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Full Length Article

Phenotypic Selection of Wheat Genotypes for Drought Stress Tolerance

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Abstract

Drought stress is the leading constraint of wheat production and yield reduction induced by drought surpasses decreases from all the other causes. Moreover, wheat is more sensitive to drought stress when imposed at anthesis stage. In this study, attempts were made to evaluate the effectiveness of seedling traits as selection criteria for drought tolerant genotypes and highlights losses in yield due to drought particularly on anthesis stage. One hundred and fifty wheat genotypes and 65 F_1 generations of selected parents were assessed in separate experiments for various seedling traits *i.e*., root length, shoot length and root/shoot ratio) and yield attributes *i.e*., spike length, number of spikelets per spike, number of grains per spike, grain weight per spike, 1000-grain weight and grain yield per plant under controlled and drought stress. Owing to the diverse genetic background of germplasm, genotypes exhibited variation in their response towards drought. Correlation analysis depicted the existence of significant relationship between seedling and yield related traits under drought stress. Significant decrease in seedling traits and yield was observed with the onset of drought stress. Genotypes Chakwal-86, Manthar-2003, Aas-11, Chakwal-50, Miraj-2008, 9488, 9859, 9805, 9637 and 9512 showed tolerance to drought in terms of seedling growth and yield. Genetic studies divulge the existence of non-additive genes for all the characters excluding spike length which exhibited additive gene action. Cross combinations 9633 × Chakwal -86, Faisalabad-08 × Chakwal-50, 9507 × 9805, 9805 × 9633, 9507 × Manthar-03 observed high yield under drought conditions. These crosses can be exploited in various developmental programs aimed for drought-hit areas of Pakistan. Selection based on seedling traits was found effective for selection of drought-tolerant wheat genotypes at anthesis. Mass selection of wheat crosses at anthesis stage may be an effective option to cope with the drought stress owing to their non-additive gene action.

Keywords: Anthesis; Drought stress; Genetics; Seedling; Wheat; Yield

Introduction

After rice (*Oryza sativa*), wheat (*Triticum aestivum* L.) is the main staple food of the world and it has earned reputation as a prominent source of vegetable protein (13% protein contents) for humans as compared to other major cereal crops of this group (Chu 2016). In case of Pakistan, it is the major cereal crop cultivated annually on an area of about 8–9 million hectares. It alone contributed 9.1% of value added in agricultural sector and 1.7% in country's Gross Domestic Product (GOP 2018). The latest Economic Survey of Pakistan (2017–2018) has revealed a decline of 4.43% in wheat production as compared to last few years. This decline has is due to lesser cultivated area due to delayed sugarcane season, water shortage and fog/smog (Siddiqui 2019).

Depletion of water resources throughout the world has gained much attention lately. Pakistan, being one of the developing geographical entities of the world, has also severely been struck by this grave situation. Steps of adaptation and mitigation are being implied both by the public and the government in order to conserve water, raise awareness amongst masses and cultivation of stress/drought-resistant crops (Hu and Xiong 2014).

Drought causes unavailability of water for plant to carry on life supporting processes and lowers its water using efficiency. Different cultivars have contrasting response towards water scarcity due to diverse genetic makeup (Noorka and Harrison 2013; Farooq *et al.* 2015; Qadir *et al.* 2017). Water deficiency at early stages of seedling is a limiting factor that reduces seedling growth (Farooq *et al.* 2009; Misra *et al.* 2002). Similarly, anthesis stage of wheat is considered very prone to drought and causes reduction in yield (Mirbahar *et al.* 2009; Farooq *et al.* 2014, 2015).

Strategy to improve crop production under drought is to evaluate and assess genotypes that show good performance under water stressed conditions (Rashidi and Seyfi 2007; Waqas *et al.* 2013). Though yield attributes of wheat can also be associated with drought for hunting drought tolerant genotypes but efficient and inexpensive method for selection against drought is mostly based on seedling traits (Rauf *et al.* 2007).

