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Original Research

Effect of Water Stress Through Skipped Irrigation on Growth and Yield of Wheat

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Abstract

Wheat cultivars displaying water stress tolerance traits are highly desirable for water scarce regions of Pakistan. To achieve this aim, a 2-years field research experiment was undertaken to assess the outcome of water stress on physiological and agronomic traits at different growth stages in selected wheat cultivars. The experiment comprised evaluation of five wheat cultivars viz., Atta Habibb-2010, Siran-2008, Pirsabak-2008, Hashim-2008 and Pirsabak-2005 under water stress by skipped irrigation at each of the following growth stages: crown root initiation (CRI), tillering stage, pre-anthesis and milk stages, compared with well-watered treatment. Data of tillers number, 1000 grain weight, grain yield, drought susceptibility index and drought tolerance efficiency were evaluated. The two years data revealed significant impact of water stress on growth, physiological and yield traits of wheat, and pre-anthesis stage was found as most sensitive to water deficiency. For water stress at CRI, Pirsabak-2005 produced higher yield than the rest of the cultivars. Hashim-2008 followed by Pirsabak-2008 produced higher grain yield than rest under water stress at pre-anthesis stage; whereas water deficit at this stage adversely affected the performance of cv. Atta Habib, Hashim-2008 and Pirsabak-2008. Pirsabak-2005, Hashim-2008 and Pirsabak-2008 may be utilized as breeding material for development of local water stress tolerant wheat varieties.

Keywords: wheat, growth, yield, water stress, deficit irrigation

Introduction

Wheat is staple food for Pakistani population that fulfills about 50% of total dietary needs [1]. Deficiency of irrigation water is the key reason behind the reduction in wheat yield and water deficiency during critical growth stages of wheat crop is considered as maximum restrictive feature in achieving the optimum wheat production [2]. In Pakistan, wheat is produced in different ecological zones of arid and semi-arid regions; as a result, an estimated 88% total area of country is under wheat cultivation that faces severe dry spells. Pakistan is 6th country in the world prone to climatic changes and water availability that results in low to

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moderate droughts [3]. Wheat grown under extremely dry conditions constitute about 15% of total area of Pakistan; however, yield is proportionally lower due to water scarcity [4]. Judicial utilization of water become crucial factor in harvesting high yield of wheat crop. Many studies reported that wheat grain production was non-significantly reduced by skipping irrigation instead of a flowering stage [5].

Skipping irrigation at critical growth stages of wheat crop could be an alternative to save irrigation water; nonetheless, wheat yield and growth reaction to skipped irrigation is investigated in depth [6]. Particularly, skipping irrigation technique is applied in areas with low water availability. Skipping irrigation reduces wheat grain yield in sandy loam soils under semi-arid conditions. Plants continue their normal growth and transfer of photosynthetic assimilates to grains under water deficit condition, which becomes possible by osmotic adjustment which helps cell organelles and cytoplasmic activities at normal level [7]. Skipping irrigation results in drying of soil surface during crown root initiation stage may inhibit development of root system causing reduced root length due to soil hardness [8].

Studies on various field crops about skipping irrigation showed best approach [9]. Practicing this technique may be beneficial for net income and use of water can be reduced without adverse effects on crop yield in different ecological zones, especially in lower water availability cases [10]. Skipping irrigation could be exceptionally helpful due to less evaporation losses, appropriate assimilates in vegetative and regenerative parts, enhanced interaction with water supply, fertilizers and best agronomic ways for enhanced water efficiency. The technique has both beneficial aspects and some drawbacks simultaneously, as it is used for increasing water use efficiency (WUE), but threshold point of irrigation must be maintained [11].

Skipping irrigation at any of wheat growth stage, especially during tillering, booting, heading, blooming, and milk stages, resulted in decrease in grain yield [12]. Decreased yield was strongly associated with skipped irrigation during tillering or heading stage. The milk or dough and booting stages were sensitive stages to water stress [13].

