EVALUATION OF SALT TOLERANT WHEAT VARIETIES CULTIVARS BY OBSERVING GROWTH AND PHYSIOLOGICAL RESPONSE UNDER DROUGHT STRESS

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Abstract. Generally, the yield of most crops relies the intensity of drought and the stage of plant growth period where it occurs. Various wheat genotypes viz. IBWSN-1010, IBWSN-1025 (Salt tolerant liens), TD-1, ESW-9526 (Hybrid lines) Khirman (Commercial cultivated cultivar) and Chakwal-86 (Drought tolerant) were evaluated to examine the growth and physiological responses to drought stress. Growth and water relations were investigated in the fourth leaf over a twenty-day timescale under drought and control conditions. The results were used to evaluate whether the salt tolerant cultivars IBWSN-1010 and IBWSN-1025 are also tolerant to drought stress. In the drought treatment, the cultivars Chakwal-86 (drought tolerant), IBWSN-1010, IBWSN-1025 (salt tolerant liens) and TD-1 and ESW-9525 (Lines) had a significantly higher number of live leaves, leaf and shoot fresh and dry mass, retained higher leaf and relative water content, and had a lower leaf mortality compared to Khirman. The salt and drought tolerant cultivars all showed significantly higher leaf water potential compared to the hybrid lines and Khirman. No significant differences were observed in soil water content and potential, meaning that all cultivars depleted soil water equally. Longer leaf longevity and greater fresh mass retention show that salt tolerant cultivars are also drought tolerant.

Keywords: *evaluation, salt tolerant, wheat, Triticum aestivum, cultivars, growth, physiological response, drought*

Introduction

Due to the rapid climatic change drought becomes abiotic constraint globally (Nariman et al., 2017). Abiotic stresses lead to desertification, loosing productive lands and severely limited growth and development (Chunthaburee et al., 2016). Insufficient availability of water to plants more precisely, when the amount of water is lost by evapotranspiration drought exceeds tremendously in the tissues (Aldesuquy et al., 2012). The effect of drought can be enhanced under conditions of low humidity and high temperatures. Chronic temperatures and light stresses highly affect the kernel filling stage and reduces the kernel dry weight (Tanaka and Gustavo, 2009). Globally, the production of wheat is progressively decreasing due to a shortage of irrigation water, and this is seriously influenced by global climatic change and an increasing shortage of irrigation resources (Shao et al., 2005; Saba et al., 2010; Monneveux et al., 2012). Once a plant is exposed to drought stress, it will be less resistant other types of stress. Abiotic stresses are major agriculture disasters affecting the vulnerability of wheat production, particularly in arid and semiarid regions of the world (Daryanto et al., 2016). Environmental stresses and their influences on plant growth and productivity are receiving a great deal of attention because of the potential impacts of climatic change on rainfall patterns, increasing temperatures and salinity (Verslues et al., 2006). Wang et al. (2014) have claimed that more crop losses are caused by abiotic stresses than any other factor. Major crops have reduced yield more than 50% compared with their yield potential.

Wheat is a major food crop with an annual production of 620 Mt worldwide; it supplies more than 20% of the total human food calories, Moreover, growth and yield of wheat significantly decrease under stressful environmental conditions. Salinity and drought together causes about 37% losses to the potential yield of crops. However, in the arid and semi-arid cropping systems, water stress caused by drought and salinity is the most important abiotic factor limiting plant growth and crop productivity (Zahid and Mohammad, 2016).

Among abiotic stresses drought and salinity are the major factors limiting the growth and yield of cereals (Tester and Bacic, 2005). Plant responses to drought and salt stress are closely related and the protection mechanisms overlap; for example salt stress reduces plant growth by reducing the ability of roots to take up water (Knipfer et al., 2020). It has been observed that drought stress and salt stress (Chaves et al., 2003; Jiang and Zhang, 2004; Liu and Baird, 2004; Shao et al., 2005) share similar physiological and biochemical processes (Chen et al., 2003; Zhu et al., 2004). Water stress in its broadest sense includes both drought and salt stresses (Kaur and Zhawar, 2015). During water stress some plants loose turgor when soil water potential is too low and are very sensitive to dry and saline conditions, but other plants are able to maintain their turgor during these same environmental stresses, and are considered tolerant.

Several hundred plants were obtained and tested for salt tolerance in a hydroponic culture (Al Hattab et al., 2018). The plant drought tolerance is complex involving diverse physiological and molecular mechanisms. These physiological responses vary to drought from phenological stage to another (Punia et al., 2011). Understanding the mechanisms of how these plants respond to drought stress should lead to the identification of new ways to optimize plant growth and productivity under dry conditions. Improvement of wheat growth and productivity under drought stress is therefore the main objective of research inferring the physiological behavior and tolerance of different wheat genotypes under drought. Salt stress significantly affected growth and yield attributes, as well as physiological traits of wheat genotypes (Mahboob et al., 2017).