Owing to an imminent and persistent threat of drought in Pakistan, the dawn of this century has witnessed various research work being reported regarding drought indices of wheat genotypes, both indigenous and exotic (Mirbahar *et al.*

2009; Noorka and Harrison 2013). The present study was designed with an aim of assessing 150 wheat genotypes and their F_1 product for their various seedling traits (root length, shoot length and root-shoot ratio) and yield attributes (spike length, number of spikelet per spike, number of grains per spike, grain weight per spike, 1000-grain weight and grain yield per plant) under well-watered and drought environment, both at seedling and anthesis stages. Though, many wheat genotypes have already been used for drought study; however, in this study a lot of new wheat germplasm both exotic and local have been introduced. It also included the study of drought tolerance genetics at seedling and anthesis stage and some genotypes have been identified as drought tolerant and recommended for further investigations under drought stress.

Materials and Methods

This study was conducted from 2014 to 2017 at research area of Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad both in greenhouse and field conditions. A total of 150 spring wheat genotypes (both local and exotic) were attained from International Maize and Wheat Improvement Centre (CIMMYT) Mexico, U.S.A., Ayub Agriculture Research Institute, Faisalabad, Pakistan, and Plant Breeding and Genetics Department, University of Agriculture Faisalabad, Pakistan.

Greenhouse experimentation

Germplasm screening

First part of this experimentation involved screening of 150 wheat germplasm under two moisture regimes *i.e.*, well-watered and drought stress conditions. Experiment was conducted in completely randomized two factor factorial design with three replications. Genotypes were assessed on the basis of root-associated traits for drought tolerance. Experiment was carried out in wire-house which was covered with sheets to avoid rain water. Plants were grown in Polythene bags (18 × 9 cm) filled with sandy loam soil having pH 7.8 and E.C 1.7dS m^{-1} (450 g/ bag). Well-watered bags were irrigated equal to field capacity and in drought stress environment; genotypes were watered only once after sowing (Khan *et al.* 2010). In each replication, ten bags for each genotype were used to grow 10 seeds per bag. After germination, only one seedling per bag was kept by discarding the rest. Seedlings were removed from the bags at three-leaf stage and washed carefully to remove soil particles. Data was collected and mean value of ten seedlings per genotype in each replication was calculated. For the analysis of seedling characters, data for root and shoot lengths and root-shoot ratio were collected.

Percentage decrease due to change in environment was calculated by:

$$Percentage\ decrease = \frac{Well\ watered - Drought}{Well\ watered} \times 100$$

Line-tester crossing

For second part of this experimentation, germplasm of 150 wheat genotypes which had already been sown in field was used for crossing purpose. Genotypes that exhibited few changes at seedling traits in response to drought were tagged as ‘testers. While genotypes that showed extensive decline at seedling traits were tagged as ‘lines. Based on seedling traits, 10 water stress tolerant (lines) and five susceptible genotypes (testers) were selected and crossed in line × tester fashion (Rajaram *et al.* 2002). These 15 parents and 50 crosses (65 genotypes) were also evaluated by repeating the experimental conditions and same setup that was used for germplasm screening.

Field experimentation

In wheat growing season, the 65 genotypes used in greenhouse experimentation were subjected to field experiment for yield related traits *i.e.*, spike length, number of spikelets per spike, number of grains per spike, 1000-grain weight and grain yield per plant under normal and drought-stress conditions at anthesis stage. Split-plot layout was employed in randomized complete block design. Moisture conditions were kept in main plot and genotypes in sub-plot with three replications. Each genotype per replication was assigned 5-meter long row for sowing. Plants were parted by 15 cm while distance among rows was kept 0.3 m resulted in 97.5 m^2 plot size per replication. In order to maintain the drought conditions, the shed was constructed using PVC pipes for main structure and polythene sheets were used as top-cover till harvesting. Drought stress was achieved by restricting water supply *i.e.*, 30–35% mean soil water contents (SWC) during anthesis stage for drought treatment and after that water supply was restored to 70–75% FWC. Standard irrigation was applied to control treatment. Fertilizer was applied at the rate of 150, 100 and 50 kg NPK ha^{-1} by using urea, di-ammonium phosphate and sulphate of potash as source. Herbicides named bromoxynil and enoxaprop-P-ethyl along with manual hoeing were applied to control weeds.

