

Full Length Research Paper

Resilience of physiological attributes of wheat (*Triticum aestivum* L.) to abiotic stresses

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Water stress and high temperature variability are the major constraints for wheat crop productivity and food security in the context of climate change. Impact of high temperature and water stress at anthesis stage of spring wheat was studied through field experiments conducted during 2008 to 2009 and 2009 to 2010. Five wheat varieties of diverse origin namely Tatar, National Agricultural Research Centre (NARC)-2009, Sehar-2006, SKD-1 and F-Sarhad were sown in randomized complete block design (RCBD) replicated four times. Physiological parameters that is, net photosynthesis (A_n), transpiration rate (E), SPAD chlorophyll contents and prolines were recorded at anthesis stage. The results indicated reduction of A_n and increased E due to high temperature and moisture stresses. Among genotypes, maximum photosynthetic rate was recorded for Tatar (30.52 μ mole/m²/s) followed by NARC-2009. The E recorded maximum in Sehar-2006 (2.80 mole/m²/s) which had low photosynthetic activity whereas minimum E observed in Tatar (2.27 μ mole/m²/s) followed by NARC-2009. Maximum SPAD value observed in Tatar (53.17) followed by NARC-2009 (49.00) where as Sehar-2006 (37.17) depicted less chlorophyll contents and ultimately reduced photosynthesis and productivity. The highest proline contents were recorded in Tatar (59.69 μ g g⁻¹) followed by NARC-2009 (55.05 μ g g⁻¹) as compared to SKD-1 (46.27 μ g g⁻¹) and F-Sarhad (50.58) which might be due to genetic potential and physiological adaptability of Tatar cultivars against stress conditions. Water stress and high temperature at anthesis led to reduction in photosynthesis resulting reduced biomass and limited yield. Therefore, genotypes having better physiological performance under biotic stresses need to be considered for cultivation under changing environment. Since Tatar performed best in our study, it is recommended for cultivation under high temperature and moisture stresses. The values of all physiological attributes (A_n and E) were higher during first year (2008 to 2009) as compared to second year (2009 to 2010) which was due to relatively high temperature and low moisture availability during the second year.

Key words: Temperature, water stress, photosynthesis, transpiration, proline, SPAD chlorophyll, anthesis, wheat.

INTRODUCTION

Resilience is the ability of a system to show stability against climatic abiotic stresses like temperature and water. Resilience of crop is the opposite of vulnerability

where a crop develops the capacity to adapt in the face of environmental stresses and disturbances. The crops having flexibility in their biodynamism from emergence till maturity are considered to be more resilient to particular systems. Abiotic stresses like temperature and water due to extreme climate vulnerability threatens Pakistan's food production systems, thus, life of people will be affected. Since, whole of the cropping system of the rainfed area is dependent upon rainfall; therefore, building of resilient

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Abbreviations: A_n , Net photosynthesis; E, transpiration rate; NARC, National Agricultural Research Centre.

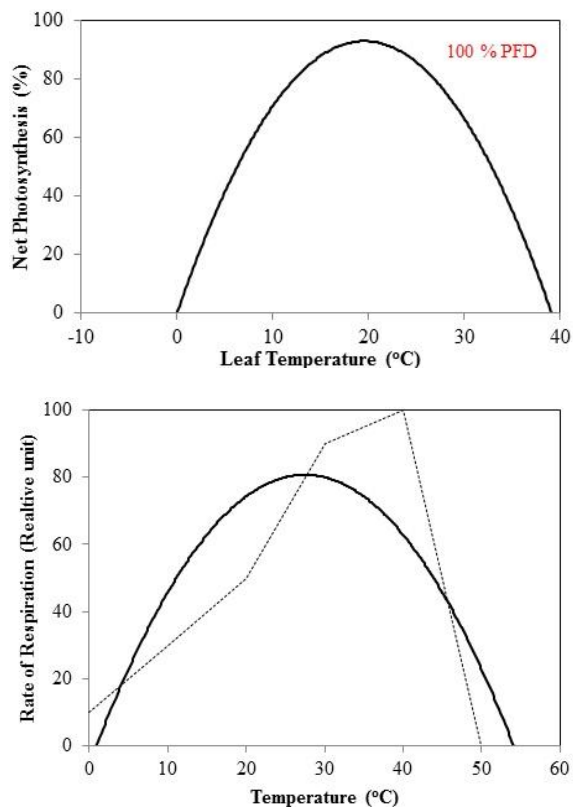


Figure 1. The response of net photosynthesis and rate of transpiration to temperature.