Materials and methods

In our research trial the, ability of the six wheat cultivar s under water stressed, its particular focus was on leaf growth and mortality (%), leaf area, leaf water content, soil water content, relative water content, leaf water potential and soil water potential for six different wheat cultivars (IBWSN-1010, IBWSN-1025, TD-1, ESW-9525, Khirman and Chakwal-86). Different genotypes and their respective references are shown in *Table 1*. Seed were obtained from ARI Agriculture research institute, Sindh Agriculture University, Sindh, Pakistan. Seeds germinated on Whatman’s filter paper in petri dishes moistened with distilled water (ddH_2O) for five days at growth room temperature 20 ± 15°C. A complete randomized design (CRD) was used in the whole series of experiments of growth and physiological responses. Statistical differences were evaluated between day zero and other days and also between genotypes on each selected day. A drought treatment was applied by withholding water when the fourth leaf was fully expanded, as indicated by ligule emergence. Sampling of the fully expanded fourth leaf was carried out at 0, 5, 10, 15, and 20 days of the drought treatment and controlled conditions (normal four irrigations). Only one plant was grown in each pot. Samples of the fully expanded fourth leaf (five replicates for each point) were harvested using a razor blade, immediately weighed, and then dried in an oven at 72˚C for 48 hours. Dry weight of samples was recorded to a precision of 0.001 g. Determination of water content was expressed as both a percentage of fresh and dry weights (Ali et al., 2014). Water potential of the fully expanded fourth leaf was measured using a pressure chamber, as described by Gomes et al. (2012). The number of live leaves and dead/senesced leaves were recorded on 0, 5, 10, 15, and 20 days of the drought stress and control. All the data were expressed as means of five replicates ± SE, calibrated using standard salt solutions (NaCl) of 0.1, 0.2, 0.5, and 1.0 m (molality) for to see the performance at salt stress. The data were expressed as means of five replicates ±SE on a cm^2 basis. Relative water content (RWC) was expressed as the percentage water content at a given time as related to the water content at full turgor: RWC (%) = [(FW-DW)/(TW-DW)] X 100. Where: FW= Fresh weight, TW= Turgid weight, and DW= Dry weight, Fresh weight and dry weight measurements. The TW was measured by keeping the leaves in ddH_2O over night (12 hours) at room temperature.

Table 1. *Different genotypes and their respective references*

S. No	Genotypes	References
1	IBWSN-1010	Abro et al., 2020
2	IBWSN-1025 (Salt tolerant liens)	Abro et al., 2019
3	TD-1	Malik et al., 2015
4	ESW-9526 (Hybrid lines)	
5	Khirman (Commercial cultivated cultivar)	
6	Chakwal-86 (Drought tolerant)	

Statistical analysis

The data recorded were subjected to analysis of variance to discriminate the superiority of treatment means and LSD test were applied to compare the means. Statistics 8.1 is the name of the statistical software which was used in this experiments data analysis.

Results

Leaf mortality

Leaf mortality increased with the severity of drought stress, and all the genotypes had significantly higher ($P<0.001$) leaf mortality rates under the drought treatment. The leaf mortality was greatest in the cultivar Khirman, which had a significantly ($P<0.05$) higher leaf mortality rate of 53% than the other genotypes, which had only up to 25%

leaf mortality on the twentieth day of the drought treatment (*Fig. 1*). Under control conditions, all the genotypes showed a non-significant leaf mortality of up to 3%, excluding Chakwal-86, which showed statistically significant (*P*<0.05) leaf mortality of 13% on the twentieth day.

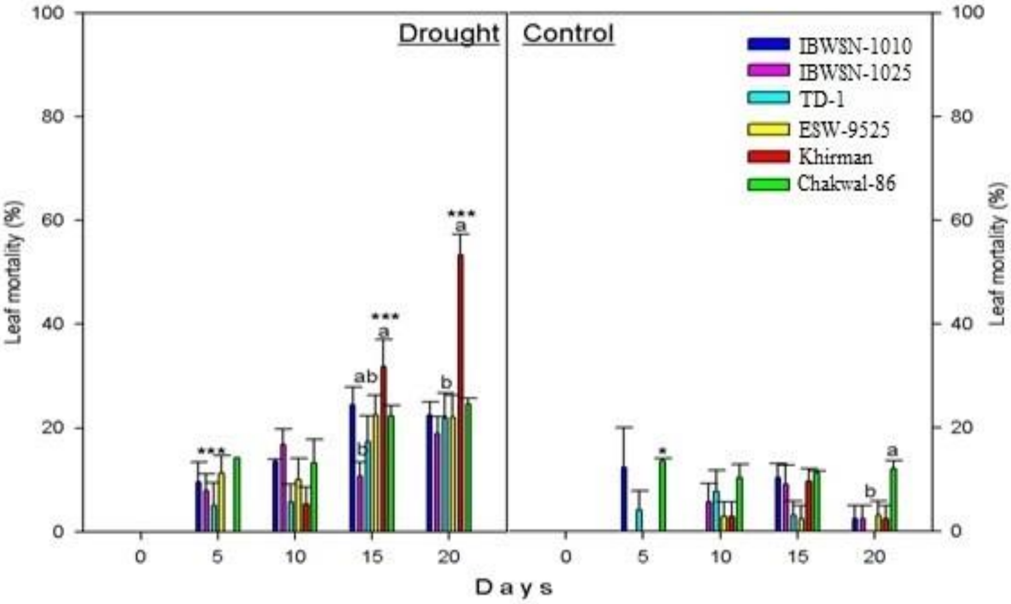

Figure 1. *The leaf mortality rate (%) ± SE (Standard Error) of six wheat genotypes (n=5) under drought stress and control conditions. Statistically significant differences between zero and the other days (ANOVA) are marked with an asterisk where ***, equals P=0.001; letters show significant differences (P<0.05) among genotypes on each selected day*