The data collected for both experiments was analyzed using analysis of variance (Steel *et al.* 1997). The significant traits were further exploited via correlation analysis for determination of linkage between seedling and yield related traits using software Minitab16. Line × Tester analysis was employed for genetic studies were conducted using Microsoft Excel.

Results

Drought stress and its interaction with wheat genotypes *i.e.*, germplasm and F_1 population, at seedling stage had highly significant effect on root and shoot length while effect was non-significant on root shoot ratio (Table 1). The results regarding response of genotypes to the drought stress were

Table 1: Analysis of variance for some seedling traits of wheat genotypes at early stage of growth

Germplasm	Characters	Genotypes (G) (df=149)	Drought stress (D) (df=1)	G×D (df=149)	Error (df=600)
	Root length	25.875**	2426.272**	6.825**	1.673
	Shoot length	62.161**	8990.681**	18.648**	2.780
	Root shoot ratio	0.021**	0.0003^{NS}	0.007^{NS}	0.005
F_1	Characters	Genotypes (G) (df=64)	Drought Stress (D) (df=1)	G×D (df=64)	Error (df=260)
	Root length	60.425**	460.69**	9.33**	1.318
	Shoot length	82.41**	2030.92**	30.77**	1.792
	Root shoot ratio	0.03^{NS}	0.031^{NS}	0.01^{NS}	0.001

** $P \leq 0.001$; NS= Non-significant

Table 2: Range, mean and percentage decrease under well-watered and drought stress conditions in wheat for germplasm and F_1*

Traits	Germplasm/F_1	Moisture condition	Range	Mean ± SE	Decrease under drought (%)
Root length (cm)	Germplasm	Well-watered	19.98-9.35	13.57 ± 0.53	23.74
		Drought stress	17.86-3.94	10.35 ± 0.54	
	F_1	Well-watered	21.99-10.58	15.8 ± 0.16	13.76
		Drought stress	21.63-6.48	13.63 ± 0.21	
Shoot length (cm)	Germplasm	Well-watered	33.50-17.10	26.99 ± 0.65	22.84
		Drought stress	30.25-6.92	20.83 ± 0.66	
	F_1	Well-watered	34.15-22.02	28.94 ± 0.16	15.77
		Drought stress	32.62-10.23	24.38 ±0.29	
Root shoot ratio	Germplasm	Well-watered	0.59-0.33	0.50 ± 0.02	1.31
		Drought stress	0.59-0.31	0.49 ± 0.02	
	F_1	Well-watered	0.72-0.41	0.54 ± 0.003	2.2
		Drought stress	1.11-0.41	0.54 ± 0.003	

* P≤0.001

also found highly significant ($P \leq 0.001$) both for germplasm and F_1 population (Table 2). Root length shoot length and root-shoot ratio exhibited of 23.74, 22.84 and 1.31% decrease for germplasm; and 13.76, 15.77 and 2.2 percent for F_1 population, respectively.

Based on the performance of wheat genotypes for seedling traits, two groups of genotypes out of 150 wheat genotypes were selected as 'line' and 'tester'. Genotypes Chakwal-86, Manthar-2003, Aas-11, Chakwal-50, Miraj-2008, 9488, 9859, 9805, 9637 and 9512 were selected as lines since they showed high values for root and shoot length and non-significant ($P \geq 0.05$) difference in their performance for both environments (well-watered and drought stress). Similarly, genotypes Sehar-06, Faisalabad-08, 9507, Lasani-08 and 9633 were selected as tester as they exhibited significant ($P \leq 0.05$) decline in their performance for all the seedling traits when exposed to drought (Table 3). The testers were mainly commercial cultivars having high crop yield except one that is 9633. In case of F_1, for root length under both well-watered and drought conditions, cross Faisalabad-08 × 9805 had highest value (21.98 cm and 20.5, respectively). Similarly, the shoot length ranged from 22.01 cm to for 9637 × Lasani-08 to 35.15 cm for Miraj-08 × 9633 under well-watered conditions. Whereas, under drought conditions, shoot length ranged from 10.23 cm for 9488 × Lasani-08 to 32.61 cm for Miraj-08 × 9633.

