39	5.87	5.26	10.39
Grains $spike^{-1}$	52.48	41.39	21.13	52.48	41.39	21.13	52.48	41.39	21.13
1000-Grain weight (g)	42.93	39.83	7.22	42.93	39.83	7.22	42.93	39.83	7.22
Biological yield (g)	51.99	30.62	41.10	51.99	30.62	41.10	51.99	30.62	41.10
Grain yield $plant^{-1}$ (g)	16.7	10.8	35.33	16.7	10.8	35.33	16.7	10.8	35.33
Harvest index	32.69	35.48	+8.53	32.69	35.48	+8.53	32.69	35.48	+8.53

*Normal Moisture, ** Drought, *** Reduction, + Increase

drought resistant. Thus, the highest grain yield of 19.60 gram per plant and the minimum reduction of 16.33 present was noted in cluster I. Similarly, genotypes of cluster I exhibited significantly more values for photosynthesis rate of 85.80 (µ mole m^{-2} s^{-1}) transpiration rate of 9.97 (m mole m^{-2} s^{-1}), stomatal conductance of 24.89 (m mole m^{-2} s^{-1}) photo active radiation (1107 m mole m^{-2} s^{-1}), plant height (58.42 cm), productive tillers per plant (6.09), grains per spike, 1000 grain weight of 44.09 g and biological yield of 83.33 gram per plant under normal soil moisture supply; whereas, redaction in values of these parameters was the minimum under drought stress conditions.

A perusal of data (Table 4) predicted that drought stress adversely affected all physiological, morphological and agronomic attributes in all the wheat genotypes. However genotypes showed varied response under normal soil moisture as well as drought stress conditions. Eventually, V1, V2 and V3 expressed maximum grain yield of 22.42, 22.35, and 21.56 gram per plant under normal moisture supply, respectively. These genotypes were followed by V4, V5, V6, V7 and V11 with per plant grain yield of 19.28, 19.70, 18.85, 18.59 and 18.89 gram under normal moisture conditions. All these genotypes under moisture stress too, performed better with less reduction in grain yield. Similarly, the highest values of photosynthesis, transpiration, stomatal conductance and photoactive radiation were observed in V1, V2 and V3 under normal moisture and drought stress conditions. In the same manner these three genotypes produced more number of productive tillers, higher 1000-grain weight, more biological yield and better harvest index with lesser reduction in these attributes under drought stress conditions.

Correlation analysis of the data (Fig. IV) predicted that all the physiological, morphological, and agronomic parameters have strong and positive correlation with grain yield as well as with each other irrespective of moisture conditions.

Table 4
Mean values of different attributes of high yielding drought tolerant Genotypes (Average of 2005-06 and 2006-07).

Genotypes	SNI/PBW 65/3/KAUZ*2/TRAP //KAUZ (V_1)		CONDOR'S'/ANA 75//CONDOR'S'V-97088 (V_2)		HD 2236//SA.42/HARRIER' S' V-97088 (V_3)		PB81//F3.71/TRM/3/B ULBUL//F3.71/TRM=V 00055 (V_4)	
Attributes	N	D	N	D	N	D	N	D
Photosynthetic rate (µ mole m^{-2} s^{-1})	65	60	62	57	59	53	60	56
Transpiration rate (m mole m^{-2} s^{-1})	9.17	5.39	9.97	6.85	9.91	7.85	8.83	5.98
Stomatal conductance (m mole m^{-2} s^{-1})	22.41	10.94	22.91	11.29	21.46	10.63	20.30	10.17
Photoactive radiation (m mole m^{-2} s^{-1})	728	662	785	645	751	683	950	864
Plant height (cm)	60.42	53.45	61.72	52.85	56.08	48.95	51.84	43.49
Productive tillers plant^{-1}	5.67	5.13	5.33	4.98	5.67	5.34	5.75	5.14
Grains spike^{-1}	53.44	49.35	54.65	50.12	54.46	48.95	55.12	49.75
1000-Grain weight (g)	45.10	39.25	45.23	39.64	42.79	39.75	46.54	42.86
Biological yield (g)	45.76	40.65	46.45	48.75	47.95	41.43	45.67	45.10
Grain yield plant^{-1} (g)	22.42	18.69	22.35	19.82	21.56	19.64	19.28	17.54
Harvest index	48.99	45.98	48.12	40.66	44.96	47.41	42.21	38.89

Genotypes	PB81L/F3.71/TRM/3 /BULBUL/F3.71/TR M=V-00127 (V_5)		WEEBILL-1 (V_6)		LLR38 (V_7)		CROC_1/AE.SQ.(205)// KAUZ/3/CASIA (V_8)	
Attributes	N	D	N	D	N	D	N	D
Photosynthetic rate (µ mole m^{-2} s^{-1})	56	50	47	40	53	46	58	52
Transpiration rate (m mole m^{-2} s^{-1})	8.72	5.84	8.69	5.79	7.56	5.72	7.05	4.70
Stomatal conductance (m mole m^{-2} s^{-1})	21.42	11.67	24.89	10.74	19.55	11.72	19.42	10.67
Photoactive radiation (m mole m^{-2} s^{-1})	840	764	869	790	863	785	929	845
Plant height (cm)	58.25	47.60	58.87	52.93	54.39	45.65	58.32	51.07
Productive tillers plant^{-1}	6.43	5.95	6.67	6.45	6.50	6.05	5.67	5.12
Grains spike^{-1}	54.98	51.05	53.56	50.76	53.68	49.04	54.15	48.95
1000-Grain weight (g)	45.84	41.30	44.25	40.95	44.29	40.65	43.96	39.74
Biological yield (g)	42.86	44.25	40.75	42.91	41.63	43.45	48.19	41.63
Grain yield plant^{-1} (g)	19.70	17.92	18.85	16.27	18.59	16.27	17.83	15.54
Harvest index	45.96	40.49	46.25	37.91	44.65	37.44	36.99	37.33

Table 4 (continued)
Mean values of different attributes of high yielding drought tolerant Genotypes (Average of 2005-06 and 2006-07).

