Wheat Performance Evaluation at Drought Environment

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***Abstract*—In this research, we studied the performance of a wide variety of wheat ecotypes in arid and semiarid environments region of Iran. To evaluate the performance of the wheat we studied variables including changes in dry weight of stem, leaves, spike and dry matter remobilization from these organs as well as grain yield and harvest index. We evaluated the responses of sink and source to several treatment methodologies. The performance of the photosynthesis transport mechanism before and after treatments for two core categories in wheat genotypes were studied. To further evaluate performance we analyzed the water-soluble and alcohol-soluble carbohydrate volume in the stem with two methodologies. The results showed significant relationships between increasing severity of drought stress and a decrease in grain yield for various genotypes and an increase in sink limitation. Moreover, dry matter remobilization also decreased to a greater extent. Additionally, the results show that in an arid environment drought stress causes the transportation mechanism to malfunction. Outcomes show that under drought stress grain yield will be more confined and therefore the soluble carbohydrate will reside and accumulate in the stem and transpiration to spikes will be slowed down dramatically.**

***Index Terms*—crop, abiotic, drought stress, drought tolerance, carbohydrate, sustainability**

I. Introduction

A limited water and drought environment will be challenges in the very near future. Accordingly, crop performance evaluation and stress resistance improvement (especially drought tolerance) at the molecular and physiological level is a complex and challenging phenomenon that needs further research. Wheat is one of the most important and strategic crops in the world. As such, monitoring and analyses of physiology and phenotype expression at the crop level needs sophisticated methodologies and well established labs. Drought is a severe abiotic stress and it is considered as the major constraint on wheat productivity globally with noticeable restrictive effects on plant growth [1]. Drought mechanism at the molecular and physiological level is a multi dimensional complex phenomenon. Beltrano and Marta at 2008 listed the most significant factors of the plant response to drought stress as development stage, duration of stress, severity of stress, and the cultivar genetics [2]. Osakabe at 2014 reorganized the mechanism that a plant might choose to adapt with the drought stress [3] These strategies are summarized into drought tolerance, drought avoidance, and drought escape [3]. In small grains the stored carbohydrate is one of the most important elements of resources to the stem [3]. Dreccer *et al.* at 2013 described in detail that during the filling up of the grain this resource is having a great role in relative stability of the grain performance while it is under the abiotic stress. [4] This study is in accordance with the research by Dordas at 2012 which showed that these materials are having the most significant role and value in stabilizing the performance during the filling up the grain under sever environmental conditions. [5] Wardlaw and Wilenbrink at 1994 reported that the carbohydrate of stems' role in filling up the wheat grain is 10% to 12% when the optimum humidity condition is held for wheat [6]. This participation role of carbohydrates will increase to 40% at the water deficient stress situation [6]. MengYun *et al.* at 2015 mentions that the storing and transportation of the photosynthesis materials to grain are the core mechanisms of keeping the sink and resource balance. [7] The accumulated carbohydrates are in the form of water and alcohol soluble but in most cases they are in the form of water soluble. Water deficiency affecting the storing and transportation of stem resources in wheat [8], [9].

Having access to the wheat cultivars that are able to survive and grow under the drought and severe abiotic stress is highly valuable and needed. This important concept would be achievable by improving the performance of the re-transpiration of the resources under the severe abiotic conditions.

This research studies the variation and adaptation of the water and alcohol soluble carbohydrate in the wheat as the most significant material in the remobilization matter. Therefore, in this research we studied the wheat cultivars with lowest water consumption and highest remobilization performance.

II. Materials, Location, and Methodology

The location for this research was found after a specific search with the aim of providing the approximate situation for simulating the desired environment. After applying controlled drought stress we evaluated the temporal performance of the treatments at 1, 14, 28, and 42 days after anthesis. The core of our methodologies for the evaluation of these performances was based on a

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chemical phenol-sulfuric acid performance evaluation method and non-chemical near infra-red approach. The research farms in this study are at the Grizeh region in Kurdistan, Iran. The experimental farms are located the south eastern side of the city of Sanandaj with the geographical latitude 4t°1'E and longitude of 35°16'N. The elevation (Altitude) of the farms is 1375 meters above the sea level. The average of the precipitation in the studied area is 492 mm. We classified the soil as Sandy Loam with the electrical conductivity of 4.0 decisiemens per squared centimeters (dS/cm^2). The pH is measured at average of 6.7 with the 81.1% of organic carbon content. We collected 12 category of Sardari wheat in the region for this research as our primary wheat type in accompaniment with Azari-2 cultivar as secondary wheat type. Each experiment repeated 3 times in a split plot manner in the randomized block frame work. We designed the experiment in 6 drought stress classes which is described in detail:

S1) Full irrigation till April 19th and stop irrigation and applying drought stress from April 19th till maturity. With the inclusion of rain shelter at this duration.