Genotypes that showed stable and prominent performance under drought also exhibited optimum root shoot ratio. Minimum percentage decrease in root length and shoot length due to water shortage as compared to well-watered condition was shown by cross combinations Miraj-08 × 9633 (0.53%, 4.48%), 9507 × 9805 (1.84%, 1.05%), 9507 × Manthar-03 (2.23%, 5.02%), 9633 × Chakwal-86 (2.24%, 4.37%, 9805 × 9633 (2.52%, 6.63%), Seher-06 × Manthar-03 (3.1%, 6.87%), Faisalabad-08 × 9488 (3.23%, 6.25%) and Faisalabad-08 × Chakwal-50 (4.9%, 3.79%) (Table 4).

Results for analysis of variance of various yield related traits (spike length, number of spikelets per spike, number of grains per spike, grain weight per spike, 1000-grain weight and grain yield per plant) in F_1 population are presented in Table 5 which revealed a highly significant trend ($P \leq 0.01$). All the yield parameters significantly ($P \leq 0.01$) reduced under drought condition at anthesis stage as given in Table 6. In general, genotypes specified in Table 7 stood against drought as their performance declined minimum as compared to others like 9633 × Chakwal 50 and Lasani 08 × 9512. Overall performance of genotypes named Faisalabad-08 × Chakwal-50, 9507 × 9805, 9805 × 9633, 9507 × Manthar-03, Seher-06 × Manthar-03, 9633 × Chakwal -86, Faisalabad-08 × 9488 and Sehar-06 × 9637 showed minimum reduction in their yield related traits in response to the drought at anthesis stage. Correlation analysis was utilized to find the relationship between seedling and yield related traits. Root and shoot length showed highly significant correlation with all yield related traits except spike length since it was found as non-significant (Table 8). Further, Line × tester approach was utilized and the investigation identified additive genes accountable for spike length and non-additive genes for rest of characters (Table 9) under both moisture conditions (well-watered and drought stress).

Discussion

The present work is the first of its kind being reported from Pakistan as it incorporates a large number (150) of both local and exotic spring wheat genotypes and its F_1 population

Table 3: Seedling traits of wheat genotypes tagged as line and testers from germplasm under well-watered and drought stress conditions

Genotypes	Root length (cm)		Shoot length (cm)		Root shoot ratio	
	Well-watered	Drought stress	Well-watered	Drought stress	Well-watered	Drought stress
			LINE			
Chakwal-86	17.9^{bc}	16.9^{a}	30.8^{bc}	30.3^{a}	0.581^{a}	0.558^{a}
Manthar-03	16.8^{cd}	15.3^{c}	30.2^{cd}	29.3^{b}	0.556^{a}	0.522^{a}
Aas-11	15.3^{ef}	14.8^{cd}	28.3^{e}	26.5^{e}	0.541^{a}	0.558^{a}
Chakwal-50	16.3^{bc}	15.4^{c}	28^{e}	26.4^{e}	0.582^{a}	0.583^{a}
Meraj-08	16.4^{d}	15.3^{c}	30.5^{c}	28.5^{bc}	0.538^{a}	0.537^{a}
9488	17^{c}	16.1^{ab}	30^{cd}	28.4^{bc}	0.567^{a}	0.567^{a}
9859	15.7^{e}	14.6^{cd}	29.2^{d}	28.2^{c}	0.538^{a}	0.518^{a}
9805	15^{ef}	14.3^{d}	29.7^{d}	27.3^{d}	0.505^{b}	0.524^{a}
9637	16.7^{cd}	16^{b}	30.6^{bc}	29.8^{ab}	0.546^{a}	0.537^{a}
9512	14.9^{f}	14.6^{cd}	29.3^{d}	27.7^{cd}	0.509^{b}	0.527^{a}
			TESTER			
Sehar-06	18.5^{b}	9.3^{e}	31.5^{b}	16^{gh}	0.587^{a}	0.581^{a}
Faisalabad-08	20^{a}	9.7^{ef}	33.5^{a}	16.7^{g}	0.597^{a}	0.581^{a}
9507	18^{b}	9.7^{ef}	30.5^{ac}	17.7^{f}	0.59^{a}	0.548^{a}
Lasani-08	19.2^{ab}	6.5^{g}	32.8^{ab}	11.2^{i}	0.585^{a}	0.58^{a}
9633	17.4^{c}	8.2^{f}	33.2^{a}	15^{h}	0.524^{b}	0.547^{a}

