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Research Article

Evaluation of wheat genotypes for drought tolerance using PEG-6000 at different phenological stages

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ABSTRACT

Drought stress significantly affects the growth and yield of wheat crop. However, tremendous variability exists amongst genotypes concerning their reaction to drought stress. Therefore, figuring out the effects of drought stress on yield and growth of crop plants might assist to select the superior genotypes. In the current study, forty wheat genotypes were assessed for drought tolerance using PEG-6000 at seedling, tillering, heading and maturity stage at PMAS-Arid Agriculture University, Rawalpindi, Punjab, Pakistan during 2022-23. ANOVA revealed significant variation ($P \leq 0.05$) among genotypes for all traits in all the growth stages in both conditions (drought and normal). Mean comparison analysis showed the genotypes LLR-25 (12.73g), Lasani-08 (12.69g) and WC-26 (12.57g) were high-yielding and also performed well in terms of root-shoot-related traits under drought condition. Correlation depicted the highly significant positive association of yield per plant with 1000 grain weight (0.85**) as well as positive association with traits i.e., root length at seedling (0.08), tillering (0.27) and heading (0.14) stage, no. of crown roots at tillering (0.13), no. of seminal roots at tillering (0.04) and heading (0.17) under drought condition. Moreover, spike length showed a positive highly significant association with root length (0.48**) at seedling and no. of seminal roots (0.4**) at heading stage under drought condition. PCA bi-plot analysis emphasized genotypes related to specific traits showing their importance under drought stress condition. Moreover, PCA bi-plot revealed the distinctness and strong association with key drought-resilient traits of genotype Chakwal-50. Hence, this study identified the genotypes viz. Chakwal-50, LLR-25, Lasani-08 and WC-26 have desirable root parameters as well as found best regarding yield and related traits under water deficit condition. The selected genotypes can be sown directly under water-deficit condition and may be further utilized for drought-tolerance breeding programs for varietal improvements in the current scenario of the changing climate.

Keywords: Root traits; genetic diversity; drought tolerance; PEG-6000.

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INTRODUCTION

Wheat (Triticum aestivum L.) provides 35% of the world's food consumption (Mohammadi-joo et al., 2015; Hossain et al., 2021) and is the second most important cereal crop in Asia and South Asian areas, providing 68% of energy (Qasim et al., 2022). As the world's population continues to grow, wheat supply will become an increasingly difficult challenge, with a projected 60% increase in yield required by 2050 compared to current levels (Tian et al., 2021).Climate change and a rapidly growing population are causing serious issues with food security worldwide (El Bilali et al., 2020).

The reduction in precipitation and rainfall due to climate change has resulted in global drought stress (Seleiman et al., 2021). Recent studies from 1985-2015 have shown that low water stress has caused a 20-40% decrease in the production of wheat and maize (Qasim et al., 2022). In the last thirty years, the world average temperature has increased by 0.85°C, which has led to rising greenhouse gases and an increase in CO_2 concentration (Mozaffari et al., 2022). In Pakistan, 75% of the total cultivated area is facing water stress. For instance, drought stress can decrease wheat yield potential by 10% to 90% (Fatima et al., 2018) and negatively affect seedling stage and germination (Mahpara et al*.,* 2022). Grain yield is the most affected parameter and the primary concern of breeders. Improving plant productivity can enhance grain yield (Morales *et al.,* 2020).

One of the effective strategies for adapting to drought stress in the long term is to develop new genetic cultivars that improve tolerance to abiotic stresses (Reynolds et al*.,* 2016; Prasad et al., 2017). Studying morphological responses under drought stress condition can advance our understanding of crops' ability to adapt to drought-prone environments (Pour-Aboughadareh et al., 2020). Drought directly affects yield by distressing the primary and secondary metabolites in wheat. Several studies reported a rise in the concentration of hormones, carbohydrates, organic acids (malic acid, oxalic acids), and various amino acids (threonine, proline, gamma-aminobutyric acid (GABA), glutamine) and sugar alcohols such as myo-inositol (Mundim and Pringle, 2018; Marcek et al., 2019). Water stress is responsible for increasing the carbon-based secondary metabolites in green parts of wheat plants whereas it lowers them in roots (Mundim and Pringle, 2018).

Wheat plants consist of two types of root systems; the seminal root system (lateral roots or vertical) and the crown root system (nodal or adventitious or horizontal). The seminal roots develop when primary roots emerge through coleorhiza. This system proliferates two meters deep into the soil supporting the plant until crown roots arise. The number of seminal roots depends on root primordia and whether it is developed or not otherwise, they are ten in number. (Kirby and Appleyard, 1987). The development of crown roots is positively correlated with the number of tillers as the crown roots appear during the development first tiller but genetic variation regarding the number of seminal roots has been observed in wheat (Robertson et al., 1979). A vertically arranged root system is important when there is not enough water in the surroundings for the crop to complete its life cycle. Vertically oriented roots play their role in accessing moisture in deeper soil layers (Liao et al., 2006). Seminal roots make up 1-14% of the entire root system of wheat and are more penetrating and functional at the vegetative stage. These roots grow earlier and penetrate deeper than the adventitious roots and function all over of vegetative stage. The seminal root system is very important for the establishment of wheat seedlings (Klepper, 1991). Crown roots may reduce in number in cereals in dried areas while increased seminal roots gain all assimilates (Blum and Ritchie 1984; Asseng et al., 2015). It is reported that the drought-tolerant varieties showed increased root length to ensure water uptake from deeper layers of soil (Manschadi, et al., 2006).

The current investigation aims to evaluate and elucidate the genetic diversity among wheat genotypes for root parameters based on the following hypothesis; early vigor helps to resist drought; deep root system helps to grow under dry condition and deep/profuse root system helps and sustain yield under dry/moisture stress condition. Studying the wheat stages that are most effective in coping with drought stress can reveal how adaptive genotypes respond to drought via morphological changes.

MATERIALS AND METHODS

In the current study, forty bread wheat genotypes including approved varieties, advanced lines and local landraces were assessed for drought tolerance (Table 1). The experiment was planned and executed in the Department of Plant Breeding and Genetics, PMAS Arid Agriculture University Rawalpindi, Punjab, Pakistan during 2022-23. The data regarding root and yield-related parameters were recorded at four stages viz. seedling, tillering, heading and maturity stage. For observing drought tolerance at seedling stage, the seeds were surface sterilized with 1% sodium hypochlorite solution for 15 minutes and subsequently rinsed with distilled water several times to remove chemical residues. For drought treatment, the seeds were placed in petri dishes sized 60×15 mm containing filter paper soaked in 20% PEG-6000 solution to develop -9 bar stress level as described by Jajarami, 2009, whereas for control, seeds were placed on filter paper soaked in distilled water. The petri dishes containing 10 seeds each were arranged in completely randomized design (CRD) with three repeats and placed in the incubator (Memmert ICP 700) for 10 days at ≅ 20˚C. Relative humidity was kept at ≅ 70%, while a light intensity of ≅ 1.2 cd was given for 12 hours. The traits recorded from 11 days old seedlings are given in Table 2 along with their assigned codes.