The current investigation was aimed to explore the outcome of water stress on physiological development, and production of wheat because irrigation water can be saved for future use by adopting skipped irrigation techniques. Optimal irrigation levels can be supplied during all sensitive growth phases of wheat under semi-arid to arid conditions because skipped water supply could lessen grain production. At the same time, crop production is also reduced due to less water availability than optimum crop requirements. The key objectives of this research study were to determine percent reduction in wheat yield as a result of skipping irrigation and to identify drought tolerant and susceptible growth stage as well as to decipher the effect water stress on growth and yield of wheat.

Experimental Procedures

Plant Material and Growth Conditions

Two field experiments were conducted in cropping season 2012-13 and 2013-14 at private farm Mang Haripur (33°54'17.5''N, 72°55'41.2'' E). Physio-chemical properties of soil were determined. Soil texture was sandy loam with 17 % moisture level, Clay 250 mg kg^{-1}, Silt 540 mg kg^{-1}, Sand 210 mg kg^{-1}, Ph 7.2, EC 0.34 dSm^{-1}, Bulk Density 1.21 g cm^{-3}, Organic Matter 10.7 mg kg^{-1}, Nitrogen 0.33 mg kg^{-1}, Phosphorus 6.7 mg kg^{-1}, Potassium 1.22 mg kg^{-1}, Zinc 1.66 mg kg^{-1}, Copper 1.95 mg kg^{-1}, Iron 14.6 mg kg^{-1} and Manganese 57 mg kg^{-1}.

Seeds of five wheat genotypes: V1-Atta Habib-2010, V2-Siran-2010, V3- Pirsabak-2008, V4- Hashim-2008 and V5-Pirsabak-2005 were sown manually @50 kg/Acre in mid-November in each cropping season. Based on the soil analysis, the 8-23-18 N-P_2O_5-K_2O fertilizer was used at 250 kg/Acre. Randomized complete block design with split plot arrangement with four replicates was used. There were 5 irrigation treatments: T1-Control irrigation, T2-Skipped irrigation at crown root initiation, T3-Skipped irrigation at tillering, T4-Skipped irrigation pre-anthesis and T5-Skipped irrigation milk stage. The irrigations were skipped to induce the water stress. Irrigation treatments were kept in main plot and varieties were placed in sub-pots. Irrigation treatments were randomized in plots.

Each sub-plot was irrigated for 6 minutes to the depth of 125 mm except skipped irrigation treatment plot for that stage. Same practice was repeated for each irrigation episode. Manual removable rainout shelters were used to avoid rain for skipped irrigation treatments.

Measurements and Calculations of Traits

Measurements for each parameter were recorded from 1m^2 area, which was marked in each sub-plot. The measured parameters included tillers m^{-2}, 1000 grains weight and grain yield.

Drought Susceptibility Index DSI (Fischer and Maurer, 1978) was calculated as follow:

$$DSI = (1-Yd/Yw)/D$$

...where: Yd = Mean yield under drought, Yw = Mean yield under well-watered treatment, D = Environmental stress intensity = 1-(Mean yield of all genotypes under drought/ mean yield of all genotypes under well-watered treatment)

Drought Tolerance Efficiency DTI (Fischer and Wood 1981) was calculated as follow:

$$DTI = (Ysi/Ypi) \times 100$$

...where: Ysi = Yield under stress for genotype, Ypi = Yield under non-stress for genotype.

Yield reduction percentage YR% was calculated:

$$YR\ \% = 100 - (Ys/Yc \times 100)$$

...where Ys = Yield under stress, Yc = Yield under control irrigation.

Statistical Analysis

The data were analyzed statistically combined over years using analysis of variance techniques appropriate for randomized complete block design. Means were compared using LSD test at 0.05 level of probability, when the F-value will significant [14].

Results

Tillers Plant^{-1} and 1000 Grains Weight

Treatments, varieties and their interaction effect was significant ($P \leq 0.05$) on the number of tillers plant^{-1} (TP^{-1}) and thousand grains weight (TGW) in combined analysis of cropping seasons 2012-13 and 2014-15 (Figs 1-2). The results indicated decrease in TP^{-1} and TGW due to water stress during different growth stages of experiment as compared to control irrigation. Treatments mean comparison showed that the maximum of 10.67 TP^{-1} and TGW of 46.32 g was produced by control irrigation. The skipped irrigation at tillering stage caused production of the minimum (5.25) TP^{-1}. The minimum of 29.05 g TGW was produced by skipped irrigation at milk stage. Regarding interactions, Atta Habib-2010 produced the maximum 11 TP^{-1} and Pirsabak-2005 produced the minimum of 7.25 TP^{-1}. The Pirsabak-2008 produced the maximum (45.87 g) and Atta Habib-2010 produced the minimum (31.87 g) TGW. Overall the minimum TGW (23.75 g) was recorded by Atta Habib-2010 under skipped irrigation at milky stage.