Means followed by different letters, within a column, for each trait differs significantly from each other at $P \leq 0.05$

Table 4: Seedling traits of F_1 wheat genotypes which showed good performance under well-watered and drought stress conditions

Crosses	Root length (cm)		Shoot length (cm)		Root shoot ratio	
	Well-watered	Drought stress	Well-watered	Drought stress	Well-watered	Drought stress
9507×9805	19.03^{bc}	18.68^{bc}	31.5^{c}	31.17^{a}	0.60^{a}	0.60^{a}
Faisalabad-08×9488	21.19^{a}	20.5^{a}	31.98^{bc}	29.98^{bc}	0.66^{a}	0.68^{a}
Faisalabad-08×Chakwal-50	19.73^{b}	18.76^{b}	32.5^{b}	31.27^{a}	0.61^{a}	0.60^{a}
Seher-06×Manthar-03	18.26^{d}	17.69^{d}	33.45^{a}	31.15^{a}	0.55^{b}	0.57^{b}
9633×Chakwal-86	19.26^{b}	18.83^{b}	32.75^{ab}	31.32^{a}	0.59^{ab}	0.60^{a}
9507×Manthar-03	19.36^{b}	18.92^{b}	32.5^{b}	30.87^{b}	0.60^{a}	0.61^{a}
9805×9633	18.46^{c}	18.00^{c}	31.66^{c}	29.56^{c}	0.58^{ab}	0.61^{a}

Means followed by different letters, within a column, for each trait differs significantly from each other at $P \leq 0.05$

Table 5: Analysis of variance of yield related traits of F_1 wheat

Traits	Stress (df=1)	E_1 (df=2)	Genotypes (df = 64)	S × G (df=64)	E_2 (df = 256)
Spike length	68.96**	0.09	13.57**	14.71**	0.08
Number of spikelet per spike	12762.5**	8215.76	56.83**	304.81**	40.64
Number of grains per spike	43587.5**	0.31	261.22**	1073.54**	3.94
1000-grain weight	485.49**	0.17	383.55**	392.22**	0.024
Grain yield per plant	3893.06**	0.128	25.23**	102.44**	0.02

** $P \leq 0.001$; E_1= Error1; E_2= Error2

Table 6: Range, mean and percentage decrease in yield related traits under well-watered) and drought stress conditions of F_1 wheat

Traits	Moisture Condition	Range	Mean ± SE	Decline under drought (%)
Spike length (cm)	Well-watered	9.4-15.9	13.04 ± 0.04	6.44%
	Drought stress	1.53-8.05	3.75 ± 0.03	
Number of spikelets per spike	Well-watered	19-23	21.00 ± 0.04	10.69 %
	Drought stress	14-22	18.75 ± 0.06	
Number of grains per spike	Well-watered	42.33-63	56.09 ± 0.14	37.67 %
	Drought stress	14.33-54	34.96 ± 0.32	
1000-grain weight (g)	Well-watered	33.26-68.64	50.1 ± 0.26	10.09 %
	Drought stress	23.92-66.5	45.04 ± 0.27	
Grain yield per plant (g plant^{-1})	Well-watered	18.3-27.38	22.89 ± 0.07	27.6 %
	Drought stress	11-22.7	16.57 ± 0.08	

attained through line × tester fashion for the study of drought. Witnessed significant differences for all seedling traits for both germplasm and F_1 could be attributed plausibly to genetic variation. Since these genotypes had diverse genetic background, genes activated in response to drought exhibited variation in their expression (Gong *et al.* 2005; Ayalew and Dessalegn 2016; Yasir *et al.* 2019).