system is need of time for the rainfed areas of Pakistan. High variability in the rainfall and increased temperature has been observed in rainfed areas in recent decade. Floods, drought, terminal heat stress and frost were the main climatic events of the decade affecting wheat physiological attributes and production in the rainfed areas.

Water plays a crucial role in agriculture and future food security. Water crisis has become a major threat for food security and agriculture due to continuous increase in temperature, change in rainfalls and huge consumption of water for non-agricultural purposes and it has enhanced irrigation water demand (Fedoroff et al., 2010). Precipitation pattern has been changed due to global warming. Water resources might be pressurised through droughts and floods which were extreme events of change in precipitation pattern ultimately limit the agricultural yield (Yang et al., 2009). Rosenzweig et al. (2004) reported that future water resources availability for agricultural use might be adversely affected by climatic variation on global scale. They also concluded that change in hydrological cycle and increasing competition among agricultural and non-agricultural water users may affect the supply and demand of water availability. Hanjra et al. (2009) commented that agricultural productivity and

food security might be affected by water insufficiency.

Stabilization of food and crop yield could be enhanced by using genotypes having low water demand and optimum physiological response under water stress. Physiological parameters of crop may greatly be dropped by drought which is major climatic hazard all over the world causing significant loss in wheat yield. Kilic and Yagbasanlar (2010) conducted an experiment to evaluate appropriate wheat genotypes under moisture stress conditions and revealed that yield reduced significantly under water stress except some cultivars which performed well under stress conditions. The criteria for an appropriate genotypes selection like improved physiological attributes, early flowering, long grain filling period, late maturity, greater number of seeds per spike, high spike weight and reduced spike length needs to be considered to get more yield under changing climate and water stress. Similarly, Rashid et al. (2003) concluded that mean yield, average productivity under stress and non-stress conditions and relative yield performance might be used as selection criteria under drought stressed and favourable environmental conditions for optimum yield.

Metabolism [net photosynthesis (A_n) and transpiration rate (E)] in plants is dependent upon temperature since they are poikilothermic and changes body temperature according to external environmental conditions. Therefore, they have to bear external harsh environmental conditions and needs to develop resistance mechanism for acclimatization under abiotic stresses. The response of A_n and E over wide range of temperature revealed that both differ significantly. Since photosynthetic response is sum of two opposite processes that is carboxylation (absorption of CO_2 by RUBISCO; Ribulose biphosphate carboxylase) which is directly related with temperature while second includes two type of carbondioxide release mechanism which includes dark respiration and photorespiration. The balance between carbondioxide fixation and loss is important but with the rise in temperature the equilibrium shifts more toward loss resulting to decline affinity of RUBISCO to carbondioxide. Similarly, solubility of RUBISCO in water also decreases which led to increased oxygen and processes of photorespiration. The graphical response of temperature to A_n resulted to a bell shaped curve (Figure 1). Meanwhile, dark respiration increases with temperature resulted to heat injuries (Larcher, 2003, 2005).