Grain Yield (kg ha^{-1}) and Yield Reduction %

Significant (*P≤0.05*) result was found for grain yield (GY) and Yield Reduction Percentage (YR %) of different varieties, treatments and their interactive effect when the two cropping seasons 2012-13 and 2014-15 were analyzed (Figs 3-4). Two years pooled data analysis revealed that GY and YR % were reduced due to water stress at multiple phases of growth in experiment with reference to optimum irrigation. Treatments means revealed that the maximum GY of 6664 kg ha^{-1} was noted for control irrigation while the maximum 39.54 % YR recorded due to skipped irrigation at pre-anthesis stage. The minimum GY of 4015 kg ha^{-1} and YR of 13.87 % were recorded due to skipped irrigation at pre-anthesis and crown root initiation stage respectively.

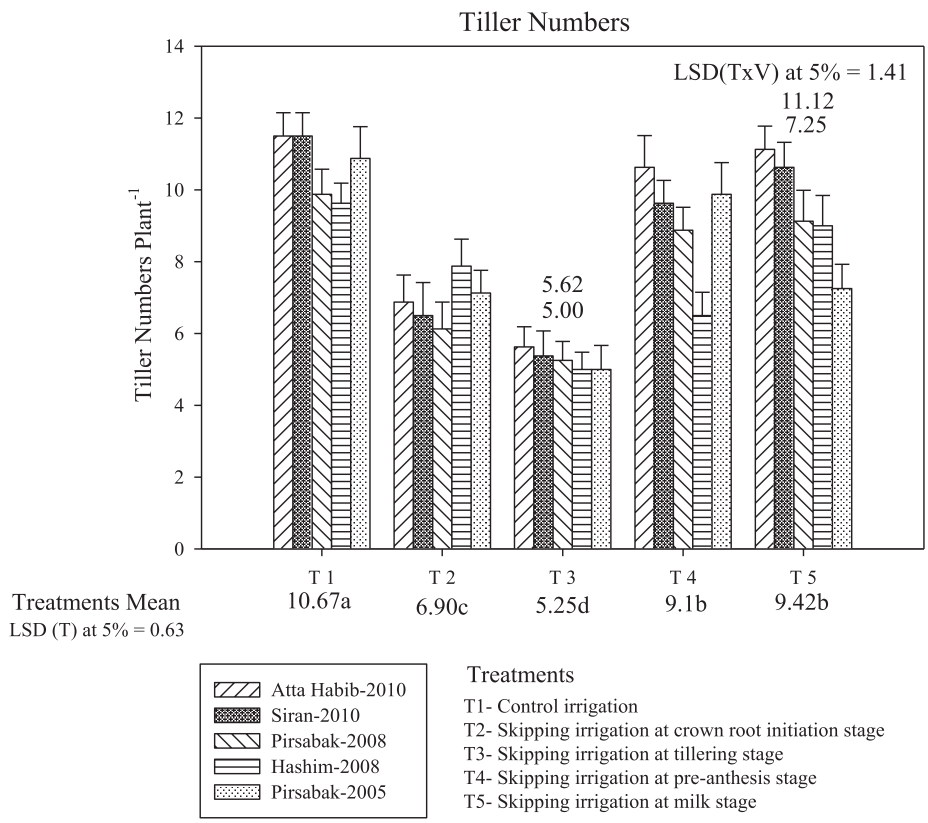

Fig. 1. Effect of water stress on TP^{-1} at multiple growth stages of winter wheat during two consecutive cropping years 2012-13 and 2013-14. Treatments mean are mentioned below the graph along with its critical value for comparison ($p<0.05$).