Overall, present study established the fact that both the early and later stages of wheat are adversely affected by drought which alters water-utilizing capacity and ultimately results in substantially reduced yield (Li *et al.* 2009; Zhong and Wang 2012). Reduction in yield related traits is the key reason for low yield under drought. Anthesis stage is highly vulnerable to drought stress as it affects the pollen grain viability which in turns reduces the number of grains per spike. Drought causes reduced leaf areas which causes insufficient supply of sugar, since it is essential for the variability of pollen grains. Reduction in spike length may be due to the diversion of nitrogen assimilates by the plant in order to cope with the stress and maintain its normal life processes. Disturbance of source-sink relationship ultimately reduces the source strength which results in reduced grain weight. Current results revealed significant reduction in seedling traits due to drought except for a few genotypes.

Table 7: Means of yield related traits of parents and F_1 Wheat genotypes which showed high yield under normal irrigation (Well-watered) and water deficit condition (drought stress) at anthesis stage

Genotypes	Spike length (cm)		Number of Spikelet/spike		Number of grains/spike		1000-grain weight (g)		Grain yield (g plant^{-1})	
	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS
Miraj-08	11.5^{e}	10.8^{f}	20.3^{e}	20.3^{d}	54.3^{g}	44.3^{g}	47.5^{i}	44.0^{h}	18.9^{j}	16.7^{i}
Chakwal-50	13.4^{bc}	12.2^{cd}	21.0^{d}	21.0^{c}	55.7^{f}	46.7^{f}	52.9^{ef}	49.4^{d}	22.9^{f}	20.2^{cd}
9805	13.3^{bc}	12.3^{cd}	19.0^{g}	19.0^{f}	50.3^{ij}	38.3^{i}	51.6^{g}	47.5^{e}	22.5^{f}	19.1^{e}
ASS-11	13.7^{b}	12.7^{c}	23.3^{ab}	21.4^{bc}	61.5^{ab}	51.0^{c}	51.9^{fg}	47.7^{e}	20.6^{h}	18.5^{f}
Manthar-03	10.7^{g}	10.5^{f}	19.7^{ef}	19.2^{ef}	49.7^{j}	39.0^{h}	43.8^{k}	39.7^{k}	19.5^{i}	17.0^{h}