Rate of development of crops are dependent upon temperature but not critical ontogenic phases like leaf senescence, breaking of bud dormancy and flowering which are photoperiodic responses. The speed at which crop passes through its phenological stages, depend upon temperature. The increased temperature might lead to early completion of phenological stages and it may shorten the grain filling period (Wheeler et al., 1996). Similarly, temperature may serve as a signal to activate or deactivate the biological clock of the crops. Water

which is required for the process of photosynthesis is limiting factor and has significant contribution to all physiological processes in plants. The effective use of water available to the crop by rainfall is an important water saving technique and it can be measured by water use efficiency (WUE) which is basic indicator of evaluation of water saving techniques. WUE can be expressed physiologically and hydrologically. However, in the hydrological point of view, it is ratio of volume of water used productively as evapotranspiration and amount of water available as rainfall, irrigation and plant available water. Physiologically, WUE can be defined as ratio between carboxylation (A_n) and transpiration. The productivity of wheat crop has strong relationship with temperature as it accelerates the crop development resulting to earlier maturity. Similarly, higher temperature affects many of physiological processes linked with photosynthesis. The principal objective of present study were: (1) to study the genetic difference in physiological attributes of wheat genotypes under abiotic stresses (2) to observe whether physiological attributes interacts with high temperature and low moisture; (3) and to compare the physiological attributes with agronomic parameters.

MATERIALS AND METHODS

Study site

The present study was conducted at Islamabad with annual rainfall of more than 1150 mm and lies between latitude and longitude of 33° 40' North and longitude 73° 08' East. The field experiment were conducted over two extreme climatic conditions that was 2008 to 2009 considered as water surplus year and designated as W^+ while 2009 to 2010 was depicted as stress year and represented as W^- . Similarly, temperature during 2008 to 2009 remained optimum at critical growth stages like three leaf, tillering and anthesis narrated as normal temperature year. However, during 2009 to 2010, there was significant rise in temperature resulted to high temperature stress. Therefore, 2008 to 2009 and 2009 to 2010 was considered as variable climatic year in this study.

Field preparation and sowing time

Summer fallow field was prepared with disc followed by cultivator. Finally, the planker was used to make final seed bed preparation. The sowing time was mid November during both growing year.

Climatic parameters

The climatic variables like minimum and maximum temperature, rainfall and solar radiation prevailed during 2008 to 2009 and 2009 to 2010 (Figures 2 and 3).

Plant material and experimental design

Five wheat varieties of diverse origin namely Tatara, NARC-2009, Sehar-2006, SKD-1 and F-Sarhad were sown with hand drill replicated four times in randomized complete block design (RCBD) in 5 × 3 m plots with row spacing of 25 cm. Nitrogen (N) and phosphorus (P) [as urea and diammonium phosphate (DAP),

respectively] were applied at the rate of 100 kg ha⁻¹ of N and P at the time of sowing.

Physiological attributes

The infrared gas analyser (IRGA, LCA-4, ADC, Hoddesdon UK) (Long and Bernacchi, 2003) were used to measures physiological attributes like A_n and E at anthesis with internal gas flow rate of 250 $\mu\text{mol s}^{-1}$, ambient gas pressure (1000 kpa) and RH (65%) while leaf area was 6.25 cm² with 1300 $\mu\text{mol m}^{-2}\text{s}^{-1}$ PAR and 28.4°C temperature. The grain yield (kg ha⁻¹) was recorded after harvesting at maturity during both growing seasons. Chlorophyll content was measured by chlorophyll meter by taking three readings and averaged them at anthesis stage. Similarly, fresh leaf tissues (0.5 g) taken from plants at anthesis stage from each plot were homogenized in 10 ml of 3% sulfosalicyclic acid and then filtered. Proline was estimated spectrophotometrically following the ninhydrin method (Bates et al., 1973).

Statistical analysis

Analysis of variance (ANOVA) was performed to test the differences between means of various parameters for five wheat genotypes at Islamabad for the year 2008 to 2010 wheat growing seasons. Regression between various physiological and yield parameters were drawn using STATISTICA 9 (Statsoft, Inc. 2010).

