Journal of Plant Physiology & Pathology

Research Article

A SCITECHNOL JOURNAL

Effects of Drought Stress on Morphological, Physiological Traits of Wheat (*Triticum aestivum* L.) Cultivars in Pakistan

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Abstract

Drought is major abiotic stress affecting the morphological, physiological and biochemical processes. Genetic improvement for drought tolerance in wheat could be possible to develop new genotypes through conventional breeding. To investigate drought resistance under water stress condition, a trial was conducted in spilt block design, using eight genotypes, i.e., Inqlab-91, PBGST-03, PBGST-01, PBGST-02, SKD-1, Hero, Sundar, and Sassuai along with two treatments (non-stress and water stress at anthesis stage). The experiment was carried out inthe field of Botanical Garden, Sindh Agriculture University, Tandojam, Sindh, Pakistan. A significant reduction appeared in morphological traits at the anthesis stage due to the reduction of irrigation. The mean squares from analysis of variance due to genotypes, treatment, and treatments x genotypes interactions were significant at $P \leq 0.05$ for all the traits, indicating that the genotypes performed variably under stress conditions. Based on the mean performance, among the cultivars; Sassui revealed better performance for grains spike^{-1}and seed index (1000gwt) under normal irrigations, whereas under stress at anthesis, PBGST-02 showed higher grain yield plant^{-1}, maximum productive tillers, and spikelets spike^{-1}. Hence, such genotypes could be suggested to be tolerant under water stress.The correlation coefficient showed that spike length, spikelets spike^{-1} and grains spike^{1} possessed positive and significant association with grain yield plant^{-1} at normal conditions. Seed index (1000gwt.) and harvest index (%) exhibited a positive but non-significant correlation. However, these all traits revealed a positive significant association under stress conditions with grain yield plant^{-1}. Based on these results, the genotypes PBGST-03, Sassuai and SKD-1 are the potential genotypes that could be used in the water-deficient condition.

Keywords: Wheat; Drought stress; Yield; Morphological traits; Correlation

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Received: February 05, 2021 **Accepted:** March 12, 2021 **Published:** March 19, 2021

Introduction

Wheat (*Triticum aestivum* L.) is known as the king crop among the main cereal crops and staple food for a large world population. It contributes about 20 to 28% to a nutritional energy source in human health [1]. People rely on grain crops and other plants to acquire nourishment [2,3]. Wheat is broadly consumed grain nutrition of the world [2,3]. Generally, the rapid climate change and increasing food demand around the world require wheat breeding that offers great quality along withhigh yield potential and resistance or tolerance to abiotic and biotic stresses [4]. Wheat has been cultivated on 228 million hectares throughout the world. However, its productivity is affected by many factors, such as drought, which is one of the main environmental factors that largely affects wheat productivity.Water deficiency is likely to become a serious global problem around 2025, particularly in highly populated areas [5,6].

The promising way to fulfill and face the food needs of the growing world population is to develop more drought-resistant and less water requiring genotypes. Up to 26% of the usable area of the earth is subjected to drought [7,8]. The response of plants to water stress depends on several factors such as development stage, severity and duration of stress and cultivar genetics [9]. It is hard to increase the yield of wheat crops such as grains, through the genetic breeding method to produce drought resistance or tolerant cultivars. However, related to grain yield, traits are the most important factors in wheat crop breeding [10]. In the development and growth stages of wheat, the most critical stages to drought stress are grain filling and flowering, during which wheat reveals the highest sensitivity to water scarcity [11,12]. Moreover, various factors are involved which affect wheat growth, such as drought stress, response to plant genotypes,gene expression [13,14] plant development and growth stage duration, severity of stress, physiological changes during growth stage [15] photosynthesis [16] and respiration activities [16,17] and other environmental factors [18].

In addition, morphological characters, for example, root length, tiller, number of spikes per m2, grains spike^{-1}, ripe tillers plant^{-1}, 1000 grain weight, peduncle length, spike weight, stem weight, awn length, grain weight spike^{-1}, grain yield, biomass, harvest index, plant height and primary spike length influence the wheat resilience to drought stress [19,20]. Enhancing the genetic potential of wheat to drought and distinguishing proof of tolerant genotypes are the primary goals of provincial breeding programs. It has been found that under the water shortage conditions, those genotypes that demonstrate the most surprising harvest record and most raised yield trustworthiness are dry season tolerant [21,22].

Water stress flexibility differs from plant to plant and even inside species. Water shortage and salt stress are worldwide issues that influence the survival of agricultural plants and maintainable nutrition productivity [23]. In plants, a greater understanding of the morpho-anatomical and physio-biochemical attributes of variations in drought resistance might be utilized to choose or make new genotypes to acquire a superior efficiency under stress conditions [24,25]. Reinforcing dry conditions duringthe development stage limits the mechanism of photosynthesis by the activation ofreactive oxygen species thatinfect photosynthetic pigments, photosystems

I and II and electron transport proteins. Lessened plant size, leaf territory, and leaf region file are important elements for directing water utilization and diminishing harm under dry spell stress [25]. The present study was designed to determine the sensitivity of wheat growth stages to drought stress and specific objectives were to determine correlations between yield, yield components and different traits related to yield under drought stress.

Materials and Methods

The present experiment was laid out at the experimental field, Department of Plant Breeding & Genetics, Sindh Agricultural University, Tandojam, to screen drought tolerance in wheat genotypes. The trial was conducted insplit block design under two treatments (non-stress and stress at anthesis) in four replications and eight genotypesviz. Inqilab-91, PBGST-03, Sundar, PBGST-01, SKD-1, Sassuai, PBGST-02 and Hero were used.The essential mechanical procedures were performed consistently in all the plots throughout the growing period. Before the first irrigation, seedlings were diluted to check uniform and reduced plant race for optimum plant growth and development. All the agronomic practices were done at the proper time. Manure at the frequency of 125-75 kg N&P ha^{-1} was applied in the form of Urea and DAP. Randomly five plants were selected from each replication as per genotype for compiling data for the following characters.