Mortality

The cultivar Khirman had a significantly (*P*<0.001) increased number of dead leaves on the twentieth day of the drought treatment compared to day zero. The same cultivar had a significant (*P*<0.001) decrease in number of living leaves under drought stress conditions on the twentieth day compared to day zero. These cultivars IBWSN-1010, IBWSN-1025, Chakwal-86, TD-1 and ESW-9525 had a significantly (*P*<0.05) higher number of living leaves compared to Khirman on the twentieth day of the drought. These cultivars also had a significantly (*P*<0.05) lower number of dead leaves on the twentieth day of the drought compared to Khirman (*Fig. 2*). Under control conditions, all the genotypes had a lower number of dead leaves except Chakwal-86 which had a significantly (*P*<0.05) higher number of dead leaves on the twentieth day of the drought treatment (*Fig. 2*).

Growth

A gradual, non-significant increase in shoot fresh weight was observed across all the cultivars during the first ten days of the drought treatment (*Fig. 3*). The cultivars IBWSN-1010, IBWSN-1025 and Chakwal-86 continued to significantly (*P*<0.01) increase in shoot fresh weight throughout the drought treatment period. However, there was a gradual decrease in shoot fresh weight in the cultivar Khirman starting after ten days, and in 5757-3 and 5746-20 after fifteen days of the drought treatment. The cultivars Chakwal-86, IBWSN-1025 and IBWNS-1010 had significantly (*P*<0.05)

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higher shoot fresh weight compared to Khirman, TD-1 and ESW-9525 under drought stress conditions. Under control conditions, all the cultivars had significantly (*P*<0.001) increased shoot fresh weight compared to day zero (*Fig. 3*). All the cultivars had significantly (*P*<0.05) increased shoot dry weight until fifteen days of the drought stress except Khirman, which stopped dry weight accumulation (*Fig. 3*). The cultivars Chakwal-86, IBWSN-1025 and IBWSN-1010 had significantly (*P*<0.01) increased shoot dry weight on the twentieth day of the drought stress. The cultivars Chakwal-86, IBWSN-1025 and IBWSN-1010 followed by TD-1 and ESW-9525 had significantly (*P*<0.05) higher shoot dry weight compared to Khirman on the twentieth day of the drought treatment. Under control conditions all the cultivars had significantly (*P*<0.001) increased shoot dry weight compared to day zero (*Fig. 3*).

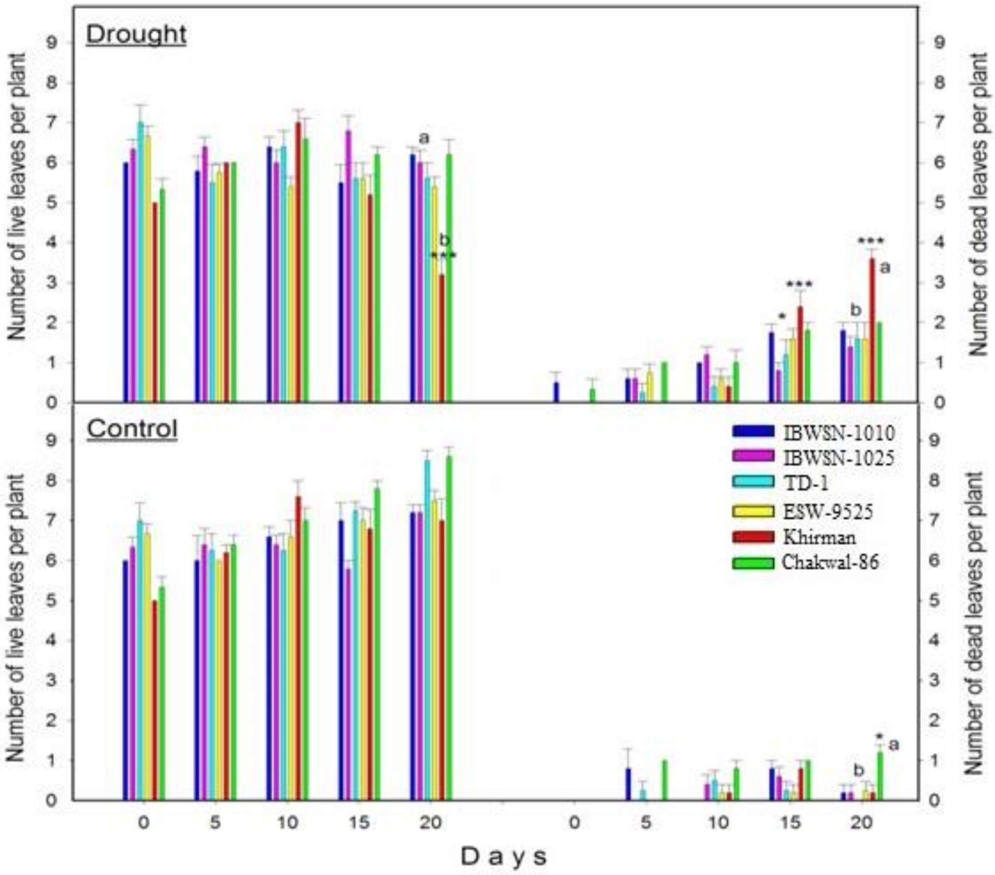

Figure 2. *Number of live leaves (left) and dead leaves (right) per plant ± SE (Standard Error) of six wheat genotypes (n=5) under drought stress and control conditions. Statistically significant differences between day zero and the other days (ANOVA) are marked with an asterisk where *, **, ***, equals P=0.05, P=0.01 and P=0.001; letters show significant differences (P<0.05) among genotypes on each selected day*

Leaf area increased in all genotypes until day ten of the drought stress (*Fig. 4*). However, it was significantly (*P*<0.001) decreased in Khirman on the twentieth day of the drought treatment compared to day zero. The genotypic differences were statistically significant (*P*<0.05), and the cultivar Khirman had significantly (*P*<0.05) smaller leaf area on the twentieth day of the drought treatment. No significant changes in leaf area were observed in any of the cultivars under control conditions (*Fig. 4*).