S2) Full irrigation till May 4th and stop irrigation and applying drought stress from May 4th till maturity. With the inclusion of rain shelter at this duration.

S3) Full irrigation till May 20th and stop irrigation and applying drought stress from May 20th till maturity. With the inclusion of rain shelter at this duration.

S4) Full irrigation till maturity.

S5) Full irrigation till maturity and spraying with Sodium Chlorate for 14 days after first sprout for stopping the photosynthesis mechanism.

S6) Rain fed.

At the S1 and S2 treatments after applying the last irrigation we applied the drought stress. We prohibited the rain to reach the crops by using a steel structure which had plastic shelter. In each 3.5 meters we harvested 280 wheat seeds in a line from each 12 ecotypes and a marginal line at each side. The distance between the lines was 40 centimeters. Therefore, each main section had a 13 line with two marginal lines. Each set of repetition of the experiments included 6 main section. Each two sections mutually placed apart from each other by 2.5 meters distance. During the full irrigation we calculated the amount of irrigation based on the water needs of the specific soil. The water irrigation was controlled mechanically.

Our core methods for the evaluation of the performance of the treatments were based on the measurements of the soluble carbohydrate in stem. We used the well known method proposed by Yemm and Wills for the performance evaluation [10]. We evaluated 780 specimens related to stem at day interval of 1, 14, 28, and 42 after the sprout.

III. Results

One of the research questions that we investigated, basically our core idea, was to evaluate the performance of the Sardari wheat ecotype against the drought stress. Variance analysis of the results tabulated in Table I shows that the effects of drought stress, ecotype, and their interaction on the performance are statically significant. Comparison the average of the performance results shows that the best performance (136.06 g/m^2) was achieved by full irrigation till maturity and the least performance was belonged to the treatment which applied the more drought stress. Table II shows that the more time we give to crop to have access to full irrigation is having positive effect on the whet performance.

TABLE I. Result of Performance Variance Analysis in 12 Sardari Ecotype and Azar-2 Cultivar under Drought Stress Treatment

Source of Variation	Degree of Freedom	Performance of Wheat Ecotype (Sum of Squares)
Repetition	2	4187.730
Drought Stress	5	3216.484**
Error	10	1308.316
Ecotype	12	2556.359
Ecotype Stress	60	1064.079
Error	144	470.010

** shows the significance at the level of 1% probability

TABLE II. Result of Performance Variance Analysis in 12 Sardari Ecotype and Azar-2 Cultivar under Drought Stress Treatment

	Drought stress applied after:			Full irrigation	Spraying	Rainfed
	April 19th	May 4th	May 20th			
Azar-2	42.32	100.3	127.7	105.5	68.37	121.70
Awehang	43.18	127.3	131.3	144.2	162.70	116.90
Baghche-Maryam	64.26	97.05	103.8	122.1	123.50	88.25
Bahar Band	84.16	119.4	111.1	184.4	144.10	138.50
Taze Abad	75.15	110.6	143.9	123.5	130.60	120.00
Telwar	73.3	109.5	124.5	144.0	170.70	131.50
Toodar	54.1	91.41	143.5	176.20	120.30	173.50
Siosemarde	84.62	117.1	126.2	123.60	121.20	102.40
Xushab	45.91	75.59	117.2	148..60	120.40	116.70
Sufian	46.26	98.45	121.4	128.40	132.30	122.10
Kalani	69.82	150.5	109.1	153.40	170.00	131.50
Gavdare	27.91	106.4	149.2	102.90	101.50	99.03
Fetre Zamin	34.8	131.5	141.3	151.00	130.60	100.40
Average	57.36	110.39	126.93	136.06	130.48	120.19

TABLE III. VARIANCE ANALYSIS RESULTS OF WATER-SOLUBLE CARBOHYDRATE OF STEM IN SARDARI ECOTYPE UNDER DROUGHT STRESS (SUM OF SQUARES)