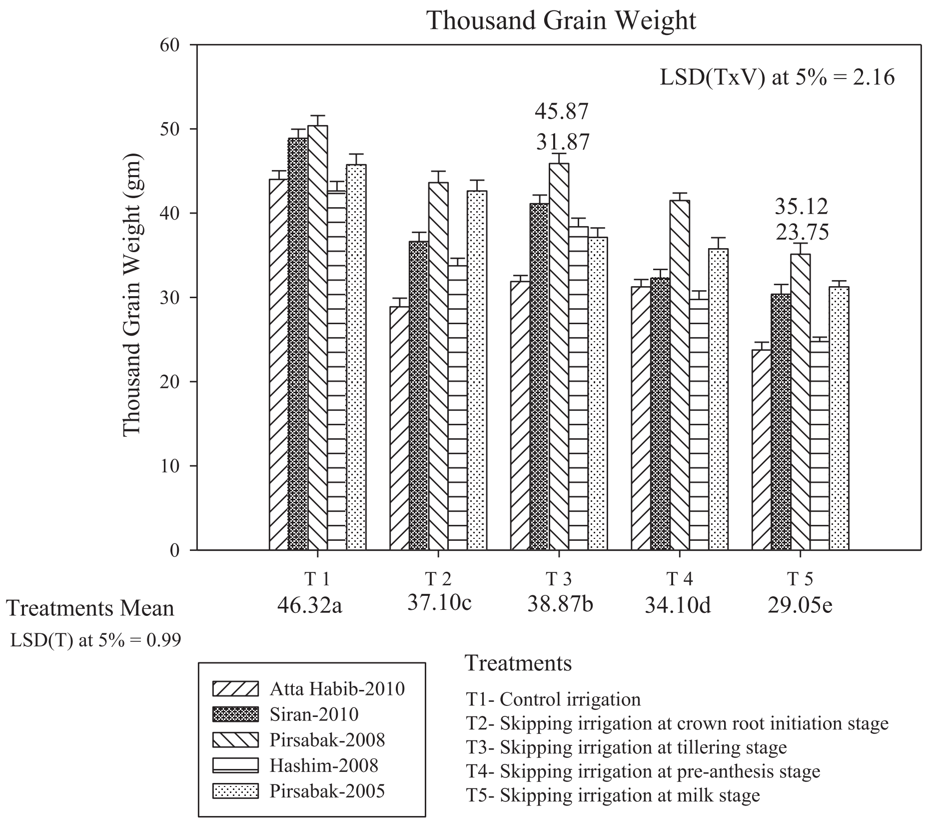

Fig. 2. Effect of water stress on TGW at various growth stages of winter wheat crop during two consecutive cropping years 2012-13 and 2013-14 combine analysis. Treatments mean were mentioned below the graph along with its critical value for comparison (p≤0.05).