9488	10.4^{g}	9.6^{g}	21.5^{cd}	21.8^{b}	52.3^{h}	37.3^{i}	49.5^{h}	45.5^{g}	23.5^{e}	20.1^{cd}
9859	14.4^{ab}	13.6^{ab}	23.8^{a}	21.5^{bc}	58.3^{d}	47.0^{e}	44.7^{jk}	41.0^{j}	18.3^{k}	16.0^{j}
9637	14.5^{ab}	13.8^{ab}	22.7^{b}	20.7^{cd}	58.7^{cd}	46.7^{f}	43.6^{k}	40.1^{k}	21.7^{g}	19.5^{de}
9512	11.8^{e}	11.2^{ef}	21.2^{cd}	19.9^{de}	56.6^{e}	47.0^{e}	50.0^{h}	45.9^{g}	19.0^{ij}	17.9^{g}
Chakwal-86	11.9^{e}	11.4^{e}	19.4^{f}	19.5^{e}	45.2^{l}	36.6^{j}	51.3^{g}	47.4^{e}	24.0^{d}	21.9^{b}
9507	12.7^{c}	12.1^{cd}	22.7^{b}	18.7^{g}	56.3^{e}	27.3^{l}	45.3^{j}	43.2^{i}	26.0^{b}	17.0^{h}
Seher-06	13.9^{b}	13.1^{b}	19.8^{ef}	14.3^{j}	50.7^{i}	21.7^{m}	55.7^{d}	49.6^{d}	25.4^{c}	16.4^{i}
9633	12.9^{c}	12.2^{cd}	23.1^{ab}	19.9^{de}	59.5^{cd}	29.3^{k}	35.3^{m}	33.0^{m}	25.8^{bc}	17.5^{gh}
Lasani-08	12.9^{c}	11.8^{d}	19.0^{g}	15.5^{i}	48.9^{k}	19.1^{n}	39.8^{l}	36.4^{l}	25.8^{bc}	17.0^{h}
Faisalabad-08	12.6^{cd}	11.7^{d}	21.0^{d}	17.7^{h}	58.4^{d}	27.3^{l}	55.4^{d}	49.6^{d}	26.7^{a}	16.0^{j}
9507 × 9805	12.4^{d}	11.2e^{f}	22.7^{b}	22.7^{a}	58.0^{d}	49.8^{d}	50.0^{h}	46.5^{f}	23.6^{e}	20.6^{c}
Faisalabad-08 × Chakwal-50	14.9^{a}	14.2^{a}	23.3^{ab}	19.0^{f}	60.3^{c}	51.3^{c}	75.3^{b}	71.3^{b}	23.7^{de}	21.7^{b}
Faisalabad-08 × 9488	15.1^{a}	14.5^{a}	21.7^{c}	21.0^{c}	56.5^{e}	46.5^{f}	49.5^{h}	45.6^{g}	21.6^{g}	19.6^{d}
Lasani-08 × Manthar-03	13.4^{bc}	12.5^{c}	19.4^{f}	19.4^{e}	50.7^{i}	38.7^{hi}	53.4^{e}	49.4^{d}	20.6^{h}	18.6^{f}
9637 × Seher-06	14.4^{ab}	13.8^{a}b	23.6^{a}	21.2^{c}	62.0^{a}	54.0^{a}	50.0^{h}	46.0^{g}	20.9^{gh}	18.9^{ef}
Seher-06 × Manthar-03	12.3^{d}	11.5^{e}	21.7^{c}	21.4^{bc}	54.7^{g}	44.7^{g}	92.7^{a}	88.5^{a}	22.8^{f}	19.8^{d}
9633 × Chakwal-86	14.9^{a}	14.3^{a}	21.3^{cd}	21.2^{c}	61.0^{b}	53.0^{b}	52.2^{f}	48.4^{de}	22.2^{fg}	19.2^{e}
9507 × Manthar-03	11.3^{f}	10.4^{f}	21.7^{c}	21.8^{b}	60.0^{c}	50.0^{d}	71.8^{c}	68.1^{c}	23.8^{de}	20.8^{c}
9805×9633	11.5^{e}	10.5^{f}	20.0^{e}	20.1^{d}	55.3^{f}	50.3^{d}	51.1^{gh}	47.2^{ef}	26.7^{a}	22.7^{a}