For assessment of drought tolerance at tillering, heading and maturity stage, seeds of all the genotypes were sown separately to observe each phenological stage in polythene bags (6 inches wide and 30 inches long) containing soil, compost and sand in the ratio of 50:30:20 respectively. Four seeds were sown in each polythene bag and arranged in CRD with three repeats for drought and control groups. To assess the drought tolerance of different wheat genotypes at all the growth stages separately, the solution of PEG-6000 with a concentration of 20% was applied to the treated group of each stage in each bag (≅ 400 ml/bag) at fifteen-day intervals whereas the same amount of tap water was added in the control case. The treated plants were covered with transparent polythene sheets to avoid rainwater. Parameters recorded at all different stages and their assigned codes are mentioned in Table 2.

The data of each phenological stage were subjected to analysis of variance (ANOVA) to determine the statistical differences among the genotypes using the software Statistix 8.1. A biplot analysis based on principal component analysis was performed to elucidate the tolerant genotypes (Johnson and Wichern, 2002) using R packages i.e., “ggplot2”, “factoextra”, “pca3d” and correlation was conducted to assess the relationship between traits using R package “metan”.

Table 1. List of wheat genotypes used in the experiment.

Sr. No	Variety Name	Sr. No	Variety Name	Sr. No	Variety Name	Sr. No	Variety Name
1	LLR-8	11	PARI-73	21	SEHER-06	31	WC-6
2	LLR-9	12	PUNJAB-85	22	INQ-91	32	WC-7
3	LLR-22	13	BLUE SILVER	23	PASBAN-90	33	WC-8
4	LLR-24	14	YACORA-70	24	MAXPAK	34	WC-9
5	LLR-25	15	PAVON	25	WEEBIL	35	WC-10
6	LYP-73	16	NESSER	26	PARWAZ	36	WC-22
7	LASANI-08	17	SHAHKAR-95	27	PRL	37	WC-23
8	AUQAB-2000	18	SA-42	28	LLR-23	38	WC-24
9	MH-97	19	PAK-81	29	CHANAB-70	39	WC-25
10	CHAKWAL-50	20	SA-75	30	FROTANA	40	WC-26

Table 2. Parameters recorded at all stages and their codes.

Sr. No	Stages	Parameters	Codes	Sr. No	Stages	Parameters	Codes
1	Seedling Stage	Coleoptile length (cm)	CoL.S	12	Heading Stage	Shoot length (cm)	SL.H
2		Shoot length (cm)	SL.S	13		No. of tillers	NOT.H
3		Root length (cm)	RL.S	14		Leaf area (cm2)	LA.H
4		No. of roots	NOR.S	15		Root to Shoot ratio	RSR.H
5	Tillering Stage	Shoot length (cm)	SL.T	16		Root length (cm)	RL.H
6		No. of tillers	NOT.T	17		No. of crown roots	NOCR.H
7		Leaf Area (cm^2)	LA.T	18		No. of seminal roots	NOSR.H
8		Root to Shoot Ratio	RSR.T	19	Maturity Stage	Plant height (cm)	PH.M
9		Root length (cm)	RL.T	20		Spike length (cm)	SPL.M
10		No. of crown roots	NOCR.T	21		Number of spikelets	NOS.M
11		No. of seminal roots	NOSR.T	22		1000 grain weight (g)	GW-1000
				23		Yield per plant (g)	YPP

RESULTS AND DISCUSSION

Analysis of variance (ANOVA) revealed significant variation (P≤0.01) among all genotypes for all traits at all the growth stages under both control and drought conditions (Table 3). The results exposed the genetic variability among the genotypes for all the measured traits. The mean performance of different wheat genotypes along with homogenous groups and ranges for all recorded traits at all stages for control and drought conditions are given in Table 4(a), 4(b), 5(a) and 5(b) respectively.

At seedling stage, in control, the mean coleoptile length ranged from 3.83 cm to 7.38 cm (Table 4a & 4b) while it varied from 3.15 cm to 5.49 cm under drought condition (Table 5a & 5b). LLR-24 (5.49 cm) and LLR-9 (5.47 cm) were found with longest coleoptile length under drought condition. The number of roots ranged from 2.60 to 5.06 in control condition and from 2 to 4.40 in drought condition. Genotypes Chakwal-50 and WC-8 both exhibited the mean value of 4.4 and performed best for the number of roots under drought condition at seedling stage. Root length ranged from 6.24 cm to

13.36 cm in control and from 5.73 cm to 12.76 cm in drought condition. LLR-25 and LLR-9 were found with longest root under drought condition with mean values of 12.76 cm and 12.44 cm, respectively. Shoot length ranged from 5.67 cm to 13.84 cm in control and from 5.21 cm to 12.98 cm in drought condition. Genotypes, WC-10 (12.98 cm) and WC-25 (12.54 cm) were produced tallest shoot under drought condition.

At tillering stage, the number of crown roots varied between 5.33 to 10.11 in control and 2.86 to 9.41 in drought condition. The cultivars Pak-81, Lasani-08, and Pari-73 produced maximum number of crown roots under drought condition. Increased mean values were observed for the number of seminal roots under drought condition ranged from1.73 to 5.23 as compared to the control varied from 2.26 to 5. Cultivars, Chakwal-50 and Lasani-08 produced maximum number seminal roots under drought condition with mean values of 5.23 and 5.05, respectively. The number of tillers ranged from 3.86 to 7.30 under control and 2.60 to 6.80 under drought condition. Cultivar WC-22 was produced maximum number of tillers under drought condition. Increased values were observed for the root-to-shoot ratio under drought condition (9.79% to 88.55%) when compared to the control (14.23% to 75.3%) which indicated that the plants modified their morphology under drought stress. The cultivars LLR-24 and LLR-22 performed best in terms of root-to-shoot ratio under drought condition. The leaf area ranged from 16.34 cm^2 to 32.13 cm^2 in control and 15.14 cm^2 to 30.88 cm^2 in drought condition, with the top-performing cultivars (Seher-06 and SA-42) in terms of leaf area under drought condition. Root length ranged from 5.30 cm to 9.99 cm in control and 3.77 cm to 9.87 cm in drought condition, however, the cultivars Seher-06 and WC-8 found with longest root length under drought condition with the mean values of 9.87 cm and 9.07 cm, respectively. Similarly, shoot length ranged from 25.73 cm to 41.13 cm in control and 22.40 cm to 40.40 cm in drought condition. Top-performing cultivars in terms of shoot length under drought condition were PRL (40.4 cm) and WC-9 (37.6 cm).