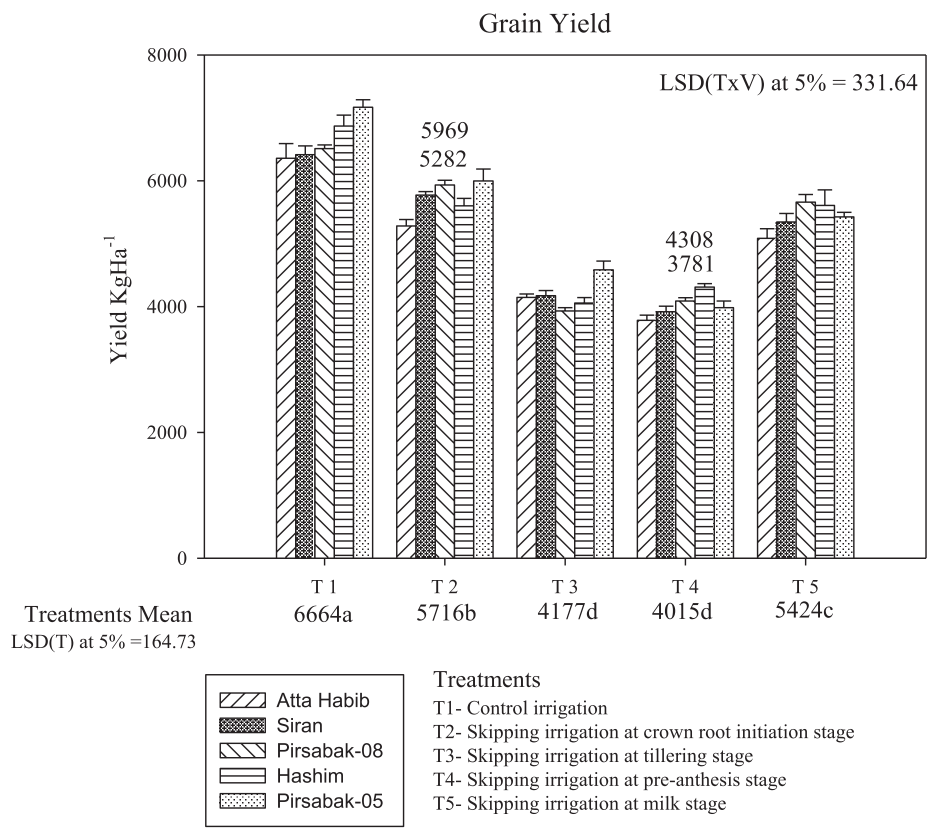

Fig. 3. Effect of water stress on grain yield at different growth stages of winter wheat crop during two consecutive cropping years 2012-13 and 2013-14 combine analysis. Treatments mean were mentioned below the graph along with its critical value for comparison (p≤0.05).

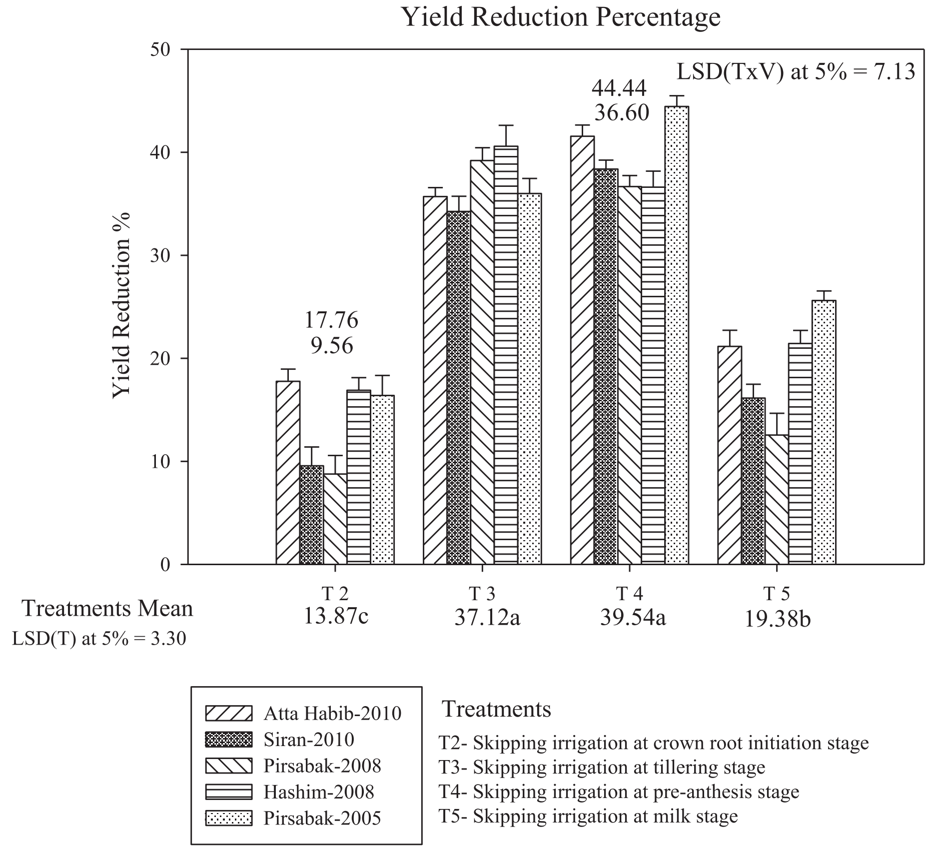

Fig. 4. Effect of water stress on yield reduction percentage at different growth stages of winter wheat crop during two consecutive cropping years 2012-13 and 2013-14 combine analysis. Treatments mean were mentioned below the graph along with its critical value for comparison (p≤0.05).