RESULTS AND DISCUSSION

Photosynthesis (A_n , $\mu\text{mole/m}^2/\text{s}$)

Photosynthesis is a determinant factor for crop growth and development as maximum photosynthesis contributes toward more yield and production. Results demonstrated significant variation for photosynthetic efficiency for various genotypes. Genotypes from diverse climatic regions behaved differently for photosynthetic efficiency. Tatara performed well over all other genotypes for photosynthesis (30.52 $\mu\text{mole/m}^2/\text{s}$) followed by NARC-2009. Minimum photosynthesis observed in Sehar-2006 (18.13 $\mu\text{mole/m}^2/\text{s}$) which ultimately led to reduced yield (Table 1). Temperature was very high and less water available during 2009 to 2010 at critical growth stages which led to limited photosynthetic efficiency. Tatara genotype has some adaptability characteristics which promoted physiological attributes and ultimately better production. Our results were in the line with the findings of Ahmed et al. (2010) who reported significant impact of climatic variation upon photosynthetic efficiency of wheat crop. Anthesis stage is crucial stage in crop growth and development as crop produces maximum photosynthate using all available resources and it can only be achieved if suitable genotype sown at optimum time. Increased temperature and reduction in moisture promote photosynthetic efficiency upto an optimum (Wang et al., 2008). Scatterplot diagram showed positive relationship between photosynthetic rate and grain yield (Figure 4) which depicted that more photosynthesis led to maximum accumulation of photoassimilate from source to sink and

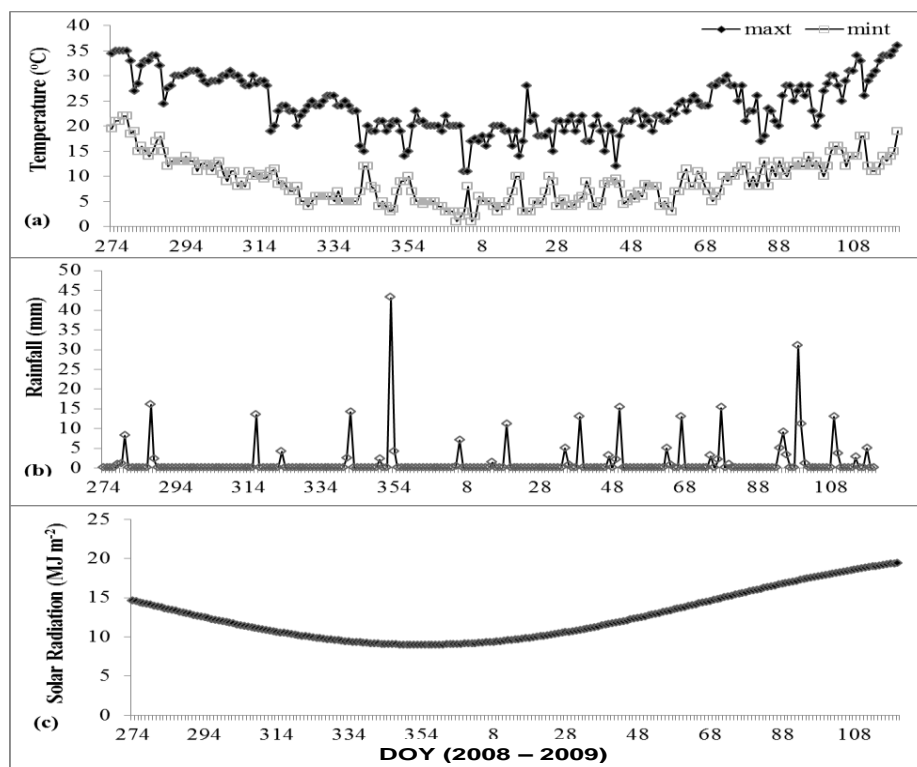


Figure 2. Climatic conditions throughout the experiment during 2008 to 2009 at Islamabad: (a), Maximum (closed symbols) and minimum (open symbols) temperature; (b), rainfall (mm); (c), solar radiation.