Plant height (cm)

The plant height was taken from each of the selected plant in centimeters from bottom to tip of spike without awns at the time of maturity to calculate the mean performance of plant height per cultivar.

Productive tillers plant $^{-1}$

The number of productive tillers was counted randomlyfrom selected plants at the time of maturity and total fertile tillers from each plant were recorded.

Spike length (cm)

The spike lengthwas taken in centimeters from the lowest point of the spike to the uppermost spikelets of a spike of main tillers without awns.

Spikelet spike^{-1}

The spikelets of main spikes from each particular plant were counted per genotype and used as mean spikelets for each cultivar.

Grains spike^{-1}

The total numbers of grains in the main spike were counted for data analysis.

Seed index (1000-grain weight)

One thousand seeds were counted and weighed in the laboratory with the help of electronic balance in terms of grams.

Grain yield plant^{-1}(g)

After harvesting, each plant was threshed separately by hand to obtain pure seeds, cleaned in the laboratory and grains were weighed on an electronic balance and yield plant^{-1}was recorded in grams.

Grain yield kg ha^{-1}

Grain yield kg ha^{-1} was calculated with the help of the following formula.

Seed yield per plot (kg) x 10,000 (m^2)

Plot size (m^2)

Harvest index (%)

Harvest index (%) was calculated as the ratio of seed yield divided with total dry matter x 100.

Relative water content (RWC%)

Relative water content (RWC%) was noted by cutting the leaves from the base of lamina, taken in polythene plastic bags and carried to the laboratory as rapidly as probable. The fresh weight was recorded within two hours of excision, and the turgid weight was taken after leaves were placed in distilled water for 4 hours at room temperature (20 ± 2°C) and 60% relative humidity under low light conditions. The leaves were kept on tissue paper after taking them out of the water and turgid weight was noted. Dry weights were taken after drying the leaves in the oven for 24 hours at 70°C and finally, the leaf relative water content was calculated by the following formula [26].

RWC%= (fresh weight-dry weight) / (turgid weight-dry weight) x 100.

Chlorophyll content (R.G)

Chlorophyll was taken with the help of a chlorophyll meter (SPAD 500 Plus) in random units. The physiological observation was examined at anthesisbefore soaking the plants. However, growth and developmental data were calculated at the time of Anthesis.

Statistical analysis

The data were subjected to analysis of variance and least significant differences between means according to the method suggested by Gomez and Gomez (1984) and were compared using Duncans Multiple Range Test as suggested by Duncans [27]. SPSS.V. 8.1 computer software was used to estimate correlation.

Results

Analysis of variance

Mean squares from analysis of variances (Table 1) revealed that plant height, productive tillers plant^{-1}, spike length, spikelets spike^{-1}, grains spike^{-1}, grain yield plant^{-1}, grain yield (kg ha^{-1}), seed index, harvest index, relative water content (RWC %) and chlorophyll content showedsignificant shun caused by the water stress. All genotypes under observation showed significant differences for all morpho-physiological traits studied, which could help a wheat breeder in the selection and evaluation of drought-resistant varieties based upon one or more morpho-physiological characters. The mean squares were recorded significant as to the interaction of treatment × genotype for all these traits except plant height was non-significant. This interaction indicated the significant performance of varieties over the stress treatments and such interaction could help the wheat breeders to select promising varieties based on one or more suitable drought-tolerant indicators and place them in breeding programs to create new drought-tolerant material.

Table 1: Mean squares from analysis of variance for various morpho-physiological traits of wheat genotypes grown under water stress conditions.

Yield Trait	Replication D.F = 3	Genotypes (G) D.F=7	Error (a) D.F=21	Treatment (T) D.F=1	G x T D.F=7	Error (b) D.F=24
Plant height	1.54	190.52**	3.83	1332.25**	5.01n.s	2.68
Productive tillerplant^{-1}	0.56	5.86**	1.11	27.30**	1.05**	0.21
Spike length	1.41	7.03**	0.88	36.90**	1.09**	0.22
Spikelets spike^{-1}	0.20	4.25**	0.11	84.66**	2.19**	0.16
Grains spike^{-1}	1.51	1013.01**	1.24	1766.42**	57.33**	1.03
Seed index	1.16	89.07**	1.41	1427.23**	63.28**	0.69
Grain yield plant^{-1} (g)	0.079	1.13**	0.27	51.17**	0.29n.s	0.24
Grain yield (kg ha^{-1})	7755	1775.3**	2647	9890.91**	1898.11**	5463
Harvest index (%)	0.15	4.01**	1.56	86.29	1.64**	0.48
Physiological Traits						
Relative water content (%)	10.5	104.7**	6.4	22019.2**	58.8**	5.4
Chlorophyll content (RG)	1.773	141.62**	3.221	784.840**	8.208**	2.300

Mean Performance of Genotype under the Water Stress at Anthesis

Plant height (cm)

For to shun lodging, optimal plant height is taken as a significant trait, through the maximum harvest index. On account of an average, -9.13 cm reduction in plant height was noted in stress environment, while Sassuai showed minute reduction (-7.25) followed by PBGST-01 (-7.65), Sunder -8.3 and Inqlab -8.6, whereas the PBGST-03 (-12.2) showed maximum reduction followed by SKD-1 (-10.25), PBGST-02 (-9.25) and Hero (-9.5) (Table 2).

Productive tillers plant^{-1}

On average a decline of -1.3 tillers, plant^{-1} was observed caused by water stress at the anthesis stage. PBGST-01 showed the minimum relative decline of -0.9 followed by PBGST-03 and Sassuai -0.95, while the maximum decline was observed in Inqlab-91 (-3) followed by PBGST-02 (-1.65), Sunder (-1) SKD-1 (-1) and Hero (-1) (Table 3).