Means followed by different letters, within a column, for each trait differs significantly from each other at $P \leq 0.05$
WW= Well-watered; DS= Drought stress

Table 8: Correlation between seedling traits and yield related traits of wheat under drought stress

Characteristics	Spike length (cm)	Number of Spikelet/spike	Number of grains/spike	1000-grain weight (g)	Grain yield (g plant^{-1})	Root length (cm)	Shoot length (cm)
Number of Spikelet/spike	0.43**						
Number of grains/spike	0.33*	0.82**					
1000-grain weight (g)	-0.01^{NS}	0.18^{NS}	0.34*				
Grain yield (g plant^{-1})	0.69**	0.47**	0.55**	0.41**			
Root length (cm)	0.05^{NS}	0.75**	0.87**	0.45**	0.71**		
Shoot length (cm)	-0.01^{NS}	0.77**	0.88**	0.4**	0.62**	0.96**	
Root Shoot Ratio	0.24*	0.11^{NS}	0.18^{NS}	0.28*	0.47**	0.4*	0.12^{NS}

** Highly significant, * significant, NS Non significant

Table 9: GCA and SCA effects of various yield related traits in wheat under well-watered and drought conditions in F_1 wheat

Traits	Well-watered		Drought stress	
	σ^2 gca*	σ^2 sca*	σ^2 gca	σ^2 sca
Spike length (cm)	1.13	0.29	0.91	0.68
Number of spikelets per spike	0.134	1.39	0.13	3.22
Number of grains per spike	4.38	12.2	1.44	105.7
1000-grain weight (g)	11.55	43.4	10.66	28.15
Grain yield per plant (g plant^{-1})	0.41	6.33	0.63	9.19

*gca = General combining ability, sca = Specific combining ability

This variation in response towards drought can be attributed to the fact that all genotypes used in this study belonged to varying. The combined effects of these genes plausibly resulted in variation in their response to drought (Noorka and Harrison 2013; Qadir *et al.* 2017).

Best indicator for drought-tolerant genotypes is the long roots and well-developed root system that encourages the better absorption of water (Zhong and Wang 2012). Even after hindrance of shoot growth, roots kept on growing deep in the soil. The significant reduction in root length may be depicted due to the suppression of lateral meristem. The evaluation of F_1 crosses revealed that many genotypes had substantial performance in terms of seedling traits under drought. Genotypes *viz.*, Faisalabad-08 × Chakwal-50, 9507 × 9805, 9805 × 9633, 9507 × Manthar-03, Seher-06 × Manthar-03, 9633 × Chakwal -86, Faisalabad-08 × 9488 and Sehar-06 × 9637 were desirable in terms of their better performance under drought stress. Crossing of selected parents in line × tester fashion brought about considerable new genetic variation and hence resulted in drought-tolerant genotypes (Saeed *et al.* 2001; Akbar *et al.* 2009).

The genotypes selected from our first experiment showed tolerance to drought at seedling stage supported by the literature review which is swarming with work related to sole reliability of seedling traits as selection criteria (Farooq *et al.* 2009). Yet, there was a need to assess the effectiveness of seedling traits-based selection criteria of these genotypes. For this purpose, the present study caters assessment starting from seedling stage till anthesis. All the yield parameters of present study (spike length, number of spikelet per spike, number of grains per spike, 1000-grain weight and grain yield per plant) significantly reduced for drought condition at anthesis stage. Such vulnerability of these traits to drought at anthesis stage has been affirmed by previous works (Abdoli and Saeidi 2013; Ali *et al.* 2015). Drought and aspects of plant nutrition have been reviewed by Bista *et al.* (2018) who concluded that mineral nutrients are responsible for the synthesis of essential organic molecules. Current study suggested that drought disturbed mineral nutrient relations and hindered plant growth which is, ultimately, reflected through substantially decreased yield (Ali *et al.* 2015).

Assessment of individual genotypes revealed that some genotypes were not affected by drought-stress and had higher yield hence depicting their drought-tolerant ability. Upon tracing them back towards our first experiment (Table 3), it was discovered that Faisalabad-08 × Chakwal-50, 9507 × 9805, 9805 × 9633, 9507 × Manthar-03, Seher-06 × Manthar-03, 9633 × Chakwal -86, Faisalabad-08 × 9488 and Sehar-06 × 9637 genotypes were the same genotypes which had exhibited drought tolerance at seedling stage as well. Further, correlation also emphasized the existence of significant and positive relationship between seedling and yield related traits. Results clearly indicated the significance and effectiveness of selection criteria for drought tolerance at anthesis stage based on seedling traits *i.e.*, root length, shoot length and root shoot ratio. Line × tester approach utilized for genetic studies identified additive genes responsible for spike length but non-additive genes for rest of the traits which suggested the delay in selection till later generations (Singh and Kumar 2014).

Conclusion

Drought stress negatively affected both seedling and yield attributes of wheat genotypes. It is clear from current study that drought affects the growth and yield when imposed at seedling and anthesis stage of wheat. In preview of the results deduced through this study, it is recommended that mass selection of wheat crosses may be an effective option to cope with the drought stress due to their non-additive gene action. Owing to the significant correlation between seedling and yield related traits under drought stress; the study also affirms the reliability of seedling traits at seedling stage as optimal selection markers for drought-tolerant genotypes.

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