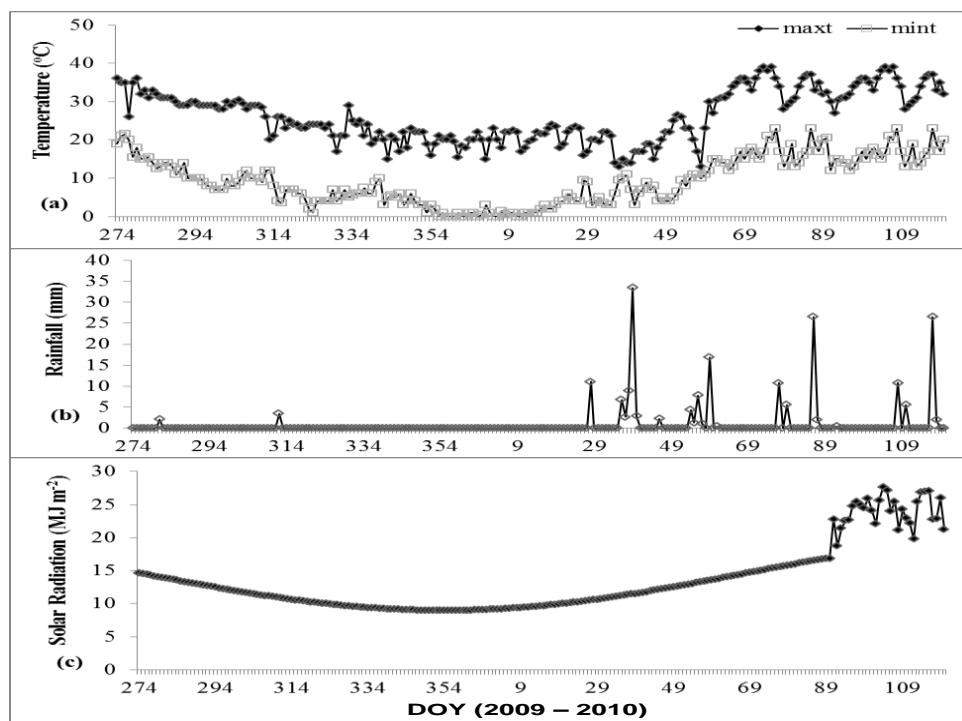
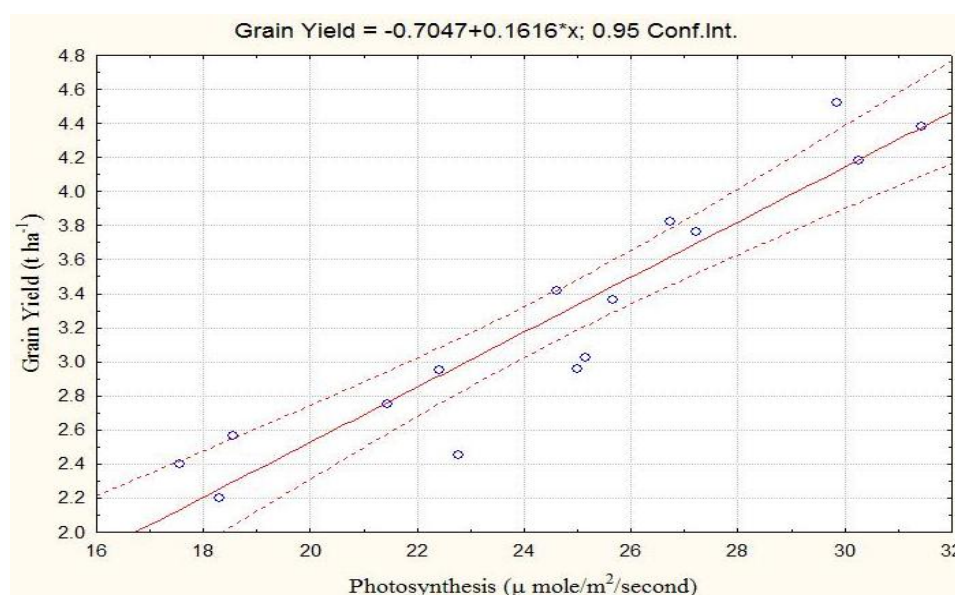


Figure 3. Climatic conditions throughout the experiment during 2009 to 2010 at Islamabad: (a), Maximum (closed symbols) and minimum (open symbols) temperature; (b) rainfall (mm); (c), solar radiation.