Spike length (cm)

On average -1.56 cm reduction was recorded in spike length due to water stress, yet minimum reduction was observed in Sunder -0.8 followed by PBGST-03 -1.1, SKD-1 -1.2, Sassuai -1.3 and Hero -1.1, whereas Inqlab with -3.50 showed a maximum reduction in spike length followed by PBGST-01 (-1.65) and PBGST-02 (-1.80) (Table 4).

Spikelets spike^{-1}

The results regarding the trait Spikelets spike^{-1} (Tables 5-9) indicated that a reduction of -1.79 wasrecorded due to water stress for the character spikelets spike^{-1}. On average, the minimum reduction was recorded in SKD-1 (-0.48) followed by Sunder (-1.22).The maximum reduction was observed in PBGST-03 (-3.52) followed by Sassuai (-3.22), PBGST-02 (-2.93), Inqilab (-2.87), PBGST-01 (-2.13) and hero (-2.03).The maximum number of spikelets however was recorded in PBG-01 and PBG-03 (19.41 and 19.14, respectively) under no-stress conditions. While underwater stress conditions the maximum number of spikeletswererecorded for PBG-03 and PBG-01 17.62 and 17.28, respectively.

Grains spike^{-1}

Under the non-stress condition,the grains spike^{-1} ranged from 38.85 to 74.85, whereas 26.67 to 64.85 was the range of seeds under a stress environment. On account of average -10.54 seeds decline in grins spike^{-1} was observed due to water stress. Maximum seeds among cultivars in non-stress were counted as 74.85, 65.75 64.55 and 56.35 grains spike^{-1} given by Sassuai, PBGST-01, PBGST-03 and SKD-1, respectively. While in stress condition cultivar Sassuai by maintaining its 1st rank gave 64.85 grains spike^{-1} followed by PBGST-03 62.20, and PBGST-01 57.60 respectively and proved to be more tolerant verities on account of grains spike^{-1}.

Seed index (1000 grain weight (g))

Under non-stress on average seed,the index was observed from 43.57 to 53.11, whereas under water stress conditions it ranged from 35.19 to 44.07 g. Though on average, -9.45 g reduction in thousand-grain weight was noted due to water stress, where a little decline in seed index at anthesis stress was noted in Hero -5.34, SKD-1 -5.48 and Sunder -6.39. Moreover, the sharp declines were shown by PBGST-01 -22.43, PBGST-03 -11.45, Sassuai -9.04, Inqlab -8.38 and PBGST-02 -7.08.Based on stress environment, the 1st group of cultivars (Hero -5.34, SKD-1 -5.48 and Sunder -6.39) proved more drought tolerant than that of 2nd group (PBGST-01 -22.43, PBGST-03 -11.45, Sassuai -9.04, Inqlab -8.38 and PBGST-02 -7.08), which is considered as drought susceptible.

Grain yield plant^{-1}

The character grain yield plant^{-1} is considered as the ultimate result of all physiological, agronomical and chemical responses to the drought stress condition. Under stress -2.14 is weighed maximum grain yield plant^{-1}, while PBGST-02,PBGST-03 and PBGST-01 gave high yield plant^{-1} under the non-stress environment with 12.93g, 11.08g and 9.63g, respectively. Under stress conditions the same varieties PBGST-02, PBGST-03 and PBGST-01 gave a high yield and showed minimum decline under water stress conditions, thus proved that they are drought tolerant against other cultivars in test and could sustain the water stress. It was concluded that the cultivars PBGST-02 (9.72), PBG-03 (9.06) and PBGST-01 (7.33) may be preferred for both stress and non-stress conditions. However, the maximum declinewas recorded in cultivar hero.

Harvest index (HI)

To increase wheat productivity one of the useful approaches is to divide yield in biomass at the time of maturity. Nevertheless, the most yield potential progress in wheat has been associated with increased

Table 2: Mean performance for plant heightof wheat grown under non- stress and water stress at anthesis.

Genotypes	Plant height		
	Non-stress	Water stress	R.D*
Inqlab-91	76.4	67.80	-8.6
PBGST-03	87.5	75.30	-12.2
Sunder	75.95	67.65	-8.3
PBGST-01	83.70	76.05	-7.65
SKD-1	77.70	67.45	-10.25
Sassuai	84.00	76.75	-7.25
PBG ST-02	84.85	75.60	-9.25
Hero	74.35	64.85	-9.5
Mean	80.56	71.43	-9.13
LSD (5%) (T)	0.8451		
LSD (5%) (G)	2.0350		
LSD (5%) (T X G)	2.3902		

Table 3: Mean performance for productive tillers plant^{-1} of wheat grown under non-stress and water stress at anthesis.

Genotypes	Productive tiller plant^{-1}		
	Non-stress	Water stress	R.D*
Inqlab-91	7.95	4.95	-3
PBGST-03	5.35	4.40	-0.95
Sunder	5.95	4.95	-1
PBGST-01	5.80	4.90	-0.9
SKD-1	4.40	3.40	-1
Sassuai	6.15	5.20	-0.95
PBGST-02	7.35	5.70	-1.65
Hero	5.50	4.50	-1
Mean	6.05	4.75	-1.3
LSD (5%) (T)	0.5756		
LSD (5%) (G)	1.5803		
LSD (5%) (T X G)	1.6281		

Table 4: Mean performance for spike length of wheat grown under non-stress and water stress at anthesis.

Genotypes	Spike length		
	Non-stress	Water stress	R.D*
Inqlab-91	11.70	8.50	-3.50
PBGST-03	10.90	9.80	-1.1
Sunder	10.30	9.50	-0.8
PBGST-01	12.95	11.30	-1.65
SKD-1	10.95	9.75	-1.2
Sassuai	12.20	10.90	-1.3
PBGST-02	12.95	11.15	-1.8
Hero	12.40	11.30	-1.1
Mean	11.79	10.28	-1.56
LSD (5%) (T)	0.2442		
LSD (5%) (G)	0.9774		
LSD (5%)(T X G)	0.6906		

HI and often stated that progress in HI is exhausted because values are approaching the limits of 60%, hence the focus should be on biomass rather than on HI. On average HI under water stress, decreased by-2.60, whereas the smaller decline was shown by the cultivars such as PBGST-01 -1.24, PBGST-03 -1.53 and Sunder -1.94, and the sharp reduction was observed in Sassuai -4.06, PBGST-02 -3.09, and other cultivars like Hero, Inqilab and SKD-1 with -2.52, -2.15 and -2.08, respectively.Therefore, these two cultivar groups could be considered as highly drought tolerant and susceptible ones, respectively.