At the heading stage, the mean number of crown roots varied from 6.58 to 12.78 in control, while a range from 5.88 to 11.38 under drought condition was detected. The genotypes Pavon and SA-75 produced maximum number crown roots under drought condition. The mean values for the number of seminal roots varied from 4.20 to 5.96 in control, while under drought condition, it ranged from 2.60 to 5.30. LLR-22, Chakwal-50 and Lasani-08 produced maximum number of seminal roots under drought condition. The mean number of tillers varied from 3.50 to 6.50 in control, while during drought condition, it ranged from 2.90 to 6.20. Auqab-2000, Nesser, and Parwaz produced maximum number of tillers under drought condition. The root-to-shoot ratio varied from 25.54% to 62.19% in control, while under drought condition, it ranged from 14.38% to 62.48%. The cultivars that performed the best in terms of root-to-shoot ratio under drought condition were WC-8 and LLR-24. In control, the leaf area varied from 19.88 cm^2 to 33.88 cm^2, while under drought condition, it ranged from 14.57 cm^2 to 31.53 cm^2. Genotypes Pak-81, Seher-06, and INQ-91 were found with larger leaf area than other genotypes under drought condition. In control, the mean root length varied from 8.02 cm to 15.67 cm, while under drought condition, it ranged from 7.32 cm to 14.87 cm. Genotypes Lasani-08 and Frotana were found to be have maximum mean root length under drought condition. The shoot length varied from 39.30 cm to 54.40 cm in control, while under drought condition, it ranged from 38.34 cm to 53.54 cm. The genotypes WC-22 and LLR-25 were found with tallest shoot length under drought condition.

At maturity, the mean plant height ranged from 55.30 to 67.91 cm for the control group while mean values for plant height ranged from 53.96 to 69.34 cm under drought condition. The genotypes LLR-25and WC-22 were found to tall heighted under drought condition with the mean values of 69.34 cm and 67.42 cm. In the control group, the mean spike length ranged from 6.40 to 10.50 cm, while the mean values for spike length ranged from 5.20 to 10.30 cm under drought condition. The genotypes Chakwal-50 (10.3 cm) and WC-10 (9.9 cm) produced longest spike under drought condition were Chakwal-50 (10.3 cm) and WC-10 (9.9 cm). The mean number of spikelets ranged from 14 to 20 in the

Table 3. Analysis of variance under control and drought condition.

Growth Stage	SOV	Control			Drought		
		Treatments	Error	CV (%)	Treatments	Error	CV (%)
Tillering Seedling	CoL.S	2.08**	0.06	5.17	1.05**	0.33	14.2
	SL.S	10.28**	0.13	3.32	8.94**	1.01	9.74
	RL.S	7.38**	1.31	10.29	10.46**	1.02	10.12
	NOR.S	1.45**	0.03	4.57	1.48**	0.02	5.47
	SL.T	47.63**	0.27	1.55	51.42**	1.08	3.21
	NOT.T	2.39**	0.01	2.25	3.26**	0.02	3.47
	LA.T	68.72**	0.3	2.2	71.26**	1.03	4.29

	RSR.T	418.58**	7.55	8.04	691.95**	15.2	11.78
	RL.T	4.04**	0.08	3.77	4.31**	0.11	4.91
	NOCR.T	4.54**	0.03	2.33	6.43**	1.01	13.62
	NOSR.T	1.65**	0.03	5.1	1.89**	0.009	2.67
Heading	SL.H	44.84**	1.41	2.57	48.96**	1.38	2.62
	NOT.H	4.15**	0.03	4.17	4.01**	0.11	7.86
	LA.H	41.40**	2.42	5.6	50.62**	1.01	4
	RL.H	13.25**	0.11	2.88	11.69**	1.01	9.43
	NOCR.H	6.40**	0.11	3.51	4.96**	0.11	3.96
	NOSR.H	0.49**	0.02	3.26	1.37**	0.02	4.14
	RSR.H	252.63**	5.27	5.36	394.8**	9.9	8.25
Maturity	PH.M	30.58**	1.43	1.94	43.39**	1.01	1.66
	SPL.M	2.90**	0.02	1.95	4.25**	0.11	4.32
	NOS.M	5.43**	1.06	5.99	6.61*	4	15.72
	GW-1000	27.77**	2.7	5.4	30.27**	0.11	1.18
	YPP	8.51**	0.02	1.52	9.65**	0.11	3.38

Key: *=(P≤0.05), **=(P≤0.01), Source of variation "SOV", coefficient of variance "CV", At seedling stage: (coleoptile length (cm) "Col.S", shoot length (cm) "SL.S", root length (cm) "RL.S", no. of roots "NOR. S"), At tillering stage: (shoot length (cm) "SL.T", root length (cm) "RL.T", leaf area (cm2) "LA.T", no. of tillers "NOT.T", no. of crown roots "NOCR.T", no. of seminal roots "NOSR.T", root to shoot ratio "RSR.T"), At heading stage: (shoot length (cm) "SL.H", root length (cm) "RL.H", leaf area (cm2) "LA.H", no. of tillers "NOT.H", no. of crown roots "NOCR.H", no. of seminal roots "NOSR.H", root to shoot ratio "RSR.H"), At maturity stage: (plant height (cm) "PH.M", spike length (cm) "SPL.M", Number of spikelets "NOS.M", 1000 grain weight (g) "TGW", Yield per plant (g) "YPP".

control group, while in the drought condition, it ranged from 10 to 16. The genotypes WC-7 (16), INQ-91 (16) and Frotana (15) produced maximum number of spikelets under drought condition. In the control group, the mean thousand-grain weight ranged from 24.50 to 36.98 g, while in the drought condition group, thousand-grain weight ranged from 22.87 to 34.52 g. The genotypes WC-7, Lasani-08, and Seher-06 produced maximum thousand-grain weight under drought condition than the other genotypes. In the control group, the mean yield per plant ranged from 8.34 to 13.76 g, while in the drought condition group, yield per plant ranged from 6.85 to 12.73 g. The genotypes LLR-25 followed by Lasani-08 produced maximum yield per plant under drought condition with mean values of 12.73 g and 12.69 g, respectively.

Correlation Studies

Under control condition

Coleoptile length (seedling) had a highly significant and positive correlation with the root-to-shoot ratio (heading) and root-to-shoot ratio (tillering). The number of seminal roots showed a significant and positive correlation with the root-to-shoot ratio at the heading stage. The number of tillers showed a highly significant and positive correlation with the number of crown roots during the tillering stage. In contrast, number of tillers showed a significant but negative association with the number of seminal roots at tillering. The number of crown roots had a highly significant but negative correlation with root length at tillering as well as with the root length at the heading stage. Shoot length recorded at the tillering stage had a highly significant but negative correlation with the number of crown roots and shoot length at the heading stage. Shoot length had a highly significant and positive correlation with root length at the seedling stage, while it showed a significant but negative correlation with the number of tillers recorded at the heading stage. The root length recorded at the tillering stage had a highly significant and positive correlation with leaf area at the tillering and heading stage as well as with root length at the heading stage. The leaf area at the tillering stage had a highly significant

Table 4(a). Mean values and homogenous groups of all recorded traits of different wheat genotypes at all stages “under Control condition”.