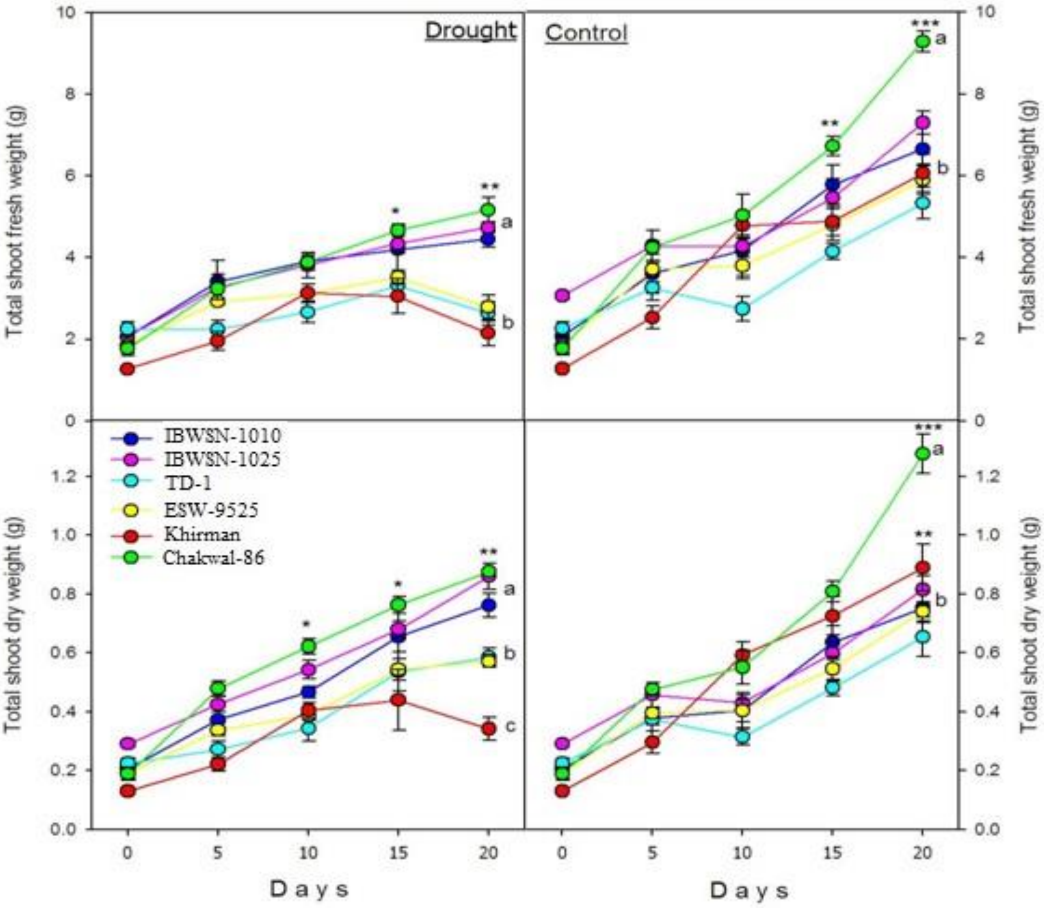

Figure 3. *Shoot fresh and dry weight ± SE (Standard Error) of six wheat genotypes (n=5) under drought stress and control conditions. Statistically significant differences between day zero and the other days (ANOVA) are marked with an asterisk where *, **, ***, equals P=0.05, P=0.01 and P=0.001; letters show significant differences (P<0.05) among genotypes on each selected day*