Grain yield kg ha^{-1}

On an average,-743.14 reduction in grain yield kg ha^{-1}occurred due to water stress as indicated by analysis of data presented in (Table 10), where PBGST-03, PBGST01, PBGST-02 and Sassuai gave the high yield kg ha^{-1} as 5628.3, 5390.5, 4907.5 and 4905.9, respectively under normal irrigation and water stress condition Sassuai ranked 1st and PBGST-03 with 4291.7, 3884.4 respectively and proved as drought-tolerant against other cultivars in the test.

Table 5: Mean performance for Spikelets spike^{-1} of wheat grown under non-stress and water stress at anthesis.

Genotypes	Spikelets spike^{-1}		
	Non-stress	**Water stress**	**R.D***
Inqlab-91	17.58	14.71	-2.87
PBGST-03	19.14	17.62	-1.52
Sunder	17.37	16.15	-1.22
PBGST-01	19.41	17.28	-2.13
SKD-1	16.60	16.12	-0.48
Sassuai	18.69	15.47	-3.22
PBGST-02	18.16	17.23	-0.93
Hero	17.25	15.22	-2.03
Mean	18.02	16.22	-1.79
LSD (5%) (T)	0.2060		
LSD (5%) (G)	0.3433		
LSD (5%) (T X G)	0.5828		

Table 6: Mean performance for Grains spike^{-1} of wheat grown under non-stress and water stress at anthesis.

Genotypes	Grains spike^{-1}		
	Non-stress	**Water stress**	**R.D***
Inqlab-91	48.55	41.41	-7.14
PBGST-03	64.55	62.20	-2.35
Sunder	44.45	40.19	-4.26
PBGST-01	65.75	57.60	-8.15
SKD-1	56.35	45.65	-10.7
Sassuai	74.85	64.85	-10
PBGST-02	55.90	46.60	-9.3
Hero	48.85	36.67	-12.18
Mean	57.40	49.39	-8.01
LSD (5%) (T)	0.5247		
LSD (5%) (G)	1.1588		
LSD (5%) (T X G)	1.4840		

Table 7: Mean performance for Seed index of wheat grown under non-stress and water stress at anthesis.

Genotypes	Seed index		
	Non-stress	**Water stress**	**R.D***
Inqlab-91	43.57	35.19	-8.38
PBGST-03	46.07	42.62	-3.45
Sunder	44.26	37.87	-6.39
PBGST-01	48.36	39.93	-8.43
SKD-1	44.32	38.84	-5.48
Sassuai	53.11	44.07	-9.04
PBGST-02	45.43	38.35	-7.08
Hero	43.58	38.24	-5.34
Mean	46.96	39.51	-7.07
LSD (5%) (T)	0.4275		
LSD (5%) (G)	1.2338		
LSD (5%) (T X G)	1.2091		

Relative water content (%)

A significant sign of water stress in leaves is Relative water content percentage, (Table 11), which showed that RWC% varied from 74 to 90.81% under normal irrigation and in stress condition the recorded range of RWC% was 41.36 to 54.57%, where the average reduction of -37.09 in RWC% was observed. PBGST-03 (54.47) and SKD-1 (50.28) were the two topmost retaining cultivars to RWC% in a stress environment.Whereas the lowest RWC% was recorded in Hero, Sunder and Inqilab with 41.36, 41.82 and 45.04, respectively, and these results indicated that the 1st group was drought tolerant and 2nd was drought susceptible, however, PBGST-01, PBGST-02 and Sassuaiwere noticed as moderately retaining cultivars of RWC%.

Chlorophyll content / relative greenness (rg)

On average, -7.00 decline in chlorophyll content was noticed due to water stress conditions. The highest chlorophyll content was observed in Sassuai with 56.81, SKD-1 53.76 and PBGST-03 52.81 in normal irrigation, whereas under stress,Sassuai (49.57) revealed the

Table 8: Mean performance for grain yield plant^{-1} of wheat grown under non-stress and water stress at anthesis.

Genotypes	Grain yield plant^{-1}		
	Non-stress	Water stress	R.D*
Inqlab-91	7.85	6.22	-1.63
PBGST-03	11.08	9.06	-2.02
Sunder	9.12	7.17	-1.95
PBGST-01	9.63	7.33	-2.3
SKD-1	8.04	6.66	-1.38
Sassuai	8.70	7.2	-1.5
PBGST-02	12.93	9.72	-3.21
Hero	8.11	5.78	-2.33
Mean	9.48	7..37	-2.14
LSD (5%) (T)	0.2517		
LSD (5%) (G)	0.5443		
LSD (5%) (T X G)	0.7118		

Table 9: Mean performance for grain yield kg ha^{-1} of wheat grown under non-stress and water stress at anthesis.

Genotypes	Grain yield kg ha^{-1}		
	Non-stress	Water stress	R.D*
Inqlab-91	3489.8	2310.7	-1179.1
PBGST-03	5628.3	4884.4	-743.9
Sunder	3792.5	3141.3	-651.2
PBGST-01	5390.5	4372.5	-1018
SKD-1	4265.4	3844.3	-421.1
Sassuai	4905.9	4591.7	-314.2
PBGST-02	4907.5	3971.2	-936.3
Hero	3800.9	2774.8	-1026.1
Mean	4654.04	3910.90	-743.14
LSD (5%) (T)	38.137		
LSD (5%) (G)	53.498		
LSD (5%) (T X G)	107.87		

Table 10: Mean performance for harvest index of wheat genotype grown under non-stress and water stress at anthesis.