Genotypes	Col.S	RL.S	SL.S	NOR.S	SL.T	RL.T	LA.T	NOCR.T	NOSR.T	RSR.T	NOT.T	SL.H	RL.H	LA.H	NOT.H	NOCR.H	NOSR.H	RSR.H	PH.M	SPL.M	TGW	NOS.M	YPP
LLR-8	6.59^{B}	13.29^{A}	12.12^{EF}	3.93^{H-J}	34.77^{JK}	7.81^{M-P}	23.95^{H-J}	6.25^{J}	4^{B}	24.72^{ST}	5.70^{L}	40.29^{RS}	12.67^{F}	27.83^{I-M}	5.5^{C}	10.32^{FG}	5.2^{D-F}	48.49^{E-G}	56.29^{RS}	9^{GH}	29.11^{I-M}	17.33^{C-E}	8.56^{P}
LLR-9	7.06^{A}	13.24^{A}	11.45^{GH}	4.40^{D-F}	37.47^{CD}	8.78^{F-I}	19.48^{MN}	7.76^{G}	5^{A}	39.42^{G-I}	5.67^{L}	44.33^{L-P}	14.08^{CD}	25.25^{N-R}	5.5^{C}	9.31^{I-L}	5.5^{BC}	50.04^{D-F}	60.33^{K-O}	7.4^{OP}	27.9^{K-O}	16.67^{D-F}	9.84^{JK}
LLR-22	6.35^{B}	12.78^{A-C}	13.24^{A-C}	3.13^{OP}	33.73^{LM}	6.58^{S-U}	18.96^{NO}	9.33^{C}	4^{B}	63.56^{B}	5.87^{J-L}	49.59^{E-G}	9.02^{PQ}	21.76^{T-V}	4.5^{D}	9.98^{GH}	5.9^{A}	52.87^{CD}	65.59^{B-D}	9.1^{FG}	30.9^{F-J}	17.33^{C-E}	11.34^{G}
LLR-24	6.63^{B}	11.21^{B-J}	10.34^{L-N}	3.80^{I-K}	31.20^{PQ}	7.90^{K-N}	25.27^{F}	8.33^{F}	4^{B}	75.31^{A}	5.93^{I-K}	51.36^{B-E}	12.77^{EF}	30.33^{B-I}	3.5^{E}	10.99^{C-E}	5.4^{B-D}	62.19^{A}	67.36^{AB}	7.5^{O}	32.2^{C-H}	16.00^{E-G}	13.24^{B}
LLR-25	7.38^{A}	13.23^{A}	12.56^{DE}	3.40^{L-O}	27.60^{U}	9.23^{C-F}	27.40^{DE}	7.67^{G}	3^{C}	35.65^{I-M}	6.87^{CD}	54.51^{A}	11.67^{I}	29.65^{D-J}	3.5^{E}	8.62^{M-O}	4.6^{J-L}	48.71^{E-G}	63.17^{F-I}	8.1^{MN}	31.88^{D-H}	16.67^{D-F}	13.43^{B}
LYP-73	4.71^{F-K}	9.10^{L-N}	10.22^{L-N}	2.73^{QR}	32.70^{NO}	8.40^{H-J}	20.40^{L}	6.66^{I}	4^{B}	16.41^{V}	3.87^{T}	48.09^{G-I}	13.27^{E}	25.72^{L-Q}	6.5^{A}	7.99^{PQ}	4.2^{M}	31.00^{NO}	64.09^{D-G}	6.4^{R}	32.77^{C-F}	15.33^{F-H}	11.57^{E-G}
LASANI-08	5.09^{C-F}	12.85^{AB}	11.45^{GH}	4.87^{AB}	37.40^{C-E}	7.32^{QR}	17.68^{P}	9.99^{A}	5^{A}	25.88^{R-T}	5.30^{MN}	44.05^{L-P}	14.62^{BC}	23.33^{Q-T}	5.5^{C}	8.99^{K-M}	5.3^{C-E}	33.96^{MN}	60.05^{K-O}	9.6^{CD}	36.987^{A}	16.67^{D-F}	13.74^{A}
AUQAB-2000	4.30^{K-N}	10.40^{E-M}	9.87^{M-O}	3.00^{PQ}	27.47^{U}	9.51^{A-C}	27.54^{DE}	8.67^{E}	3^{C}	14.33^{V}	6.37^{G}	48.51^{G-I}	11.94^{G-I}	29.35^{E-K}	6.5^{A}	8.2^{O-Q}	4.4^{LM}	25.54^{P}	64.51^{D-F}	9^{GH}	31.49^{E-J}	16.67^{D-F}	10.87^{H}
MH-97	5.31^{CD}	9.98^{G-N}	9.45^{O}	3.40^{L-O}	25.73^{V}	8.44^{H-J}	18.60^{NO}	5.66^{K}	4^{B}	32.09^{M-P}	5.70^{L}	50.72^{C-F}	15.18^{A}	23.17^{R-T}	4.5^{D}	10.54^{EF}	5.4^{B-D}	48.70^{E-G}	66.72^{A-C}	8.4^{J-L}	27.73^{L-O}	14.67^{GH}	9.65^{KL}
CHAKWAL-50	4.59^{H-M}	11.95^{A-F}	10.76^{I-L}	4.60^{B-D}	30.27^{RS}	6.29^{U}	20.35^{LM}	8.33^{F}	5^{A}	14.24^{V}	5.42^{M}	51.91^{B-D}	10.15^{LM}	24.75^{O-S}	3.5^{E}	8.99^{K-M}	5.6^{B}	37.52^{LM}	67.91^{A}	10.5^{A}	25.27^{OP}	17.33^{C-E}	9.05^{NO}
PARI-73	4.68^{F-L}	12.20^{A-E}	11.04^{H-K}	4.13^{F-H}	31.07^{P-R}	7.11^{QR}	24.05^{HI}	9.66^{B}	4^{B}	36.67^{G-L}	5.73^{KL}	45.81^{J-L}	8.55^{QR}	26.25^{L-P}	4.5^{D}	8.79^{L-N}	5.5^{BC}	47.21^{E-H}	61.81^{H-K}	9.4^{DE}	29.07^{J-N}	16.67^{D-F}	8.96^{O}