When irrigation skipped at crown root initiation stage, Pirsabak-2005 produced the maximum 5969 kg ha^{-1} GY and Atta Habib-2010 produced the minimum GY of 5282 kg ha^{-1} within same treatment of different varieties. Regarding interactions skipped irrigation at pre-anthesis stage produced overall the minimum GY (3781 kg ha^{-1}) by Atta Habib-2010. Irrigation skipped at pre-anthesis stage caused the maximum and the minimum YR % in Pirsabak-2005 and Hashim-2008 values of 44.44% and 36.60%, respectively within same treatment. Regarding interactions skipped irrigation at CRI had the minimum YR % (9.56) by Pirsabak-2008. This study results revealed that the skipped irrigation at pre-anthesis severely damaged wheat crop yield.

Drought Susceptibility Index and Drought Tolerance Efficiency

Treatments, varieties and their interactive effect caused significantly (*P≤0.05*) different result on drought susceptibility index (DSI) and drought tolerance efficiency (DTE) in combined analysis of cropping seasons 2012-13 and 2014-15 (Figs 5-6). The collective analysis of both cropping years showed variation in DSI and DTE due to water stress at various growth stages with the reference to control irrigation. Treatments mean revealed that the maximum DSI of 1.48 was recorded due to skipped irrigation at pre-anthesis stage while the maximum DTE 86.14 was recorded for skipped irrigation at crown root initiation stage. The minimum DSI (0.53) was recorded by skipped irrigation at crown root initiation stage while the minimum DTE 60.45 was resulted due to restricted water supply at pre-anthesis stage

Pirsabak-2005 and Hashim-2008 had the maximum (1.72) and the minimum (1.34) DSI respectively within same treatment with restricted irrigation at the time of pre-anthesis. Water stress at crown root initiation stage had triggered the minimum DSI (0.33) for Pirsabak-2008. Among all the wheat genotypes, Pirsabak-2008 had less drought susceptibility or strong genetic background to drought as compared to all other genotypes grown. Likewise, pre-anthesis and crown root initiation stages were recorded as the most and the least susceptible stages in response to skipped irrigation. Among all the wheat genotypes grown in this experiment, Pirsabak-2008 had greater drought tolerance as compared to all other genotypes grown. Regarding interactions Pirsabak-2008 had the maximum (91.23) and Attta Habib-2010 the minimum (82.23) DTE under skipped irrigation at root crown initiation stage. The analysis showed that the skipped irrigation at pre-anthesis stage had the minimum (55.56)