Genotypes	Harvest index		
	Non-stress	Water stress	R.D*
Inqlab-91	49.06	46.91	-2.15
PBGST-03	49.78	48.28	-1.5
Sunder	50.39	48.45	-1.94
PBGST-01	49.82	48.58	-1.24
SKD-1	50.60	48.52	-2.08
Sassuai	50.35	46.29	-4.06
PBGST-02	50.29	47.20	-3.09
Hero	48.85	46.33	-2.52
Mean	49.98	47.38	-2.60
LSD (5%) (T)	0.3556		
LSD (5%) (G)	1.2957		
LSD (5%) (T X G)	1.0057		

highest chlorophyll content followed by PBGST-03 and SKD-1(48.74 and 47.77) respectively (Table 12).

Correlation between morpho-physiological traits

Plant height (cm)

In non-stress condition,plant height (cm) established significant and negative correlation with spike length (r = -0.79**), grains spike^{-1} (r = -0.80**) and grain yield plant^{-1} (r = -0.77**). In non-stress condition,plant height (cm) established significant and positive correlation for relative water content (r=0.74**) and chlorophyll content (r = 0.77**). Considering the water stress condition,plant height (cm) showed significant and negative association with productive tillers plant^{-1} (r =-0.81**) only, it also showed the positive association with spike length (r = 0.76**), spikelets spike^{-1} (r = 0.69**), seed index (r=0.79**), grain yield (kg^{-ha}) (r=0.48**) and chlorophyll content (r = 0.64**).

Productive tillers plant^{-1}

In non-stress condition,productive tillers plant^{-1} established important and optimistic correlation with grains spike (r=0.83**) grain yield plant^{-1} (r=0.80**) grain yield^{-ha} (r=0.83**) harvest index

Table 11: Mean performance for relative water content in leaf of wheat genotype grown under non-stress and water stress at anthesis.

Genotypes	**Relative water content (%)**		
	Non-stress	**Water stress**	**R.D***
Inqlab-91	84.60	45.04	-39.56
PBGST-03	82.40	54.47	-27.93
Sunder	85.52	41.82	-43.7
PBGST-01	85.11	48.75	-36.36
SKD-1	84.38	50.28	-34.1
Sassuai	90.81	47.12	-43.69
PBGST-02	86.51	48.01	-38.5
Hero	74.30	41.36	-32.94
Mean	84.22	47.10	-37.11
LSD (5%) (T)	1.1963		
LSD (5%) (G)	2.6276		
LSD (5%) (T X G)	3.3836		

Table 12: Mean performance for chlorophyll content in leaf of wheat genotype grown under non-stress and water stress at anthesis.

Genotypes	**Chlorophyll content (RG+)**		
	Non-stress	**Water stress**	**R.D***
Inqlab-91	46.48	36.16	-10.32
PBGST-03	52.81	48.74	-4.07
Sunder	48.70	42.35	-6.35
PBGST-01	49.10	42.81	-6.29
SKD-1	53.76	47.77	-5.99
Sassuai	56.81	49.57	-7.24
PBGST-02	48.24	42.02	-6.22
Hero	47.50	37.95	-9.55
Mean	50.42	43.42	-7.00
LSD (5%) (T)	0.78		
LSD (5%) (G)	1.86		
LSD (5%) (T X G)	2.21		

(r=0.47**) relative water content (r=0.81**) and chlorophyll content (r=0.73**), it also showed the significant but negative correlation with the traits like spike length(r=-0.84**). While, under the water stress conditions, the productive tillers plant^{-1} showed the positive association with grains spike^{-1}(r=0.75**), grain yield plant^{-1}(r=0.85**) and grain yield kg-^{ha} (r=0.51**).Harvest index (r=0.60*), relative water content (r=0.49**) and chlorophyll content (r=0.70) showed negative association with spike length (r= -0.78**) under water stress condition.

Spike length (cm)

In non-stress condition, spike length established significant and positive correlation with spikelets spike^{-1} (r=0.90**), grains spike^{-1} (0.90**), grain yield plant^{-1} (r=0.76**) grain yield kg ha^{-1} (r=0.89**) relative water content (r=0.68**) and chlorophyll content (r=0.68**), and showed significant but negative correlation with seed index (r=-0.83**). In stress condition, spike length established significant and positive correlation with spikelets spike^{-1} (r=0.93**), grains spike^{-1} (0.84**), seed index (r=0.71), grain yield plant^{-1}(r=0.78**), grain yield kg ha^{-1} (r=0.43*), harvest index (r=0.45*), relative water content (r=0.63**) and chlorophyll content (r=0.67**).

Spikelets spike^{-1}

Under normal irrigation, spikelets spike^{-1} showed positively significant correlation with grains spike-1(r=0.86**) grain yield plant^{-1}(r=0.77**) grain yield kg ha^{-1} (r=0.88**) and chlorophyll content (r=0.75**). While in water stress condition,spikelets spike^{-1} were significant and positively correlated with grains spike^{-1}(r=0.77**), seed index (r=0.65**), grain yield plant^{-1}(r=0.70**), harvest index (r = 0.43*), relative water content (r = 0.64*) and chlorophyll content (r=0.59**).

Grains spike^{-1}

In non-stress condition, grains spike^{-1} established significant and positive correlation with grain yield plant^{-1} (r = 0.91**) grain yield kg ha^{-1} (r = 0.87**), harvest index (r0.79**) and chlorophyll content (r=0.79**). This character also revealed significant but negative association with seed index (r = -0.79*). Considering the water deficient condition, grains spike^{-1} showed significant and positive association with seed index (r = 0.81*), grain yield plant^{-1} (r = 0.73**), yield ha^{-1} (r = 0.46*), harvest index (r=0.49*), relative water content (r = 0.63**) and chlorophyll content (r = 0.70**).