PUNJAB-85	4.07^{NO}	12.91^{AB}	12.56^{DE}	3.00^{PQ}	33.33^{MN}	7.15^{QR}	18.43^{OP}	8.66^{E}	3^{C}	38.61^{G-K}	7.30^{A}	47.23^{IJ}	10.45^{KL}	25.03^{O-S}	3.5^{E}	10.32^{FG}	5.1^{E-G}	41.61^{JK}	63.23^{F-H}	9.4^{DE}	26.84^{M-P}	18.00^{B-D}	8.34^{P}
BLUESILVER	4.57^{H-M}	12.15^{A-F}	11.34^{G-I}	4.53^{C-E}	35.58^{IJ}	7.42^{N-Q}	23.11^{JK}	8.66^{E}	4^{B}	36.24^{H-M}	4.60^{Q}	43.22^{N-Q}	9.85^{M}	25.31^{M-R}	5.5^{C}	11.19^{C}	4.8^{H-J}	46.64^{F-I}	59.22^{M-Q}	9.5^{DE}	29.86^{H-L}	17.33^{C-E}	9.54^{L}
YACORA-70	4.28^{L-N}	11.21^{B-J}	10.67^{J-L}	4.27^{E-G}	29.55^{S}	5.80^{V}	24.32^{GH}	9.33^{C}	3^{C}	27.15^{Q-S}	6.63^{EF}	47.57^{H-J}	8.87^{PQ}	24.57^{P-S}	3.5^{E}	10.99^{C-E}	4.5^{KL}	46.32^{F-I}	63.57^{E-H}	7.9^{N}	24.5^{P}	16.67^{D-F}	8.34^{P}
PAVON	4.43^{I-N}	11.17^{B-J}	10.40^{LM}	4.40^{D-F}	28.57^{T}	9.51^{A-C}	29.67^{B}	8.99^{D}	2.2^{D}	28.11^{P-S}	6.70^{D-F}	50.57^{D-F}	12.38^{F-H}	31.07^{B-G}	6.5^{A}	12.78^{A}	5.6^{B}	47.58^{E-H}	66.57^{A-C}	9.3^{EF}	25.85^{OP}	16.00^{E-G}	9.24^{MN}
NESSER	4.53^{H-M}	9.24^{K-N}	8.65^{P}	4.20^{F-H}	32.33^{O}	8.24^{J-M}	28.11^{CD}	9.33^{C}	3^{C}	18.50^{UV}	7.10^{AB}	49.42^{F-H}	10.68^{J-L}	30.31^{B-I}	6.5^{A}	9.59^{H-J}	4.9^{G-I}	30.67^{NO}	65.42^{C-E}	7.1^{Q}	30.42^{F-K}	18.67^{A-C}	10.65^{H}
SHAHKAR-95	4.83^{F-I}	8.31^{N}	7.89^{QR}	4.13^{F-H}	33.03^{M-O}	8.96^{D-G}	28.98^{BC}	9^{D}	4^{B}	32.07^{M-P}	6.00^{IJ}	46.71^{I-K}	13.83^{D}	30.38^{B-H}	6^{B}	10.8^{C-F}	4.9^{G-I}	50.73^{DE}	62.71^{F-J}	8.4^{J-L}	32.6^{C-G}	16.00^{E-G}	11.76^{E}
SA-42	4.56^{H-M}	10.72^{D-L}	12.45^{DE}	4.93^{A}	31.33^{P}	8.83^{E-H}	31.75^{A}	9.66^{B}	3^{C}	24.16^{ST}	6.50^{FG}	43.91^{L-P}	15.13^{AB}	31.35^{A-G}	3.5^{E}	10.69^{C-F}	4.7^{I-K}	33.95^{MN}	59.91^{K-O}	8.2^{LM}	24.91^{P}	16.67^{D-F}	9.56^{L}
PAK-81	3.86^{O}	11.55^{A-I}	13.76^{AB}	3.60^{K-M}	33.13^{M-O}	7.34^{PQ}	29.52^{B}	10.11^{A}	4^{B}	44.01^{D-F}	6.77^{C-E}	40.05^{RS}	9.78^{MN}	31.72^{A-E}	4.5^{D}	9.06^{J-M}	4.7^{I-K}	47.73^{E-H}	56.05^{RS}	8.6^{IJ}	30.97^{F-J}	17.33^{C-E}	10.65^{H}
SA-75	4.73^{F-J}	10.31^{F-M}	9.44^{O}	3.47^{L-N}	28.57^{T}	9.14^{C-F}	31.86^{A}	8.33^{F}	4^{B}	30.51^{N-Q}	4.50^{QR}	47.06^{IJ}	14.01^{D}	32.26^{AC}	5.5^{C}	11.99^{B}	4.4^{LM}	47.18^{E-I}	63.06^{F-I}	8.8^{HI}	29.7^{H-L}	16.67^{D-F}	11.65^{EF}
SEHER-06	4.56^{H-M}	12.03^{A-F}	11.20^{G-J}	3.60^{K-M}	37.43^{CD}	9.99^{A}	31.68^{A}	6.66^{I}	3^{C}	30.98^{N-Q}	5.10^{NO}	41.48^{QR}	12.43^{FG}	33.88^{A}	3.5^{E}	9.09^{J-M}	5.1^{E-G}	40.13^{KL}	57.48^{QR}	9.1^{FG}	34.71^{A-C}	18.67^{A-C}	12.36^{D}
INQ-91	4.07^{NO}	12.51^{A-D}	11.78^{FG}	4.00^{G-I}	38.13^{BC}	8.41^{H-J}	29.25^{B}	8.66^{E}	3^{C}	40.15^{E-H}	5.43^{M}	42.85^{O-Q}	13.28^{E}	33.65^{A}	5.5^{C}	10.39^{FG}	4.6^{J-L}	27.31^{OP}	58.85^{N-Q}	9.9^{B}	26.41^{N-P}	19.33^{AB}	9.45^{LM}