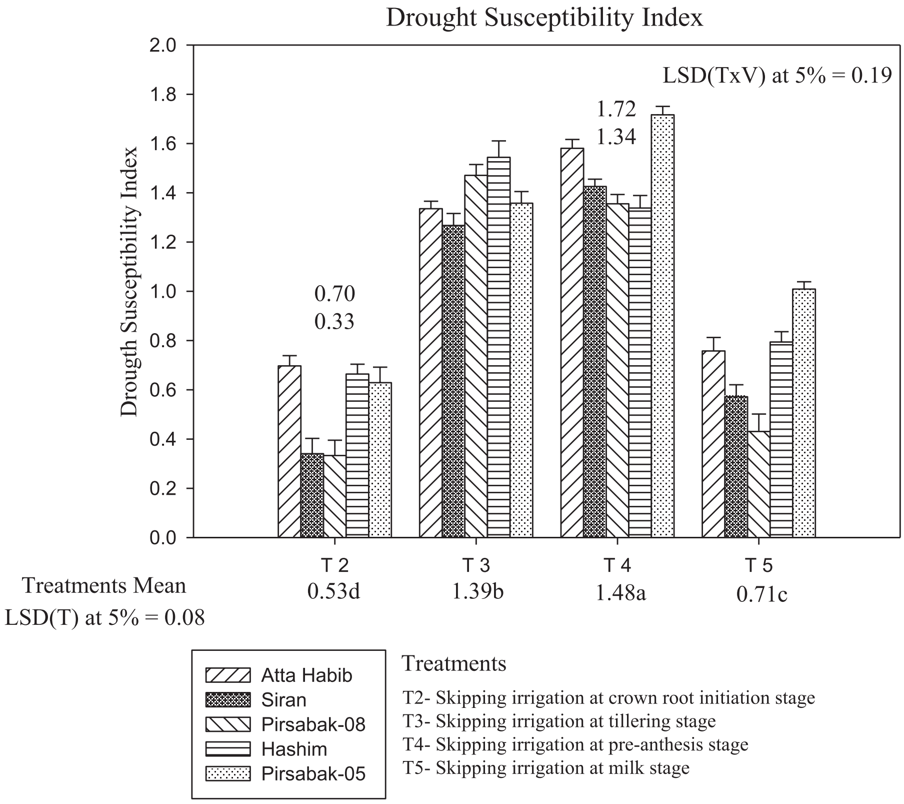

Fig. 5. Effect of water stress on drought susceptibility index at different growth stages of winter wheat crop during two consecutive cropping years 2012-13 and 2013-14 combine analysis. Treatments mean were mentioned below the graph along with its critical value for comparison (*P≤0.05*).

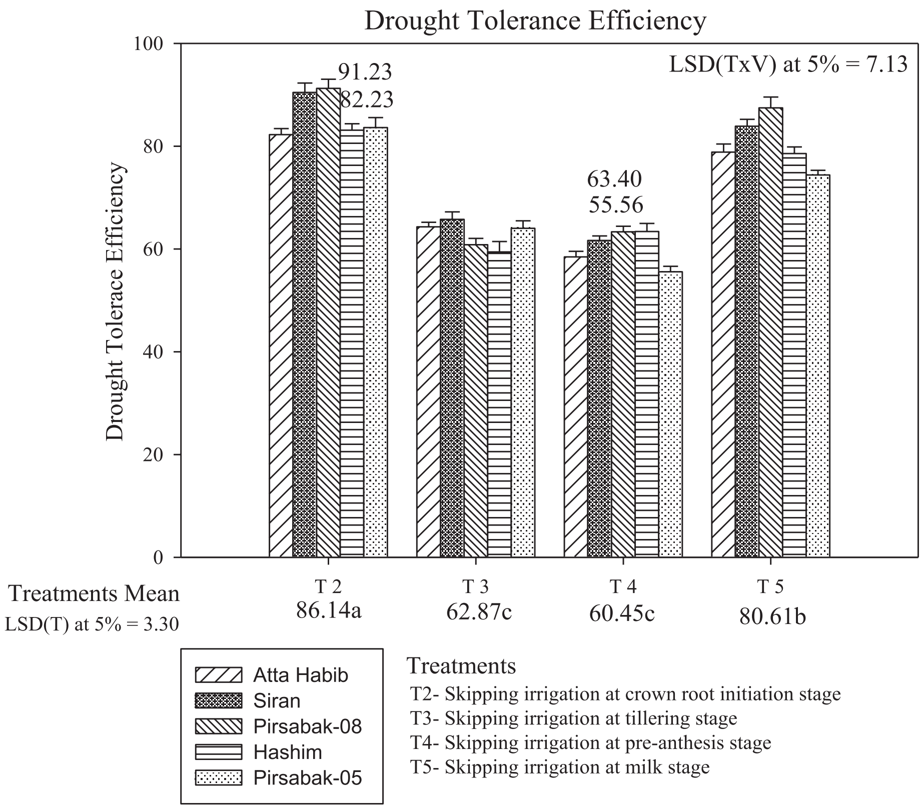

Fig. 6. Effect of water stress on drought tolerance efficiency at different growth stages of winter wheat crop during two consecutive cropping years 2012-13 and 2013-14 combine analysis. Treatments mean were mentioned below the graph along with its critical value for comparison (p≤0.05).

DTE by Pirsabak-2005. The present results decipher that the most tolerant growth stage to water stress was crown root initiation and pre-anthesis stage was the least tolerant to skipping irrigation.