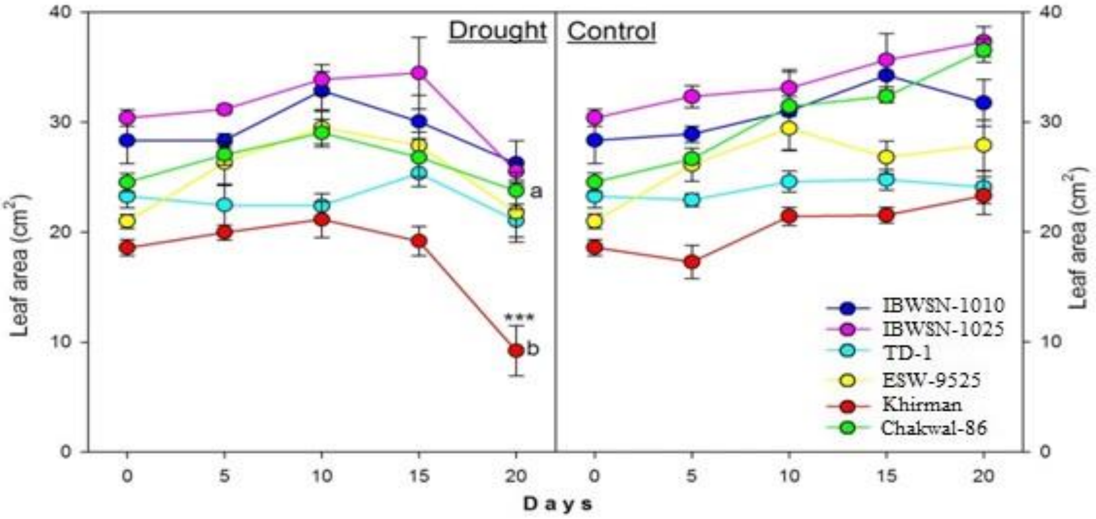

Figure 4. *Leaf area (cm^2) ± SE (Standard Error) of three wheat genotypes (n=5) under drought stress and control conditions. Statistically significant differences between day zero and the other days (ANOVA) are marked with an asterisk where ***, equals P=0.001; letters show significant differences (P<0.05) among genotypes on each selected day*

Leaf water content

No significant decrease in leaf water content was recorded in the six genotypes until fifteen days of the drought treatment (*Fig. 5*). However, after fifteen days of the drought stress, the leaf water content significantly ($P<0.001$) decreased in Khirman by 17% and, to a lesser extent, in the cultivars ESW-9525, and TD-1 which decreased ($P<0.05$) by 8% and 6% in leaf water content, respectively. The remaining three cultivars did not show significant decreases in leaf water content during the drought treatment (*Fig. 5*), while according to the caption asterisks shows significant differences between day zero and the other days. The cultivars IBWSN-1010, IBWSN-1025 and Chakwal-86 had significantly higher leaf water content compared to Khirman on the twentieth day of the drought treatment. Under control conditions, the leaves of all the genotypes contained approximately 90% water, and remained the same throughout the experimental period (*Fig. 5*).

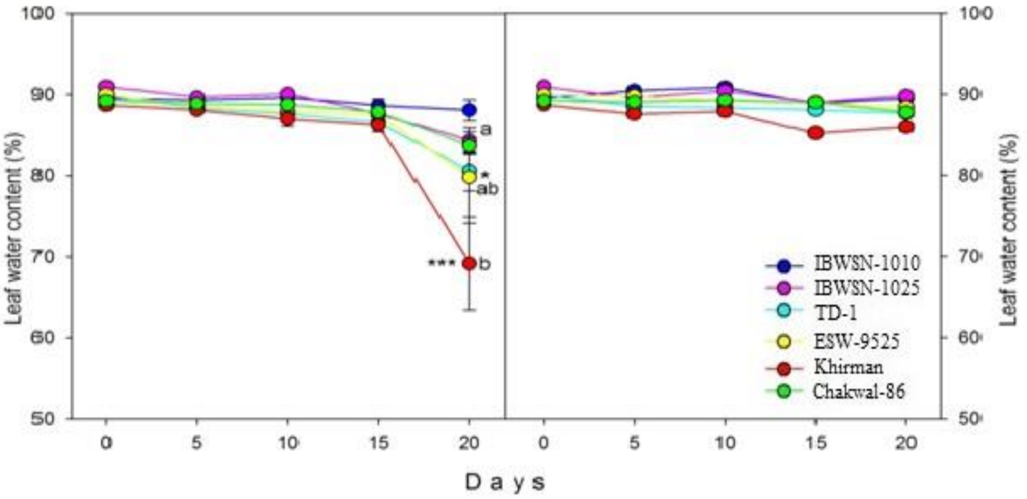

Figure 5. *Leaf water content (%) ± SE (Standard Error) of six wheat genotypes (n=5) under drought stress and control conditions. Statistically significant differences between day zero and the other days (ANOVA) are marked with an asterisk where *, ***, equals P=0.05 and P=0.001; letters show significant differences (P<0.05) among genotypes on each selected day*

Soil water content

All of the genotypes significantly ($P<0.001$) reduced the soil water content during the first five days of the drought treatment except Chakwal-86, where soil water was unchanged (*Fig. 6*). After five days, all the cultivars had significantly ($P<0.001$) decreased soil water content throughout the drought period but differed in the rate this occurred; the decreases were of 45%, 42%, 37%, 37%, and 28% in cultivars Khirman, ESW-9525, TD-1, Chakwal-86, IBWSN-1025 and IBWSN-1010 under drought stress period, respectively (*Fig. 3.14a*). Soil water content was approximately the same in all the cultivars under control conditions (*Fig. 6*). 33% was non-significant.

Soil and plant water relations

The relative water content decreased after ten days of the drought in all of the three cultivars (*Fig. 7*). The cultivar Khirman had significantly ($P<0.001$) lower RWC on the fifteenth day of the drought treatment. All of the other genotypes maintained steady RWC until fifteen days of the drought treatment. Overall decreases of 20%, 14%, and 7% were shown in cultivars IBWSN-1010, Chakwal-86, and IBWSN-1025 on the twentieth day of the drought. A significant (*P*<0.001) decrease in RWC of 52% compared to day zero was noted in Khirman from ten to twenty days of the drought treatment (*Fig. 2*). However, IBWSN-1010 and Chakwal-86 had shown significantly higher (*P*<0.05) RWC, whereas the cultivar Khirman had significantly lower RWC than other genotypes on the twentieth day of the drought treatment. All the genotypes had a relative water content of 97-100% under control conditions (*Fig. 7*).