Table 1. Physiological attributes of five wheat genotypes during 2008 to 2009.

Genotype	Photosynthesis rate	Transpiration rate	SPAD	Proline contents
Tatara	35.52 ^a	2.87 ^d	55.17 ^a	56.69 ^a
NARC-2009	28.54 ^b	2.63 ^c	50.00 ^b	57.05 ^b
Sehar-2006	20.13 ^e	2.90 ^a	39.17 ^e	41.41 ^e
SKD-1	24.21 ^d	2.78 ^{ab}	43.10 ^d	46.27 ^d
F-Sarhad	26.92 ^c	2.69 ^b	47.13 ^c	50.58 ^c
LSD	1.335	0.1335	2.914	2.695

Different letters indicates significant differences among genotypes for different physiological attributes ($p < 0.05$) according to the LSD test.

**Figure 4.** Scatterplot of grain yield against An (Net photosynthesis) for wheat genotypes.

ultimately maximum yield. Tatara genotypes performed very well due to efficient translocation of photoassimilate from source to sink using available thermal units under moisture stress conditions; whereas, SKD-1 and F-Sarhad genotypes showed similar behaviour.

Transpiration rate (E) (mole/m²/s)

Transpiration is the removal of moisture from plant parts and it has significant impact on yield of crops and a major constituent to measure WUE of agricultural crops. Crop yield is inversely related to E. It depends upon climatic variants like solar radiation, temperature, water vapor pressure deficit, wind speed and the water status of the plants (Ahmed et al., 2010). Results of current study depicted significant variation in E for different genotypes. Resistant cultivars have defensive mechanism to cope with stress. Maximum E recorded in Sehar-2006 (2.80 mole/m²/s) which had low photosynthetic activity and did not hold moisture for plant use and ultimately reduced

yield potential whereas minimum E observed in Tatara (2.27 mole/m²/s) followed by NARC-2009 (Table 1). Stomatal aperture plays a vital role in leaves as water evaporates through them. Stomatal conductance and transpiration were positively correlated and stomatal closure led to reduce transpirational losses and ultimately good production. Our results were at par with the outcomes of Kimball et al. (2002). Negative correlation was observed between transpiration rate and grain yield of different wheat genotypes under current study (Figure 5). Sehar-2006 could not hold moisture for photosynthetic activity under stressed conditions and consequently water loss through transpiration exceeded from optimum. On the other hand, Tatara showed opposite behaviour than Sehar-2006 and other genotypes.

Chlorophyll contents (SPAD)