Key: At seedling stage: (coleoptile length (cm) “Col.S”, shoot length (cm) “SL.S”, root length (cm) “RL.S”, no. of roots “NOR. S”), At tillering stage: (shoot length (cm) “SL.T”, root length (cm) “RL.T”, leaf area (cm^2) “LA.T”, no. of tillers “NOT.T”, no. of crown roots “NOCR.T”, no. of seminal roots “NOSR.T”, root to shoot ratio “RSR.T”), At heading stage: (shoot length (cm) “SL.H”, root length (cm) “RL.H”, leaf area (cm^2) “LA.H”, no. of tillers “NOT.H”, no. of crown roots “NOCR.H”, no. of seminal roots “NOSR.H”, root to shoot ratio “RSR.H”), At maturity stage: (plant height (cm) “PH.M”, spike length (cm) “SPL.M”, Number of spikelets “NOS.M”, 1000 grain weight (g) “TGW”, Yield per plant (g) “YPP”.

Table 4(b). Mean values and homogenous groups of all recorded traits of different wheat genotypes at all stages “under Control condition”.

Genotypes	Col.S	RL.S	SL.S	NOR.S	SL.T	RL.T	LA.T	NOCR.T	NOSR.T	RSR.T	NOT.T	SL.H	RL.H	LA.H	NOT.H	NOCR.H	NOSR.H	RSR.H	PH.M	SPL.M	TGW	NOS.M	YPP
PASBAN-90	4.23^{M-O}	12.13^{A-F}	12.92^{CD}	3.20^{N-P}	35.67^{HI}	8.38^{H-K}	32.13^{A}	5.33^{L}	3^{C}	44.60^{C-E}	4.20^{S}	48.07^{G-I}	15.68^{A}	32.73^{AB}	6.5^{A}	8.96^{K-N}	4.6^{J-L}	26.44^{P}	64.07^{D-G}	8.9^{GH}	31.77^{D-I}	17.33^{C-E}	13.23^{B}
MAXPAK	4.61^{G-M}	9.60^{J-N}	9.76^{NO}	4.87^{AB}	27.40^{U}	7.11^{QR}	29.23^{B}	9.33^{C}	3^{C}	36.80^{G-L}	5.70^{L}	43.85^{M-P}	11.98^{G-I}	30.63^{B-G}	3.5^{E}	11.19^{C}	5^{F-H}	34.28^{MN}	59.85^{L-O}	6.6^{R}	31.63^{E-J}	16.67^{D-F}	11.54^{E-G}
WEEBIL	4.40^{J-N}	8.58^{MN}	7.83^{R}	2.60^{R}	26.47^{V}	9.40^{B-D}	31.24^{A}	8.33^{F}	4^{B}	39.96^{F-I}	5.27^{MN}	44.85^{K-N}	12.27^{F-H}	31.64^{A-F}	5.5^{C}	11.09^{CD}	4.8^{H-J}	26.84^{P}	60.85^{J-M}	8.4^{J-L}	29.98^{G-L}	18.67^{A-C}	10.07^{J}
PARWAZ	4.41^{J-N}	10.96^{C-L}	10.21^{L-N}	3.00^{PQ}	30.40^{QR}	6.44^{TU}	26.78^{E}	8.66^{E}	5^{A}	30.93^{N-Q}	4.30^{RS}	52.70^{AB}	8.88^{PQ}	28.98^{G-K}	6.5^{A}	8.19^{O-Q}	5.4^{B-D}	40.43^{KL}	62.70^{F-J}	9.5^{DE}	30.54^{F-K}	16.67^{D-F}	11.43^{FG}
PRL	5.01^{C-G}	6.24^{O}	5.67^{S}	3.33^{M-O}	41.13^{A}	7.29^{QR}	28.94^{BC}	9^{D}	4^{B}	29.97^{O-R}	6.30^{GH}	42.58^{PQ}	9.73^{MN}	29.14^{F-K}	5.5^{C}	8.43^{N-P}	5.6^{B}	40.63^{KL}	58.58^{O-Q}	9.1^{FG}	26.65^{M-P}	19.33^{AB}	8.95^{O}
LLR-23	4.90^{D-H}	9.16^{L-N}	8.45^{PQ}	4.60^{B-D}	36.57^{E-G}	7.00^{Q-S}	23.25^{IJK}	9.66^{B}	4^{B}	30.90^{N-Q}	5.93^{I-K}	44.78^{K-O}	11.87^{HI}	27.65^{J-N}	6.5^{A}	10.59^{D-F}	5.2^{D-F}	50.59^{DE}	60.78^{J-N}	7.6^{O}	32.7^{C-F}	16.00^{E-G}	9.54^{L}
CHANAB-70	5.39^{C}	10.73^{D-L}	11.34^{G-I}	4.80^{A-C}	37.07^{D-G}	7.22^{QR}	25.04^{FG}	9.66^{B}	3^{C}	27.47^{Q-S}	6.93^{BC}	47.91^{G-I}	9.66^{M-O}	27.24^{J-O}	3.5^{E}	7.79^{Q}	4.8^{H-J}	31.02^{NO}	63.91^{D-G}	8.1^{MN}	33.88^{B-E}	16.00^{E-G}	13.27^{B}
FROTANA	5.28^{C-E}	11.34^{B-J}	10.56^{KL}	3.67^{J-L}	36.23^{G-I}	8.17^{J-M}	16.34^{Q}	7.33^{H}	5^{A}	34.80^{J-N}	4.87^{P}	44.12^{L-P}	15.47^{A}	22.94^{R-U}	3.5^{E}	8.59^{M-O}	5.3^{C-E}	40.62^{KL}	60.12^{K-O}	9.9^{B}	29.79^{H-L}	19.33^{AB}	11.43^{FG}
WC-6	4.93^{D-H}	11.70^{A-H}	12.45^{DE}	4.93^{A}	38.33^{B}	7.84^{L-O}	23.22^{IJK}	7.66^{G}	4^{B}	32.94^{L-O}	5.00^{OP}	42.59^{PQ}	13.28^{E}	25.42^{M-R}	3.5^{E}	6.59^{R}	4.8^{H-J}	41.92^{JK}	58.59^{O-Q}	8.6^{IJ}	30.9^{F-J}	14.00^{H}	11.65^{EF}
WC-7	4.90^{D-H}	9.71^{I-N}	11.42^{GH}	4.30^{EF}	36.47^{F-H}	7.36^{O-Q}	22.56^{K}	8.66^{E}	3^{C}	40.97^{E-G}	6.33^{GH}	41.85^{QR}	12.23^{F-H}	26.96^{K-P}	5.5^{C}	9.39^{I-K}	4.8^{H-J}	49.69^{D-F}	57.85^{P-R}	9.5^{DE}	35.97^{AB}	20.00^{A}	13.26^{B}
WC-8	4.54^{H-M}	11.05^{B-K}	10.32^{L-N}	5.07^{A}	37.30^{C-F}	9.83^{AB}	17.68^{P}	6.33^{J}	4^{B}	47.37^{CD}	4.87^{P}	39.31^{S}	12.27^{F-H}	19.88^{V}	3.5^{E}	7.98^{PQ}	5.4^{B-D}	55.68^{BC}	55.31^{S}	8.4^{J-L}	31.92^{D-H}	17.33^{C-E}	12.93^{C}
WC-9	3.84^{O}	12.63^{A-C}	13.45^{A-C}	3.67^{J-L}	38.33^{B}	8.31^{I-L}	27.54^{DE}	9.33^{C}	5^{A}	34.23^{K-O}	6.07^{IJ}	44.82^{K-N}	10.75^{JK}	29.74^{C-J}	4.5^{D}	6.58^{R}	5.4^{B-D}	44.54^{H-J}	60.82^{J-M}	7.4^{OP}	31.81^{D-H}	17.33^{C-E}	12.54^{D}
WC-10	3.85^{O}	13.36^{A}	13.20^{BC}	4.20^{F-H}	34.57^{KL}	5.31^{W}	18.24^{OP}	9.88^{AB}	4^{B}	25.36^{ST}	5.23^{MN}	50.85^{B-F}	10.18^{LM}	22.64^{S-U}	5.5^{C}	10.85^{C-F}	4.8^{H-J}	45.15^{G-J}	62.52^{G-J}	10.3^{A}	30.483^{F-K}	16.67^{D-F}	10.87^{H}
WC-22	4.89^{E-H}	11.63^{A-H}	13.62^{AB}	4.40^{D-F}	33.40^{MN}	8.64^{G-J}	25.42^{F}	8.33^{F}	5^{A}	32.47^{L-P}	7.27^{A}	52.59^{A-C}	11.08^{J}	27.62^{J-N}	3.5^{E}	7.99^{PQ}	5.2^{D-F}	42.58^{JK}	61.25^{I-L}	7.2^{PQ}	27.61^{L-O}	19.33^{AB}	9.38^{LM}
WC-23	4.76^{F-J}	11.26^{B-J}	13.84^{A}	3.60^{K-M}	36.43^{GH}	8.59^{G-J}	29.46^{B}	6.66^{I}	4^{B}	48.81^{C}	4.30^{RS}	45.70^{J-M}	8.03^{R}	31.66^{A-F}	3.5^{E}	7.86^{Q}	4.8^{H-J}	58.88^{AB}	61.70^{H-L}	9.8^{BC}	30^{G-L}	19.33^{AB}	10.36^{I}
WC-24	5.26^{C-E}	9.94^{H-N}	11.46^{GH}	4.93^{A}	37.43^{CD}	9.31^{C-E}	23.61^{HIJ}	8.33^{F}	4^{B}	40.29^{E-H}	6.07^{IJ}	48.28^{G-I}	9.18^{OP}	28.01^{H-L}	3.5^{E}	11.99^{B}	4.6^{J-L}	55.59^{BC}	64.28^{D-G}	8.5^{JK}	29.69^{H-L}	18.67^{A-C}	12.54^{D}
WC-25	4.80^{F-J}	11.81^{A-G}	13.74^{AB}	3.13^{OP}	38.73^{B}	6.12^{UV}	29.51^{B}	8.66^{E}	3^{C}	21.70^{TU}	6.13^{HI}	43.79^{M-P}	11.92^{G-I}	32.11^{A-D}	3.5^{E}	10.39^{FG}	4.8^{H-J}	40.60^{KL}	59.79^{L-P}	7.9^{N}	35.73^{AB}	16.67^{D-F}	13.76^{A}
WC-26	4.68^{F-L}	11.32^{B-J}	12.45^{DE}	3.20^{N-P}	30.40^{QR}	6.83^{R-T}	18.43^{OP}	9.66^{B}	4^{B}	38.70^{G-J}	4.93^{OP}	41.49^{QR}	9.26^{N-P}	20.63^{UV}	4.5^{D}	9.76^{HI}	5.2^{D-F}	43.45^{I-K}	57.49^{QR}	8.3^{K-M}	34.33^{A-D}	17.33^{C-E}	13.27^{B}