Genotypes	**CHEN/AE.SQ(TAUS)// BCN/3/VEE#7/… (V_9)**		**PVN//CAR422/ANA/5 / BOW/CROW//BUC/ PVN/3/YR/4/… (V_{10})**		**WATAN/2*ERA (V_{11})**		**OPATA//SORA/AE.SQ. (323) (V_{12})**	
Attributes	N	D	N	D	N	D	N	D
Photosynthetic rate (μ mole m^{-2} s^{-1})	52	46	49	43	57	51	48	42
Transpiration rate (m mole m^{-2} s^{-1})	7.86	5.75	6.60	4.49	6.68	5.02	8.31	6.54
Stomatal conductance (m mole m^{-2} s^{-1})	17.46	11.58	19.12	10.28	16.71	12.37	17.73	12.55
Photoactive radiation (m mole m^{-2} s^{-1})	992	945	999	909	1071	975	1079	984
Plant height (cm)	57.94	49.01	59.36	54.65	57.66	48.71	59.24	48.57
Productive tillers $plant^{-1}$	6.34	5.95	5.67	5.12	6.77	6.23	6.85	6.25
Grains $spike^{-1}$	54.14	51.25	55.12	52.27	54.76	51.82	55.13	49.87
1000-Grain weight (g)	44.09	41.20	43.50	40.05	42.79	39.68	45.06	40.95
Biological yield (g)	40.11	44.29	48.19	42.75	46.34	41.96	44.75	43.15
Grain yield $plant^{-1}$ (g)	17.77	15.56	17.39	14.95	18.89	16.79	16.33	15.03
Harvest index	44.30	35.13	36.08	34.97	40.76	40.01	36.49	34.83

Genotypes	**PFAU/WEAVER** (V_{13})		LU26/6/LIB64-8-15// INIA/4/ NIA/3/ CNO.// SON64/KL/...(V_{14})		**WL711/CROW'S'/3/KV Z/CNO//CHR/ONE 755** (V_{15})		**CMH81.38/2*KAUZ//A TTILA** (V_{16})	
Attributes	N	D	N	D	N	D	N	D
Photosynthetic rate (μ mole m^{-2} s^{-1})	59	52	57	49	55	50	58	52
Transpiration rate (m mole m^{-2} s^{-1})	8.43	6.52	8.74	5.97	6.86	5.43	9.17	6.39
Stomatal conductance (m mole m^{-2} s^{-1})	16.96	12.76	20.49	11.20	19.46	11.15	20.15	14.25
Photoactive radiation (m mole m^{-2} s^{-1})	1095	996	1034	958	1054	958	1043	933
Plant height (cm)	58.16	48.53	61.14	55.39	56.73	49.17	57.25	46.95
Productive tillers $plant^{-1}$	6.67	6.33	5.85	5.12	6.48	6.05	5.97	5.36
Grains $spike^{-1}$	54.63	49.96	55.09	48.75	53.59	48.98	55.32	49.62
1000-Grain weight (g)	46.71	41.78	45.65	40.79	44.06	39.50	43.75	40.06
Biological yield (g)	46.57	45.32	43.08	42.12	39.95	39.89	38.26	41.73
Grain yield $plant^{-1}$ (g)	16.59	14.98	16.55	14.28	16.57	13.27	16.63	14.80
Harvest index	35.62	33.05	38.42	33.90	41.48	33.27	43.46	35.47

Discussion

Moisture stress affected all physiological morphological and agronomic characters of all wheat genotypes. However, among 497 wheat genotypes a cluster of 16 was found to be high yielding and drought tolerant predicting less adverse effect of moisture stress on various parameters. Reduction in stomatal conductance resulted in decreased rate of transpiration and photosynthesis, as closure of stomata under water stress attributed to decrease in transpiration. Similarly, CO_2 in flux was hindered due to stomatal closure resulting in reduced photosynthetic rate. Adverse effect of water stress on stomata oscillation has also been reported by Jaleel et al., (2007) whereas reduction in rates of transpiration and photoactive radiation due to stomatal closure under water stress by Wahid and Rasool (2005) and Jaleel et al., (2009). Water stress reduced plant growth resulting in adverse effect on plant height and number of productive tillers due to hampered cell division and cell elongation. The view point is in agreement with that of Taiz and Zieger (2006). Water stress impaired grain filling due to loss in portioning of assimilates and supply of photosynthates resulted in decreased 1000-grain weight and ultimately grain yield per plant. The results are in harmony with those of Farooq et al., (2009).

Wheat genotypes constituting cluster-1 showed comparatively more drought tolerance due to conducive interaction between various morphological, physiological and agronomic attributes. The same viewpoint has also been reported by Razmjoo et al., (2008) and Kirigwi (2007).

In conclusion, sixteen genotypes out of 497 mentioned in Table 4 can be successfully grown under drought stress conditions without much sacrificing grain yield. Thus, screening of crop genotypes for drought tolerance on the basis of physiological traits may be more fruitful and may have long lasting effect as a consequence of breeding and evolution of new genotypes.

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