Seed index

In non-stress condition, seed index showed significant and positive correlation with grain yield plant^{-1} (r = 0.70*) yield ha^{-1} (r = 0.76**) harvest index (r0. =76**) and chlorophyll content (r=0.63**) and showed the negative correlation with relative water content (r=0.79**). However, in stress condition, it expressed significant and positive correlation with grain yield plant $^{-1}$ (r=0.75**) grain yield plant^{-1} (r = 0.54**), a harvest index (r=0.76) and relative water content (0.46*) and chlorophyll content (r=0.62**)

Grain yield plant $^{-1}$

In non-stress environment, the grain yield palnt^{-1} developed significant and positive correlation with total grain yield kg^{-1} (r=0.82*), harvest index (r=0.83**) and chlorophyll content (r=0.76**). However, in stress condition, it expressed significant and positive correlation with harvest index (r=0.40**), relative water content (r=0.40**) and chlorophyll content (r=0.50**)

Grain yield kg ha^{-1}

In non-stress condition, the grain yield kg ha^{-1} developed significant and positive correlation with harvest index (r=0.70**) and chlorophyll content (r=0.73**).However, in stress condition, it expressed significant and positive correlation with harvest index (r=0.61**) and relative water content (r=0.54**) and chlorophyll content (r=0.79**).

Harvest index

In normal conditions, no significant positive or negative association has been recorded. While, in stress conditions, it expressed a significant and positive correlation with chlorophyll content (r = -0.25*).

Relative water content

It expressed a significant and positive correlation with chlorophyll content under both conditions.

Discussion

Breeding also involves the observation of best yield potential varietiesunder stress and subsequent selection of high heritable traits that offer tolerance to specific stress. Thus, the present study was aimed to analyze the drought-resistance potential of different wheat varieties under water stress. Where, several morphological characters like plant height, productive tillers plant^{-1}, spike length, spikelets spike^{-1}, grains spike^{-1}, grain yield plant^{-1}, grain yield (kg ha^{-1}), seed index, harvest index, relative water content (RWC%) and chlorophyll content (relative greenness) showed significant decline due to water stress. Similar results were determined by cultivars for the yield and physiological characters, such traits could help the wheat breeder to choose water stress-resistant cultivars in terms of one or more morpho-physiological traits. Adverse effects of drought stress on the primary grain setting number during reproductive development have been reported by different experimental studies for common wheat germplasms, lines and cultivars [28-31]. The interactions of treatment × genotype were also recorded significant for all traits except plant height that was non-significant.This interaction indicated the significant performance of cultivars over the stress treatments and such interaction could be helpful to wheat breeders in breeding programs to develop new drought-tolerant breeding material and in selecting promising varieties based on one or more suitable drought-tolerant indicators.

For a plant,heightdetermines a significant character.To maintain more active photosynthetic tissues longer under water stress during anthesis and grain filling, plant height is thus considered one of the most important traits for drought tolerance [32-35]. An average of -9.13 cm decrease in plant height was observeddue to water stress.Sassuai showed the minimum reduction (-7.25) followed by PBGST-01 (-7.65), Sunder (-8.3) and Inqilab (-8.6).Whereas, the PBGST-0 showed maximum (-12.2) reduction followed by SKD-1 (-10.25), PBGST-02 (-9.25) and Hero (-9.5) (Table 2). The lowest decline in plant height by the 1stgroup of varieties (Sassuai, PBGST-01 and Inqlab) showed their tolerance,whereas the same results were achieved by [28,30]. Based on productive tillers in plants, the average decline of -1.3 tillers plant^{-1} was observed by water stress at the anthesis stage. PBGST-01 showed the minimum relative decline of -0.9 followed by PBGST-03 and Sassuai -0.95.While,the maximum decline was observed in inqlab-91 (-3) followed by PBGST-02 (-1.65), Sunder -1 SKD-1 -1 and Hero -1 (Table 3). Our results are confirmed by Jato i[36]. Due to the presence of low moisture content on the growth of tillers, the minimum relative decrease was recorded in Sarsabz.

The reduction in spike lengthon an average -1.56 cm was recorded due to water stress.The minimum reduction was observed in sunder -0.8 followed by PBGST-03 -1.1, SKD-1 -1.2, Sassuai -1.3 and Hero -1.1, whereas inqlab -3.50 showed a maximum reduction in spike length followed by PBGST-01 -1.65 and PBGST-02 -1.8 (Table 4). The same results were given by Jatoiet al.,(2011) who showedthat cultivars performed variably overstress conditions and observed a minimum reduction in biological as well as yield characters. By water stress, -1.79 reduction was observed in the number of spikelets spike^{-1} on average, and the minimum decline was recorded in SKD-1 (-0.48) followed by PBGST-02 (-0.93), Sunder -1.22 and PBGST-03 -1.52 and the maximum reduction was observed in Sassuai (-3.22) followed by Inqlab-91 (-2.87) and PBGST-01 (-2.13) (Table 5). Previouslystudies have reported that the biological and yield traits were significantly reduced by water stress, as the minimum decline was noticed in plant height, spike length, spikelets spike^{-1} and grain weight [37,28]. Due to water stress, the number of grains spike^{-1} ranged from 26.67 to 64.85, while -10.54 average seed failure was observed. Among all the genotypes under stress environment, maximum grains spike^{-1} was noted in Sassuai as 64.85 and in PBGST-03 as 62.20 and minimum results for grains spike^{-1} were observed in cultivar hero and Sunder as 36.67 and 40.19 grains spike^{-1},respectively, yet other genotypes performed moderately (Table 6). Similar results were confirmed by [30,38,31].