Source of Variation	Degree of Freedom	Number of days passed after sprout			Maturity
		1 day	14 days	28 days	
Repetition	2	525.50^{ns}	86.26 ^{ns}	683.10^{ns}	599.30^{ns}
Drought stress	5	653.60^{ns}	079.24^{ns}	689.40*	774.50^{ns}
Error	10	425.20	318.11	412.30	787.20
Ecotype	12	803.90*	29.50*	213.30ns	383.30^{ns}
Ecotype's stress*	60	069.40*	025.40*	171.50*	117.40*
Error	144	377.20	817.20	875.30	794.20

The experiment design for the treatment with spraying by Sodium Chlorate and full irrigation was the same except that we used the Sodium Chlorate spraying to stop the photosynthesis mechanism. After spraying the leaves with Sodium Chlorate. The results show that this design performed like the control (base) samples with lower performance. At the year we conducted our field study the precipitation was adequately desirable and therefore the average performance of rainfed samples was comparable and slightly better compare to few of the treatments. These finding are shown is Table III.

We evaluated that the simulated drought stress influenced the grain performance significantly. Lawlor describes in detail that the decrease in grain performance under the drought stress is caused by the decrease in size of the resource. [11] In this context the resources are mainly referred to leaves and stems and additionally decrease in the capacity of the physiological resources. Endosperm contains the protein and other nutrients and acts as the food store for the developing plant embryo. Therefore, the decrease in amount of endosperms or decrease in the functionality of enzymes of endosperms as an effect is another cause of the decrease in the performance of the grains.

Our analysis and evaluation on the interaction between the ecotypes and drought stress showed that the best performance under the full irrigation achieved with Toodar ecotype (176.2 g/m^2) and the least performance under the full irrigation achieved with Gavdare ecotype (102.9 g/m^2). Under the drought stress Toodar ecotype performed the best amongst all of the ecotypes with rainfed treatment (173.5 g/m^2). The next best performance was achieved in the Kalati ecotype under the S2 treatment with the 170 g/m^2 and the least performance amongst belonged to Gavdare under the S1 treatment with 91.27 g/m^2. Therefore, under the drought stress we classified Toodar and Gavdare ecotype as the most and the least resilient ecotype respectively. The higher performance of Toodar ecotype is showing that this cultivar is having a better grain performance which is achieved by its adaptability in utilization of the soil humidity. Osmani and Siosemarde at 2011 reported that there are significant differences between Sardari ecotypes [12]. For the very first time in the abovementioned region we evaluated the performance of the Sardari different ecotypes in this research.

A. Water Soluble Carbohydrates in Stem under Drought Stress

Table III shows the significance of the interaction effects of the drought stress and ecotype on the soluble carbohydrate in water. Our analysis showed that the level of the soluble carbohydrate in water at the stem stayed unchanged during the 14 days after the sprout. During the life grain span between 14 to 28 days the level of soluble carbohydrate in water decreased (Fig. 1). This gradual decrease is explained by the mechanism of disintegration of these carbohydrates into simpler forms of sugar compounds which are soluble in alcohol and transported to the grain. As we show this phenomenon in Fig. 1 during this life span the total amount of dissolved carbohydrate in the stem (especially at the treatments with desired irrigation) did not decrease. However, the amount of soluble carbohydrate in water (which is a portion of total amount of soluble carbohydrates) decreased dramatically. After 28 days passed from the sprout till maturity, under all treatment procedures the level of the soluble carbohydrate in water stays unchanged or increased. This evaluation is displayed in Fig. 1. Therefore we concluded that the variation in the level of the total soluble carbohydrate is corresponded to the variation in the level of carbohydrate soluble in alcohol and not water.

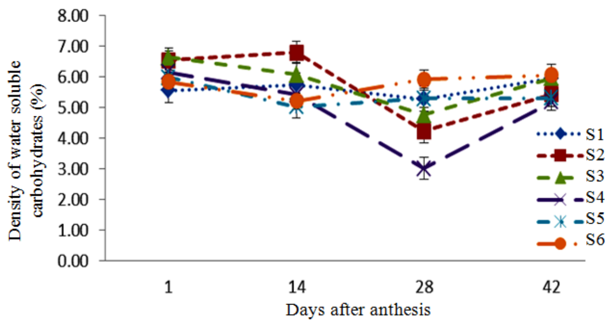

Figure 1. Average of variation in density of water soluble carbohydrates in stem of Sardari ecotype under different drought stresses