Crop growth could be related to rate of photosynthesis

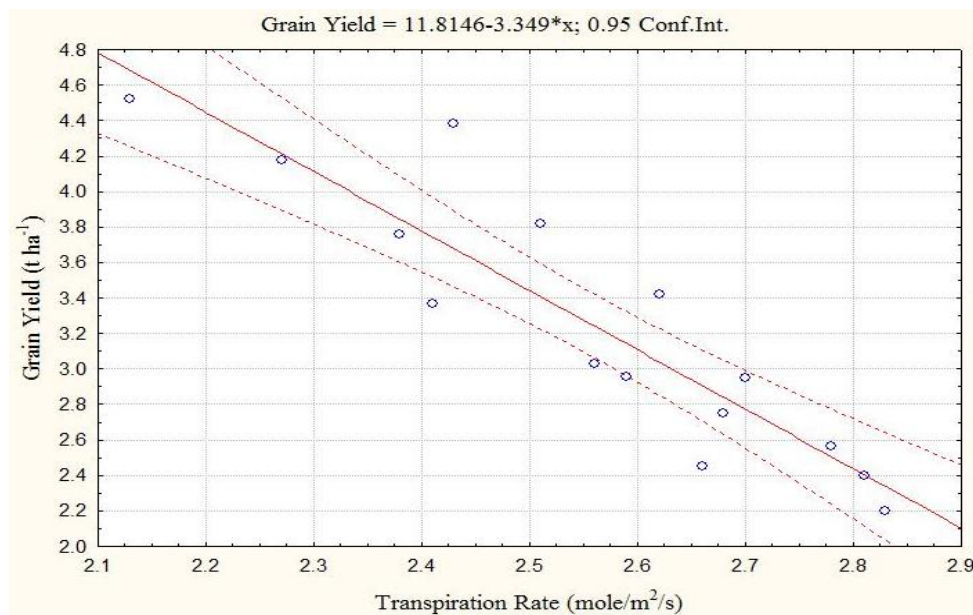


Figure 5. Scatterplot of grain yield against transpiration rate for wheat genotypes.

Table 2. Physiological attributes of five wheat genotypes during 2009 to 2010.

Genotype	Photosynthesis rate	Transpiration rate	SPAD	Proline contents
Tatara	30.52 ^a	2.27 ^d	53.17 ^a	59.69 ^a
NARC-2009	26.54 ^b	2.43 ^c	49.00 ^b	55.05 ^b
Sehar-2006	18.13 ^e	2.80 ^a	37.17 ^e	41.41 ^e
SKD-1	22.21 ^d	2.68 ^{ab}	40.10 ^d	46.27 ^d
F-Sarhad	24.92 ^c	2.59 ^b	45.13 ^c	50.58 ^c
LSD	1.345	0.1331	2.894	2.685

Different letters indicates significant differences among genotypes for different physiological attributes ($p < 0.05$) according to the LSD test.

which is directly proportional to chlorophyll contents in leaves. Plants use chlorophyll to trap light from sun for photosynthesis and green colour of plants is due to absorption of all visible colours instead green by photosynthesizing pigments. Outcomes of the present research clearly indicated that chlorophyll contents positively related to photosynthetic efficiency which affected crop productivity. The studied genotypes showed differential response toward chlorophyll contents. Maximum SPAD value observed in Tatara (53.17) followed by NARC-2009 (49.00) where as Sehar-2006 (37.17) showed less chlorophyll contents and ultimately reduced photosynthesis and productivity (Table 2). The other two genotypes SKD-1 and F-Sarhad (40.10 and 45.13, respectively) depicted similar behaviour for chlorophyll contents (SPAD). Similar findings had been documented showing positive correlation between photosynthesis and chlorophyll contents (Thomas et al., 2005). Chlorophyll contents and grain yield of wheat genotypes showed positive and linear relationship (Figure

6). Maximum chlorophyll contents led to increased yield as Tatara genotype exhibited highest chlorophyll contents with maximum yield. Our results were in line with the outcomes of Thomas et al. (2005), who were of the view that chlorophyll contents and photosynthetic rate positively correlated and had significant impact upon crop growth and productivity.

Proline contents ($\mu\text{g g}^{-1}$)

Proline, accumulates in plants under environmental stresses is proteinogenic amino acid with an exceptional conformational rigidity, and is essential for primary metabolism. It acts as a signal to triggers specific gene action which may be essential for crop recovery from stress. In the present study, proline contents differed significantly among wheat genotypes. Tatara being resistant cultivar showed better response toward proline accumulation at anthesis stage as maximum proline