Discussion

Developing new agricultural technologies for sustainable crop production are getting famous during last few decades for the mitigation of environmental stresses, especially drought stress. Thus the current research work was focused on identification of wheat drought tolerant varieties regarding critical growth stages under different water regimes. Water stress adversely affected the number of tillers plant^{-1} during critical seedling growth and tillering stage in wheat [15]. The maximum tiller numbers i.e. more than 300 were produced in wheat crop for the control treatment in which the maximum number of irrigations were supplied [16]. The previous studies also revealed that, higher number of tillers may be attributed to adequate moisture supply, particularly during tillering stage [17]. Water stress adversely affected the number of tillers plant^{-1} during its critical seedling growth and tillering stage. [18] Described that the maximum tiller numbers i.e. more than 300 were produced in wheat crop for the control treatment in which the maximum number of irrigations were supplied. This decreased in tiller numbers per plant in all genotypes might be due to the insufficient availability of water at tillering stage with low uptakes of nutrients [19]. The previous studies also revealed that, the higher number of tillers may be attributed to adequate moisture supply, particularly during tillering stage [20]. The water stressed condition at tillering stage restricted the nutrient uptake for tiller development. So, the water and nutrient deficiency at this stage caused significant decline in tiller numbers which directly contributed to grain yield reduction. Under the skipped irrigation the 1000 grains weight was less effected at the tillering stage and more affected at milking stage. Water availability at milking stage was more critical because nearly 70% of crop requirements were taken at milking stage which significantly affected the grain production and yield components of the wheat crop [21]. Wheat crop responded positively in terms of 1000 grains weight with sufficient supply of water at anthesis and milking stages [22]. Grain size was greatly affected when wheat plants were under water stress at the milking stage which results in decreased 1000 grains weight [23].

Extreme low soil moisture at CRI stage had not suppressive effect on wheat final grain yield with comparison to tillering and anthesis stages [24]. After successful germination in drought conditions wheat plant became more competent to abiotic stresses and survive well at little favorable conditions by managing its available resources, however for grain development it required sufficient amount of water [25]. Drought stress at tillering and pre-anthesis growth stages resulted in decline of grain yield [26]. Generally, the YR % depends upon plant total biomass and grain production and these parameters were found to be influenced by photosynthetic capacity of plants under skipped irrigation [27]. At anthesis stage or grain forming stage crop required enough quantity of food stored because the senescence of leaves starts under water shortage period which reduced the photosynthesis process and as well as caused the significant YR % [28]. Inadequate irrigation water or drought stress at tillering and pre-anthesis growth stages resulted decline in final grain yield and yield components [29]. The present study outcomes were also at par with [30] that skipping irrigation at pre-anthesis stage led to decreased grain yield. According to [31], early root initiation or booting stages were less pretentious by water stress as compared to anthesis or grain forming growth phase. Limited water supply before flowering or at anthesis period may affect the grain numbers per spike and kernels mass that are two important components of grain yield [32].

Mainly drought susceptibility index was determined in terms of grain yield and it was the highest in wheat crop during limited water supply at both pre-anthesis stage and grain filling stage [33]. Wheat seeds can germinate successfully with low soil moisture have high drought tolerance efficiency as compared to subsequent growth stages. Drought tolerance efficiency and drought tolerance index both were determined in terms of grain yield and wheat grain yield mostly got affected whenever drought occurred before or at flowering and grain filling stage. In our study the skipped irrigation at the CRI stage showed high drought tolerance efficiency. On other hand the water stress at the pre-anthesis and tillering stage affected the grain yield [34]. Draught stress can occur at different growth stages of crop without irrigation or limited water supply which have great negative impact on crop by limiting the productivity of agricultural crop [35].

Conclusions

Under water stress regimes, variable response of wheat cultivars at various growth stages were observed for physiological growth and yield traits. Water stress at pre-anthesis stage in wheat decreased drought tolerance efficiency and grain yield but drought susceptibility index was increased. Water stress at milk stage decreased the test weight. When irrigation was skipped at CRI and anthesis stage Pirsabak-2005 and Hashim-2008 produced higher grain yield respectively, whereas yield performance of Atta Habib was poor under water stress at these growth stages. Therefore, Hashim-2008 and Pirsabak-2008 may be considered for cultivation under low rainfall and drought-hit areas. Pirsabak-2005, Hashim-2008 and Pirsabak-2008 may also be used as breeding source for coming varietal development programs aimed to breed wheat varieties tolerant to water stress.

Conflict of Interest

The authors declare no conflict of interest.

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