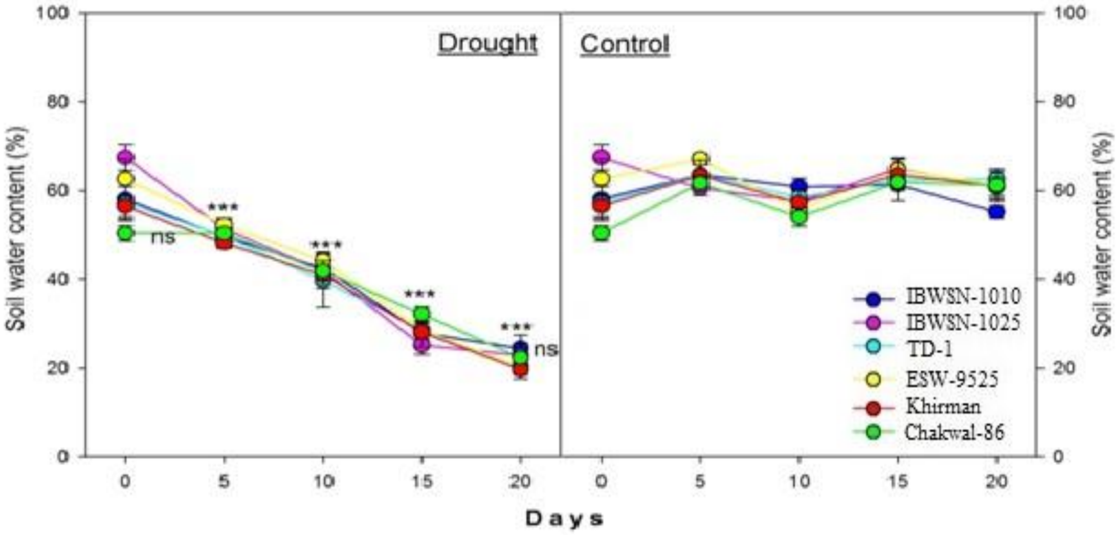

Figure 6. *Soil water content (%) ± SE (Standard Error) of six wheat genotypes (n=5) under drought stress and control conditions. Statistically significant differences between day zero and the other days (ANOVA) are marked with an asterisk where ***, equals P=0.001. ns= no significant. Ns=non-significant write in all fig description*

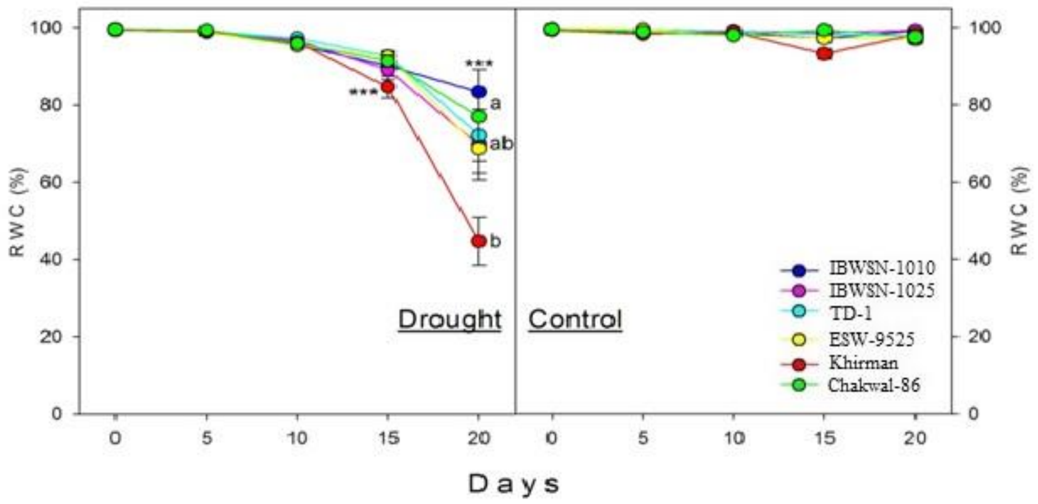

Figure 7. *Relative water content (%) ± SE (Standard Error) of three wheat genotypes (n=5) under drought stress and control conditions. Statistically significant differences between day zero and the other days (ANOVA) are marked with an asterisk where ***, equals P=0.001; letters show significant differences (P<0.05) among genotypes on each selected day*

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All the genotypes showed highly significant ($P<0.001$) decreases in soil Ψ_w on the fifteenth and twentieth days of the drought treatment (*Fig. 8*). Soil Ψ_w gradually decreased during the first ten days of the drought treatment, showing the largest decrease in 5757-3 (-3.0 MPa), Khirman (-2.3 MPa), followed by ESW-9525 (-2.2 MPa), IBWSN-1010, IBWSN-1025 and Chakwal-86 (-2.0 MPa) under drought stress conditions. Under control conditions, all the cultivars had approximately the same soil Ψ_w (*Fig. 8*). All the genotypes maintained their leaf Ψ_w until ten days of the drought stress then, from ten to fifteen days, leaf Ψ_w significantly ($P<0.001$) decreased in all the cultivars (*Fig. 8*). The cultivars Chakwal-86, IBWSN-1010, and IBWSN-1025 retained significantly higher ($P<0.05$) leaf Ψ_w than the genotype Khirman on the twentieth day of the drought treatment. No significant changes were recorded in leaf Ψ_w under control conditions in any of the cultivars (*Fig. 8*).