B. Alcohol Soluble Carbohydrates in Stem under Drought Stress

Table IV is the results of variance analysis and it shows the significance of the interaction effects of the drought stress and ecotype on the soluble carbohydrate in alcohol. Our analysis as shown in Fig. 2 described in detail that the soluble carbohydrate in alcohol are in the light form such that could be transported via dissolving in phloem sap during the fill up of the grain. During this life span of the grain we evaluated significant changes in soluble carbohydrate in alcohol level under different drought stress scenarios. This pattern was closely following the pattern of the changes in the level of total carbohydrate in the stem and not soluble carbohydrate in water. Therefore, the total variation pattern of the stem is mainly influenced by the variation pattern of the alcohol soluble carbohydrate. The soluble carbohydrate in alcohol is the ready-to-transport carbohydrate to grain. Fig. 2 shows that under the S1 treatment procedure the rate of soluble carbohydrate in alcohol keeps increasing for 28 days after the sprout. The explanation for this increase is based on unchanged level of soluble carbohydrate in alcohol. The source of the increase of this soluble carbohydrate in alcohol is not related to the soluble carbohydrate in water. The reserve of the soluble carbohydrates in alcohol is due to excess of the photosynthesis matter which accumulated in the stem. Consequently this accumulated carbohydrate by decreasing the osmosis potential enhances the stress tolerance. Fig. 2 is depicting this finding.

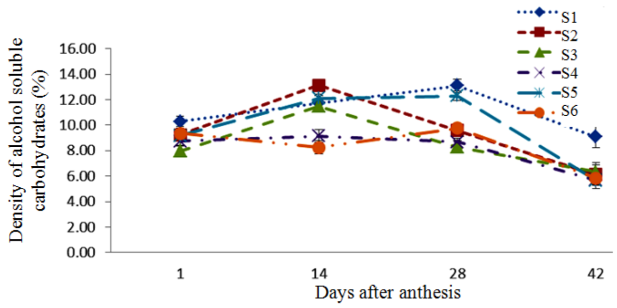

Figure 2. Average of variation in density of alcohol soluble carbohydrates in stem of Sardari ecotype under different drought stresses

TABLE IV. VARIANCE ANALYSIS RESULTS OF ALCOHOL-SOLUBLE CARBOHYDRATE OF STEM IN SARDARI ECOTYPE UNDER DROUGHT STRESS (SUM OF SQUARES)

Source of Variation	Degree of Freedom	Number of days passed after sprout			Maturity
		1 day	14 days	28 days	
Repetition	2	341.127*	602.48ns	495.36*	236.10ns
Drought stress	5	181.25*	775.132*	500.150*	729.67*
Error	10	422.70	162.32	697.60	314.50
Ecotype	12	622.27*	307.13*	755.50ns	616.50ns
Ecotype's stress*	60	352.40ns	047.16*	884.11*	245.11ns
Error	144	745.40	800.60	667.40	240.11

During the experiment of carbohydrate density variation under the S2 and S3 drought stress procedure we evaluated that the carbohydrate density is increasing for 14 days after the sprout. On the other hand while we were conducting the experiment the precipitation was adequate and since the rainfed procedure is less sensitive to drought stress in addition to lower need of osmosis adjustment we recorded lower variation in the alcohol soluble carbohydrate density. Comparison of the results (refer to Fig. 1 and Fig. 2) shows that the alcohol soluble carbohydrate is twice of the water soluble carbohydrate.

Severe drought stress (e.g. S1) will cause the smaller size of grain and spike formation. Due to this small size of grain the required amount of photosynthesis material is minimal. Therefore, the accumulated alcohol soluble carbohydrate in the stem (which is ready to be transported to the grain) will remain in the stem. The direct consequences of this mechanism are the increase in the density of alcohol soluble carbohydrate in the stem compare to the other drought stress scenarios. The inadequate transportation from the stem to the grain will lead to the deficiency in conversion of carbohydrate to grain starch. This result also is supported by the low performance of the studied genotypes in this treatment (Table II).