For the seed weight trait, -7.07 relative reduction on average under water stress condition was recorded, whereas a mean average of 39.51g of seed index was noted in the stress environment. The genotype PBGST-03 showed the minimum relative decline as -3.45, while this was maximum in Sassuai with -9.04 as shown in Table 7. Such results were previously defined by Blum [19]. The trait grain yield plant^{-1} is known as a vital trait among all the morphological, physiological and chemical responses to drought stress environment. In our study, an average relative decline of -2.14 was noted under normal environment, while underwater stress condition 7.37g was observed on account of the mean average of all genotypes, it was 9.48g under normal condition. Among all cultivars, the maximum mean average was found in PBGST-02 and PBGST-03 cultivars as 9.72g and 9.06g, respectively under stress environment as well as under normal conditions (12.93, 11.08)(Table 8). While the minimum mean average of 5.78 for grain yield plant^{-1} was noted in Hero cultivar under stress condition, while others performed well but remained sustainable to water drought. Based on these results, these two genotypes may be chosen for both conditions (stress and non-stress). Previously the same results were found and described by Sial [39,40] who described that drought stress during maturity resulted in about a 10% decrease in yield.

Grain yield based on average reduction due to water stress was -743.14 as indicated according tothe analysis of data presented in (Table 9), where PBGST-03, PBGST-01, PBGST-02 and Sassuai gave the high yield kg ha^{-1} as 5628.3, 5390.5, 4907.5 and 4905.9 respectively. Under normal irrigation and water stress conditions,Sassuai ranked 1stwith 3884.4 followed by PBGST-03 with 4291.7reduction in grain yield kg ha^{-1}and proved as drought-tolerant against other cultivars in the test.To increase wheat productivity one of the useful approaches is to divide yield into biomass at maturity and harvest index (HI). The most yield potential progress in wheat has been associated with increased HI and often stated that progress in HI is exhausted because values are approaching the limits of 60%, hence the focus should be on biomass rather than on HI. HI under water stress decreased by -2.60, where the smaller decline was shown by some of the cultivars such as PBGST-01 -1.24, PBGST-03 -1.53 and Sunder -1.94 and a sharp reduction was observed in Sassuai -4.06, PBGST-02 -3.09, and other cultivars like Hero, Inqlab and SKD-1 with -2.52, -2.15 and -2.08, respectively(Table 10). Similar results indicated that the average HI dropped due to water stress.This decline was smaller intolerant genotypes.

A significant sign of drought in leaves is relative water content percentage (Table 11), which showed that RWC% varied from 74 to 90.81% under normal irrigation and in stress conditions.The recorded range of RWC% was 41.36 to 54.57%, where the average reduction of -37.09 in RWC% was observed. PBGST-03 (54.47) and SKD-1 (50.28) were the two topmost retaining cultivars to RWC% in a stress environment.The lowest RWC% was recorded in Hero, Sunder and Inqlab with 41.36, 41.82 and 45.04, respectively and these results indicated that the 1st group was drought tolerant and 2nd was drought susceptible.However, PBGST-01, PBGST-02 and Sassuaiwere noticed as moderately retaining cultivars of RWC%. Previously same results were defined by Abdullah [41] who reported that RWC decreased significantly in the 2nd(drought conditions) as compared to the 1st(normal condition) zone at all growth stages, however, more reduction was recorded in drought susceptible varieties[41]. Many studies have described related prominence of drought tolerance in reproductive growth and different improved plant traits for high yield potentials of different crops including wheat [33,42-44].

Chlorophyll content an average -7.00 decline in chlorophyll content was noticed due to water stress conditions. The highest chlorophyll content was observed in Sassuai with 56.81, SKD-1 53.76 and PBGST-03 52.81 in normal irrigation.Whereas, in stress,Sassuai 49.55 followed by PBGST-03 and SKD-1 (48.74 and47.77)(showed the highest chlorophyll content, respectively (Table 12). These results are justified byJatoi[30] that the chlorophyll content was reduced in water stress treatment. Unpredictably,the decline in relative greenness in non-stress may be explained as higher sink demand of plant, thus higher chloroplast distribution to growing points in non-stress conditions and greater saturation in stress environment [30]. Drought stress generally reduces crop yield through decreased photosynthesis and increased leaf senescence [43,45].

Height showed native but significant association with yield-related traits i.e. with tillers plant^{-1}, spikelets spike^{-1}, grains spike^{-1} and yield plant^{-1} as r = -0.81**, r = -0.69**, 0.68**, results from correlation coefficient among all the traits under drought as well as normal environment have been given in (Table 13),which was almost positive and significant, except plant 0.70** under stress condition. The correlation coefficient for tillers plant^{-1} was observed significant and positively correlated with all yielding traits, i.e. spike length (r=0.84**), grains spike^{-1} (r=0.83**) and grain yield plant-^{1} (r=0.80**) under normal environment, while in drought condition, it was also significant and positive with all traits, i.e. grains spike^{-1} (r=0.75**), grain yield plant^{-1} (r=0.85**), except spike length, for that it was significant but negatively associated (r= -0.78**). Under irrigated condition, spike length established positive correlation with spikelets spike^{-1} (r=0.90**), grains spike^{-1} (0.90**) and grain yield plant^{-1} (r=0.76**), wherein stress condition, it was significant and positively associated with spikelets spike^{-1} (r=0.93**), grains spike^{-1} (0.84**), seed index (r=0.71) and grain yield plant^{-1} (r=0.78**). Normal irrigation, spikelets spike^{-1} showed a positively significant correlation with grains spike^{-1}(r=0.86**) grain yield plant^{-1}(r=0.77**). While in water stress condition,spikelets spike^{-1} were significant and positively correlated with grains spike^{-1}(r=0.77**), seed index (r=0.65**) and grain yield plant^{-1}(r=0.70**).

In non-stress conditions, grains spike^{-1} established a significant and positive correlation with grain yield plant^{-1} (r = 0.91**), however, this character also revealed a significant but negative association with seed index (r = -0.79*). Considering the water-deficient condition, grains spike^{-1} showed significant and positive association with seed index (r = 0.81*) and grain yield plant^{-1} (r = 0.73**).In the non-stress condition,the seed index showed a significant and positive correlation with grain yield plant^{-1} (r = 0.70*). However, in stress conditions, it also expressed a significant and positive correlation with grain yield plant $^{-1}$ (r=0.75**).Moreover, most of the yield traits were

Table 13: Correlation between morpho-physiological traits.