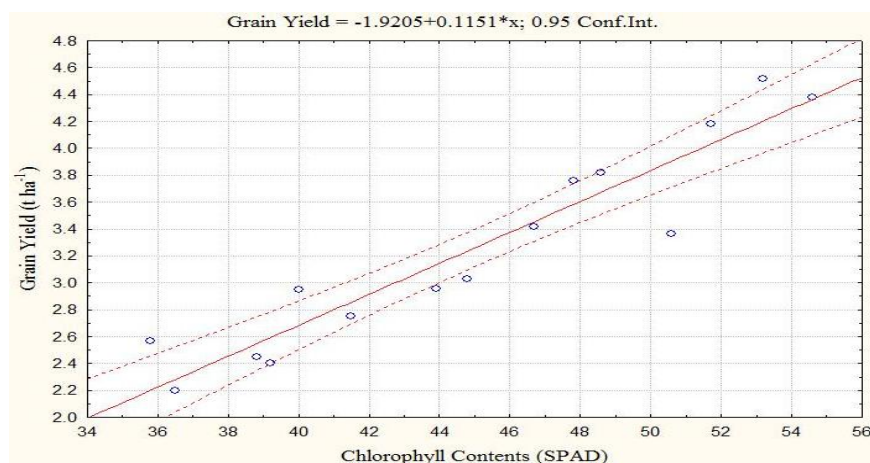


Figure 6. Scatterplot of grain yield against chlorophyll contents for wheat genotypes.

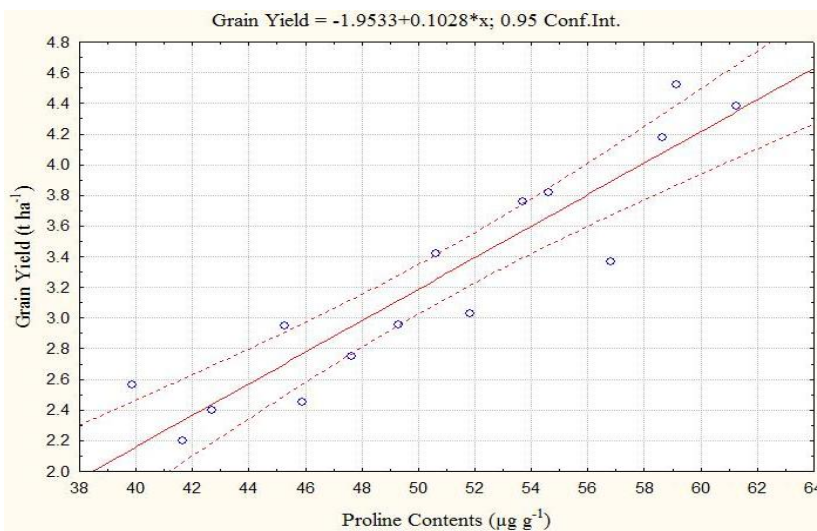


Figure 7. Scatterplot of grain yield against proline contents for wheat genotypes.

accumulated in Tatar (59.69 $\mu g\ g^{-1}$) followed by NARC-2009 (55.05 $\mu g\ g^{-1}$) as compared to SKD-1 (46.27 $\mu g\ g^{-1}$) and F-Sarhad (50.58) which might be due to genetic potential and physiological adaptability of Tatar cultivars against stress conditions; whereas, minimum proline recorded in Sehar-2006 (41.41 $\mu g\ g^{-1}$) with less yield and productivity (Table 1). Similar findings have been documented that proline contents reduced under increased temperature and moisture stress, while, proline accumulation increased in resistant cultivars which led to higher yield. The results of present study were elaborated by Scatterplot diagram which demonstrated positive relationship between proline contents and grain yield of wheat genotypes (Figure 7). Less thermal units available during early growth stages due to stressed conditions

promoted maximum proline accumulation in drought resistant genotype.

Conclusion

Climatic variation, continuously increasing population and market infrastructure are driven forces to reduce agricultural productivity and new management options, and appropriate genotypes are the need of the day to be considered for sustainable production. The present study concluded that climatic variation has significant impact upon physiological attributes. Tatar genotype performed well for all indices as compared to other genotypes under study. Maximum physiological attributes and grain yield

observed for Tataru followed by NARC-2009; whereas, Sehar-2006 showed minimum indices. Tataru used limited available resources and efficient translocation of photoassimilate from source to sink which boosted up its growth and production.

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