At S5 treatment scenario (spraying the Sodium Chlorate) like the severe drought stress treatments we evaluated the increase in alcohol soluble carbohydrate during the 28 days after anthesis. Fraire-Velazquez explains that this increase might be because of the disintegration of the insoluble carbohydrates, synthesize of compounds from non-photosynthesis routes, growth suspension, or not suing the soluble carbohydrates. [13]

Fig. 3 shows that the relation between total density of the soluble sugar (in water and alcohol) during anthesis with final performance is in reverse order. The more soluble sugar we have the lower performance we achieve. Farooq at 2014 describes that the large amount of soluble sugar is the significant sign of the grain limitation in spite of relevant continuation of the photosynthesis. [14]

Under the drought stress due to small size of the grain the soluble carbohydrate will be accumulated in stem and will not be transferred to spike. Therefore, the effect of drought stress on the grain size is more than the effect of stress on the soluble carbohydrate accumulation via the continuation of the current photosynthesis. Under the drought stress if the stress is having significant effect on the production and accumulation of soluble carbohydrate we should have evaluated a lower effects compare to the control specimens. However, we measured otherwise and this finding supported our hypothesis again. In other words our experiments show that the stress influenced the crop by decreasing the grain size more dramatically compare to the production level of soluble carbohydrate. Therefore, this phenomenon leads the crop to approach an equilibrium state between the photosynthesis matter production (resource size) and the grain capacity (grain size). Farooq described in detail that the very first response of the grain to abiotic stress is capacity reduction (smaller grain size). [14] The direct consequence of this reduction is the significant deduction in number of inflorescence.

Fig. 4 shows the inverse relation between the soluble carbohydrates in stem and grain performance at the stage of maturity. This finding explains that for those drought stress scenario which reduced the performance (at the maturity stage) soluble carbohydrates in stem increased.

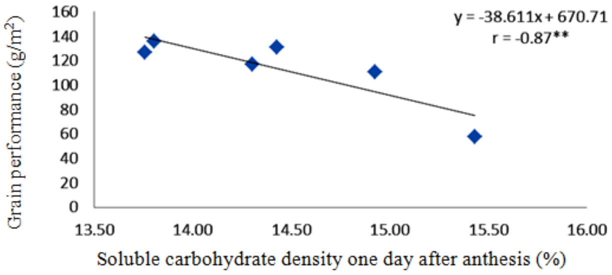

Figure 3. Relation between grain performance and soluble carbohydrate density one day after Anthesis (under the different drought stress)

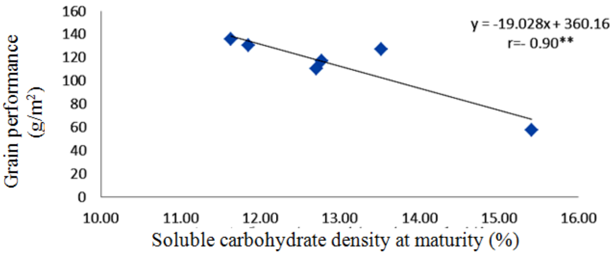

Figure 4. Relation between grain performance and soluble carbohydrate density in stem at maturity stage (under different drought stress)

Therefore, not having adequate reservation of carbohydrate in stem does not reduce the performance. However a combination of (a) grain's low need for carbohydrate, (b) low possibility for transporting the soluble carbohydrate to grain, or (c) no capability of the grain for accepting soluble carbohydrate (because of the grain's water content reduction or grain size reduction) could be the reason for the performance reduction. Javanmardi *et al.* observed similar result such that performance and soluble carbohydrates are related inversely [15]. This relation is based on the notion that reduction in grain capacity at drought stress is decreasing the need for carbohydrate compounds. In this research we evaluated the reduction of the grain size and therefore the capacity in Sardari wheat ecotypes at severe drought stress. Mostly Iran is considered as dry or semi-dry region. In these environments, first day light is adequate for a high level of photosynthesis and secondly on the other hand remobilization performance (before and after anthesis) is minimal. Based on these two facts Siosemarde describes that grain size (Endosperm count) and grain performance are the controlling factor of the grain weight [16].

IV. Discussion

The Sardari ecotype under the drought stress showed a dramatic decrease in the sink size and therefore this decrease is explained as the main reason for limitation and deficiency. The study showed that the effect of drought stress on the sink is much more than the effect of drought on the soluble carbohydrate accumulation. At another direction of this research we found a significant and very descriptive correlation between the decrease in photosynthesis material production (Resource Size) and the grain capacity (Sink Size) under the severe drought stress. This mechanism and finding was the core of the explanation of the increase in the weight of the grain while we evaluated decrease in the size of the resource and also decrease in performance. We were able to correlate the increased level of alcohol-soluble carbohydrate in the prematurity stage with the size of the sink especially after the treatment for severe drought stress. The outcomes show that under drought stress grain yield will be more confined and therefore the soluble carbohydrate will reside and accumulate in the stem and transpiration to spikes will be slowed down dramatically.

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