Characters	**Plant height**	**Tillers plant^{-1}**	**Spike length**	**Spikelets spike^{-1}**	**Grains spike^{-1}**	**Seed index**	**Grain yield plant^{-1}**	**Yield ha^{-1}**	**Harvest index**	**R.W.C**	**Chlorophyll content**
Plant height	-	0.19n.s	-0.80**	0.17n.s	-0.80**	0.15n.s	-0.77**	0.15n.s	0.15n.s	0.75**	0.77**
Tillers plant^{-1}	-0.81**	-	0.84**	0.19n.s	0.84**	0.20n.s	0.80**	0.83**	0.47*	0.81**	0.73**
Spike length	0.76**	0.78**	-	0.90**	0.90**	-0.83**	0.76**	0.89**	0.16n.s	0.68**	0.78**
Spikelets spike^{-1}	0.69**	0.67**	0.93**	-	0.86**	0.19n.s	0.77**	0.88**	0.17n.s	0.27n.s	0.75**
Grains spike^{-1}	0.68**	0.75**	0.84**	0.78**	-	-0.79**	0.91**	0.87**	0.79**	0.17n.s	0.79**
Seed index	0.79**	0.82**	0.71**	0.65**	0.81**	-	0.70**	0.76**	0.76**	-0.79**	0.63**
Grain yield plant^{-1}	0.70**	0.85**	0.78**	0.71**	0.73**	0.75**	-	0.82**	0.82**	0.18n.s	0.76**
Yield ha^{-1}	0.48*	0.51*	0.43*	0.30*	0.46*	0.54*	0.26n.s	-	0.70**	0.18n.s	0.73**
Harvest index	0.65**	0.60*	0.45*	0.44*	0.50*	0.76**	0.41*	0.62**	-	0.17n.s	0.19n.s
R.W.C	0.32*	0.49*	0.63**	0.65**	0.63**	0.46*	0.40*	0.55*	0.29n.s	-	0.64**
Chlorophyll content	0.64**	0.70**	0.67**	0.59*	0.70**	0.62**	0.50	0.69**	0.49*	0.69**	-

RWC=Relative water content.

significantly correlated with each other. The plant height was almost non-significantly in normal irrigation yet significantly associated with all the yield traits but productive tillers were highly significantly correlated with all the yield traits in both conditions except seed index in normal irrigation, where the high correlation, however, was recorded between the productive tiller and grain yield plant^{-1} in stress environment (r = 0.85**). Among the spike length and other traits under normal condition, the highest correlation value was observed between spike length and spikelets spike^{-1} (r=0.91**) and spike length with grains spike-^{1} (r = 0.91**)

In a stress environment, this was noted between the same characters, spike length and spikelets spike^{-1} (r = 0.94**) and with grains spike^{-1} (r=0.94**). While the spikelets spike^{-1} showed the highest correlation with grains spike^{-1} in both conditions, stress, and non-stress (r=0.78**, 0.86**) respectively. In non-stress, the highest correlation was obtained between the grains spike^{-1} and grain yield plant^{-1} in accordance with yield traits, though in water stress condition this was noted between the grain spike^{-1} and seed index (r=0.81**) and grains spike^{-1} with grain yield plant^{-1} (r=0.73**). Seed index was observed highly correlated with harvest index (r=0.76**) in normal irrigation, where this association was noted highly correlated with grain yield plant^{-1} (r = 0.75**) under water stress conditions. [46] stateda positive and significant association between spike length with severalspikelets spike^{-1} and the number of grain spike^{-1} in wheat under water stress conditions. The similar results to the present study were observed by Allahverdiyev [47] who described that chlorophyll content was significantly and positively associated with plant height, spike length, spikelets spike^{-1}, grain yield plant$^{-1,}$ and grain yield kg ha^{-1}. Similarly, almost all morphological traits like plant height, tillers plant^{-1}, spike length, spikelets spike^{-1}, grains spike^{-1}, grain yield plant^{-1}, seed index, harvest index and grain yield kg ha^{-1} with both physiological parameters i.e. relative water content and chlorophyll content, so that such traits may be considered a good criterion for selection [47].

Conclusion

The mean squares from the analysis of variance for the genotype, treatment, and treatment × genotype interaction, stated that water stress caused a significant reduction in all morpho-physiological and yield traits calculated and the varieties responded variably over the treatments as indicated by treatment × genotypes interaction.Among the varieties, the minimum reduction was recorded in PBGST-03, PBGST-02, SKD-1 and Sassuai for the traits i.e. grain yield plant-1, grains spike-1, grain yield kg ha-1 and water content and gave the good performance.Most of the traits, such astillers per plant, grains per spike, grains yield per plant, yield per hector, chlorophyll content and water content were recorded underwater stress condition at anthesis and regarded as drought tolerance varieties among the eight genotypes, other were drought susceptible varieties.A highly positive correlation was observed among all traits like plant height to grains per spike, spikelets per spike, grains spike to grain yield per plant under stress condition except spikelets spike^{-1}that showed the positive but non–significant correlation to grain yield kg^{-1}.Whereas, both physiological traits i.e. chlorophyll content and water content showed a positive association to the grains per spike, grains yield per plant, tillers per plant and harvest index.

Author Contributions

ZAS, QA and MB planned and designed this research. ZAS performed this research. ZAS, TMR, SM, IAB, and AH, helped to analyze the experimental data. MHS, AMA, SBS andMB revised the whole manuscript.

Conflicts of Interest

All authors declare that there is no conflict of interest either financially or otherwise.

Acknowledgment

The Department of Plant Breeding and Genetics, Sindh Agriculture University, Tandojam is greatly acknowledged for providing the platform, all necessary equipment, and the agricultural field to conduct present research.

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