Key: At seedling stage: (coleoptile length (cm) “Col.S”, shoot length (cm) “SL.S”, root length (cm) “RL.S”, no. of roots “NOR. S”), At tillering stage: (shoot length (cm) “SL.T”, root length (cm) “RL.T”, leaf area (cm^2) “LA.T”, no. of tillers “NOT.T”, no. of crown roots “NOCR.T”, no. of seminal roots “NOSR.T”, root to shoot ratio “RSR.T”), At heading stage: (shoot length (cm) “SL.H”, root length (cm) “RL.H”, leaf area (cm^2) “LA.H”, no. of tillers “NOT.H”, no. of crown roots “NOCR.H”, no. of seminal roots “NOSR.H”, root to shoot ratio “RSR.H”), At maturity stage: (plant height (cm) “PH.M”, spike length (cm) “SPL.M”, Number of spikelets “NOS.M”, 1000 grain weight (g) “TGW”, Yield per plant (g) “YPP”.

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Table 5(a). Mean values and homogenous groups of all recorded traits of different wheat genotypes at all stages “under Drought condition”.

Genotypes	Col.S	SL.S	RL.S	NOR.S	SL.T	RL.T	LA.T	NOT.T	NOCR.T	NOSR.T	RSR.T	SL.H	RL.H	LA.H	NOT.H	NOCR.H	NOSR.H	RSR.H	PH.M	SPL.M	NOS.M	TGW	YPP
LLR-8	5.05^{A-C}	11.76^{A-F}	12.28^{A}	2.8^{HI}	34.6^{F-H}	6.27^{N-Q}	21.83^{J-M}	4.5^{M}	4.85^{JK}	3.73^{D}	17.65^{S-V}	38.36^{R}	11.27^{D-I}	24.58^{EF}	4.9^{C}	8.92^{G-I}	3.8^{J-L}	40.37^{D-K}	53.96^{Q}	7.8^{J-N}	14^{AB}	26.71^{O}	7.16^{Q-S}
LLR-9	5.47^{AB}	10.87^{C-H}	12.44^{A}	3.2^{FG}	36.8^{BC}	7.28^{G-J}	17.05^{P}	4.4^{MN}	6.36^{F-J}	4.83^{C}	38.41^{FG}	42.13^{L-O}	12.68^{B-D}	21.05^{H}	4.9^{C}	7.91^{K-M}	4.1^{G-I}	44.89^{CD}	57.73^{L-N}	6.2^{ST}	12^{BC}	25.5^{P}	8.44^{K-M}
LLR-22	4.53^{B-H}	12.54^{AB}	11.75^{A-C}	2.4^{KL}	33.4^{HI}	5.82^{Q-T}	18.76^{O}	5.4^{GH}	8.63^{A-C}	3.86^{D}	67.25^{B}	48.62^{DE}	8.32^{M-O}	20.31^{HI}	4.2^{D}	9.28^{D-H}	5.3^{A}	49.65^{C}	64.42^{C-E}	8.5^{F-I}	12^{BC}	29.7^{F-I}	10.64^{E-G}
LLR-24	5.49^{A}	10.04^{G-I}	10.05^{D-G}	2^{M}	30.6^{LM}	6.37^{M-P}	24.33^{HI}	4.8^{KL}	6.93^{E-I}	3.73^{D}	88.56^{A}	50.76^{BC}	11.37^{D-I}	27.83^{CD}	2.9^{E}	9.59^{C-F}	4^{H-J}	59.13^{AB}	65.03^{C}	6.3^{R-T}	12^{BC}	29.8^{E-G}	11.84^{BC}
LLR-25	4.45^{C-I}	11.34^{A-G}	12.76^{A}	3^{GH}	27.8^{OP}	8.47^{CD}	26.65^{E-G}	6.2^{B}	6.97^{D-I}	2.86^{GH}	34.52^{G-K}	53.54^{A}	10.97^{E-I}	27.85^{CD}	3.2^{E}	7.92^{K-M}	3.9^{I-K}	45.04^{CD}	69.34^{A}	7.5^{M-P}	14^{AB}	30.68^{D}	12.73^{A}
LYP-73	4.96^{A-D}	10.22^{F-I}	6.94^{JK}	2.1^{M}	30.9^{K-M}	6.87^{J-M}	19.72^{NO}	2.6^{S}	5.26^{JK}	3.73^{D}	9.79^{W}	46.16^{F-H}	11.87^{D-G}	19.22^{I-K}	5.9^{AB}	6.59^{P}	2.8^{PQ}	22.74^{OP}	62.87^{E-H}	5.2^{U}	12^{BC}	30.37^{D}	10.17^{G-I}
LASANI-08	3.68^{H-M}	11.45^{A-G}	12.2^{AB}	3.9^{CD}	35.4^{C-G}	7.05^{I-L}	16.67^{PQ}	4.9^{JK}	9.34^{A}	5.05^{B}	27.09^{M-Q}	42.2^{L-O}	14.88^{A}	21.11^{H}	5.3^{C}	7.94^{K-M}	5.12^{AB}	30.99^{MN}	60.43^{IJ}	9.4^{BC}	12^{BC}	34.52^{A}	12.69^{A}
AUQAB-2000	4.14^{C-L}	8.67^{I-K}	9.86^{D-G}	2.4^{KL}	26^{QR}	8.74^{BC}	26.35^{FG}	5.8^{D-F}	7.97^{A-F}	2.86^{GH}	11.46^{VW}	47.54^{D-F}	11.24^{D-I}	24.25^{E-G}	6.2^{A}	7.5^{M-O}	4.2^{GH}	20.06^{PQ}	63.34^{D-G}	8.4^{G-I}	14^{AB}	30.29^{DE}	10.17^{G-I}
MH-97	3.96^{F-M}	8.05^{J-L}	7.25^{I-K}	2.5^{JK}	22.4^{S}	5.38^{TU}	15.17^{Q}	3.2^{R}	2.86^{L}	3.46^{E}	21.25^{P-T}	47.52^{D-F}	12.38^{D-F}	14.57^{L}	3.3^{E}	7.74^{L-N}	2.6^{Q}	35.45^{K-M}	62.72^{F-H}	6^{T}	10^{C}	22.93^{RS}	6.85^{S}