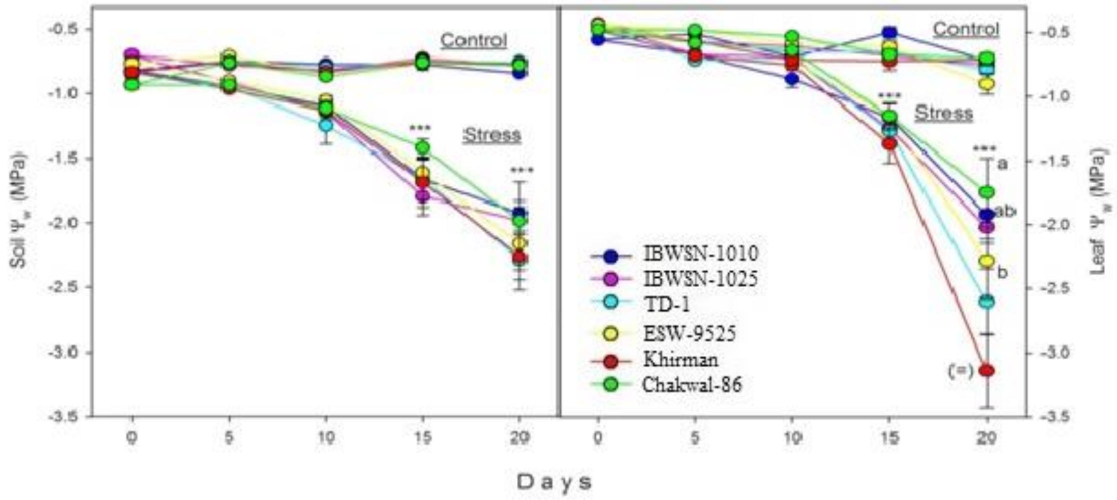

Figure 8. *Leaf water potential and soil water potential ± SE (Standard Error) of six wheat genotypes (n=5) under drought stress and control conditions. Statistically significant differences between day zero and the other days (ANOVA) are marked with an asterisk where ***, equals P=0.001; letters show significant differences (P<0.05) among genotypes on each selected day. (=): Only two replicates/leaves were alive out of five*

Discussion

Since the last decades drought has spread major areas of the world intensifying extreme loss to agriculture production (Daryanto et al., 2016). The response to stress creates wide variability at morphological, cellular, physiological, biochemical, and molecular level and the expression of key genes results in enhanced stress tolerance (Tas and Tas, 2007; Aprile et al., 2013). In the present study, the changes was observed from detrimental effects of the drought on the essential metabolic processes, leading to loss in growth, and slowing of crop development, which ultimately would have damaged crop quality and production. Drought stress restricts plant growth and crop production (Shao et al., 2005); it is therefore important for plants to continue growth during drought to avoid its influences. Tolerant cultivars Chakwal-86, IBWSN-1010 and IBWSN-1025 had significantly higher shoot fresh and dry masses under drought stress compared to the sensitive cultivar Khirman, suggesting that these cultivars were tolerant of drought stress. The results are in agreement with finding of Datta et al. (2011), and Tas and Tas (2007),

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who reported higher losses in fresh and dry masses in sensitive cultivar than tolerant under drought stress in wheat genotypes. Loss of leaf fresh weight was noted after the tenth day of the drought treatment in all the cultivars, suggesting that the severe phase of the drought started from the tenth day of withholding water (Demirevska et al., 2008). However, leaf fresh weight did not decrease in any of the cultivars in the de-tillering experiment except in Khirman, which significantly decreased its leaf fresh weight by 65% because soil water content decreased more slowly. Keles and Öncel (2004) also reported significant decrease of 40% in fresh weight in wheat under drought stress. The retention of higher leaf fresh weight suggested leaf longevity under drought stress in tolerant cultivars. Losses of fresh and dry weights under drought stress were associated with the leaf senescence and finally mortality in sensitive cultivar. Leaf senescence has importance under drought stress because it contributes to remobilization of leaf resources to other parts of the plant to ensure survival (Munné-Bosch, 2007; Qadir et al., 2019). Leaf senescence and leaf mortality had started after five days of the drought treatment in all of the cultivars. Leaf senescence progressed from the tip towards the base of the leaf, while leaf mortality was concomitant with continued shoot growth, indicating translocation of resources away from senescing tissues. Leaf mortality rates also increased with the severity of the drought and became a problem for the sensitive cultivar Khirman as most of its leaves died under drought stress conditions. All the cultivars had a significantly higher number of living leaves compared to Khirman under drought stress conditions. According to Liu and Li (2005), the drought sensitive cultivar (Khirman) is highly sensitive to severe drought stress than the moderate stress. Other cultivars intentionally reduce the leaf number to survive on available water resources and remobilization of leaf resources in the growing shoot tips, while Khirman does not managed these resources towards shoot tips.

Leaf water content (LWC) is considered as indicators of the water status of the plant (Zhou et al., 2021). LWC was significantly higher in tolerant cultivars compared to sensitive and hybrid cultivars under drought stress, suggesting that retaining higher water content in the leaf as the result of higher turgor potential. The results are in agreement with the finding of (Fresneau et al., 2007), who had observed a significant decrease in LWC under drought stress in wheat. Brown et al. (2010) and Nayyar et al. (2005) have suggested that leaf water potential (LWP) should be considered a reliable parameter to quantify plant response to drought stress, and can be used as a selectable marker for improving drought tolerance in different crops. Tolerant cultivars had significantly higher LWP under the drought treatment compared to the sensitive cultivar Khirman, which had only two leaves alive out of five replicates suggesting that the maintenance of higher LWP will enable tolerant cultivars to keep higher rate of photosynthesis and therefore maintain shoot growth under drought stress conditions. LWP was decreased significantly under the drought treatment in all the cultivars. Liu and Li (2005), and Tambussi et al. (2005) have observed significant decrease in LWP in wheat cultivars under drought stress conditions. Genotypic difference were reported by Subrahmanyam et al. (2006), and Tas (2007), who observed a significantly greater decreases in leaf water potential (leaf Ψ_w) in sensitive wheat cultivars compared to tolerant cultivars under drought stress conditions. Drought stress also significantly decreased leaf Ψ_w in other crop plants (Medeiros et al., 2012).

Leaf area only decreased in Khirman under the drought treatment. Maintenance of leaf area in the tolerant cultivars was associated with higher leaf water status, whereas loss of leaf area in the sensitive cultivar was associated with lower leaf water status under drought stress. Leaf area decreased significantly in all the cultivars under drought stress conditions suggesting leaf senescence had occurred. This could be a strategy to avoid further water loss or simply a response to insufficient water availability, because with greater leaf area, higher water losses occur. The results are in agreement with the finding of who observed leaf senescence and reported 36% of remobilization in a controlled pot experiment, while Da Ros and Mansfield (2020) reported leaf senescence and observed 57-79% remobilization of resources in field conditions. A decrease in leaf area under drought stress has also been shown in multiple crops (Chaves et al., 2002). Reductions in leaf area under the drought reduce both biomass and radiation interception by plants. Relative water content (RWC) is considered as indicators of the water status of the plant. Relative water content is an important characteristic for estimating tissue hydration and water status (Zhang et al., 2015). RWC was significantly decreased in the sensitive cultivar Khirman from the fifteenth day of the drought treatment, suggesting that it had lost water faster in early days of the drought treatment, and that this resulted in lower leaf turgor. Fresneau et al. (2007) have also reported a significant decrease in RWC after ten days of the drought stress in wheat. RWC was significantly decreased in all the cultivars under drought stress conditions. Similar results were reported by Medeiros et al. (2012), who observed significant decrease in RWC in four wheat cultivars subject to drought stress. RWC was significantly decreased under drought stress in all the cultivars in accordance with the findings of Fresneau et al. (2007), Huseynova et al., (2007), and Liu et al. (2006). A significant decrease in RWC was observed in different crops under drought stress conditions (Medeiros et al., 2012). The salt tolerant cultivars IBWSN-1010, IBWSN-1025 (salt tolerant liens), had significantly higher RWC compared to sensitive cultivar Khirman under the drought treatment, suggesting higher RWC helped to maintain photosynthesis and growth in these cultivars. Higher RWC was previously reported in tolerant and lower RWC in sensitive cultivars of wheat under drought stress (Subrahmanyam et al., 2006).

Plant water status is closely associated with the water status of the soil (Bellot and de Urbina, 2008). Soil water potential (SWP) and soil water content (SWC) are the measures of water availability to the plants and its abundance in the soil. SWP and SWC decreased significantly in all the cultivars under drought stress compared to day zero suggesting increasing drought stress caused a progressive decrease in soil water status. The results show that the drought treatment had worked properly. The results are in agreement with the findings of who observed a significant decrease in SWP in wheat cultivars under drought stress conditions. SWP also decreased significantly in a range of different crops subjected to drought stress (Volaire, 2003). SWC was significantly higher in Chakwal-86 and IBWSN-1010 on the fifth day of the drought treatment compared to remaining cultivars in tillering experiment. No genotypic difference was observed under drought stress conditions supporting the former explanation, and suggesting removal of tillers had worked, such as all the cultivars had the same available water. Similar results have been reported by Volaire (2003) and Xiong et al. (2006), who had observed significant decrease in SWC and SWP under drought stress conditions in wheat, but no genotypic differences were observed.

Conclusions

The preliminary results showed that different degrees of stability were shown by salt and drought tolerant cultivars under drought stress conditions. The drought tolerant cultivar Chakwal-86 was also found to be more tolerant to drought compared to the salt tolerant and intolerant lines. Under severe drought conditions, senescence of mature leaves reduced the leaf area and caused higher leaf mortality in Khirman, a typical drought sensitive variety, compared to tolerant lines, which showed lower leaf mortality. The cultivars Chakwal-86, IBWSN-1025 and IBWSN-1010 had significantly higher relative water content and leaf water potentials and lower decline in leaf water potential, while Khirman had significantly lower leaf water potential by the twentieth day of the drought. These results suggest that Chakwal-86, IBWSN-1010, and IBWSN-10250 retained more water and therefore had higher water use efficiency, which enables these genotypes to continue growth, as shown by the continued increase in plant biomass. The decrease in relative water content is an indication that a plant is facing osmotic stress; as a result, photosynthesis may be affected. Strong recommendations for future studies are also needed.

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