CHAKWAL-50	3.92^{F-M}	10.23^{E-I}	12.28^{A}	4.4^{A}	30.4^{LM}	6.12^{N-R}	20.24^{M-O}	5.3^{HI}	8.45^{A-E}	5.23^{A}	13.23^{VW}	52.54^{AB}	9.88^{I-M}	22.87^{G}	3.2^{E}	7.59^{L-O}	5.3^{A}	37.47^{I-L}	66.87^{B}	10.3^{A}	14^{AB}	22.87^{S}	7.65^{O-Q}
PARI-73	4.01^{E-M}	10.56^{D-H}	11.98^{A-C}	3.4^{EF}	30.4^{LM}	6.35^{M-Q}	23.25^{I-K}	5.1^{IJ}	8.96^{AB}	3.86^{D}	35.62^{G-I}	44.84^{HI}	7.85^{NO}	24.05^{E-G}	4.2^{D}	8.09^{KL}	4.8^{CD}	43.19^{D-G}	60.64^{IJ}	8.8^{D-G}	10^{C}	27.87^{M}	8.26^{L-N}
PUNJAB-85	3.58^{I-M}	11.87^{A-E}	11.38^{A-D}	2.4^{KL}	31.6^{J-L}	5.65^{R-T}	16.83^{P}	6.1^{BC}	7.26^{C-I}	2.83^{GH}	54.45^{C}	45.03^{G-I}	9.05^{J-N}	22.83^{G}	2.9^{E}	8.92^{G-I}	3.7^{KL}	34.85^{LM}	60.63^{IJ}	8.2^{H-K}	13^{A-C}	24.44^{Q}	6.94^{RS}
BLUESILVER	3.69^{H-M}	10.87^{C-H}	11.76^{A-C}	4^{BC}	34.8^{E-H}	6.65^{K-N}	22.31^{J-L}	3.9^{PQ}	7.96^{A-F}	3.86^{D}	35.16^{G-I}	42.25^{L-O}	9.15^{J-N}	23.91^{E-G}	5.2^{C}	10.49^{B}	4.1^{G-I}	42.63^{D-H}	58.05^{K-M}	9.2^{C-E}	12^{BC}	28.66^{L}	8.84^{K}
YACORA-70	3.53^{I-M}	10.03^{G-I}	10.475^{C-F}	3.65^{DE}	28.6^{NO}	4.84^{U}	23.32^{IJ}	6.05^{B-D}	8.46^{A-E}	2.80^{GH}	29.54^{I-O}	46.75^{E-G}	8.00^{NO}	22.82^{G}	3.1^{E}	10.115^{BC}	4.1^{G-I}	41.12^{D-J}	62.525^{GH}	7.15^{PQ}	14^{AB}	23^{RS}	7.465^{P-R}
PAVON	3.36^{K-M}	9.56^{H-J}	9.95^{D-G}	3^{GH}	26.9^{PQ}	7.98^{DE}	28.07^{C-E}	5.6^{FG}	7.59^{B-H}	1.73^{I}	23.69^{O-S}	48.64^{DE}	10.98^{E-I}	29.43^{BC}	5.9^{AB}	11.38^{A}	4.2^{GH}	40.61^{D-J}	64.24^{C-F}	8.1^{I-L}	12^{BC}	23.45^{R}	7.84^{N-P}
NESSER	3.67^{H-M}	8.23^{J-L}	8.73^{G-I}	3.6^{E}	31.6^{J-L}	7.48^{E-I}	27.31^{D-G}	6.6^{A}	8.63^{A-C}	2.86^{GH}	15.57^{T-W}	48.45^{DE}	9.98^{H-L}	28.07^{CD}	6.2^{A}	8.89^{H-J}	4.2^{GH}	24.98^{OP}	64.25^{C-F}	6.5^{R-T}	14^{AB}	29.22^{I-K}	9.95^{H-J}
SHAHKAR-95	4.16^{C-L}	7.32^{KL}	6.92^{JK}	3^{GH}	31.5^{J-L}	7.43^{F-I}	27.38^{D-G}	4.8^{KL}	7.60^{B-H}	3.73^{D}	28.63^{J-O}	44.78^{HIJ}	12.43^{D-F}	27.34^{D}	5.4^{BC}	9.4^{D-H}	3.3^{N}	44.51^{D}	60.38^{IJ}	7.2^{O-Q}	12^{BC}	30.2^{D-F}	10.36^{F-H}
SA-42	4.02^{D-M}	11.43^{A-G}	8.51^{G-J}	3.9^{CD}	30^{L-N}	7.73^{E-G}	30.55^{A}	5.7^{EF}	8.61^{A-D}	2.95^{G}	21.07^{Q-T}	42.06^{L-O}	14.08^{A-C}	28.98^{B-D}	3.2^{E}	9.64^{C-E}	4.6^{D-F}	24.72^{OP}	57.76^{L-N}	7.3^{N-Q}	12^{BC}	23.11^{RS}	8.51^{K-M}

Key: At seedling stage: (coleoptile length (cm) “Col.S”, shoot length (cm) “SL.S”, root length (cm) “RL.S”, no. of roots “NOR. S”), At tillering stage: (shoot length (cm) “SL.T”, root length (cm) “RL.T”, leaf area (cm^2) “LA.T”, no. of tillers “NOT.T”, no. of crown roots “NOCR.T”, no. of seminal roots “NOSR.T”, root to shoot ratio “RSR.T”), At heading stage: (shoot length (cm) “SL.H”, root length (cm) “RL.H”, leaf area (cm^2) “LA.H”, no. of tillers “NOT.H”, no. of crown roots “NOCR.H”, no. of seminal roots “NOSR.H”, root to shoot ratio “RSR.H”), At maturity stage: (plant height (cm) “PH.M”, spike length (cm) “SPL.M”, Number of spikelets “NOS.M”, 1000 grain weight (g) “TGW”, Yield per plant (g) “YPP”.

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Table 5(b). Mean values and homogenous groups of all recorded traits of different wheat genotypes at all stages *"under drought condition".*

Genotypes	Col.S	SL.S	RL.S	NOR.S	SL.T	RL.T	LA.T	NOT.T	NOCR.T	NOSR.T	RSR.T	SL.H	RL.H	LA.H	NOT.H	NOCR.H	NOSR.H	RSR.H	PH.M	SPL.M	NOS.M	TGW	YPP
PASBAN-90	4.27^{C-K}	11.87^{A-E}	10.03^{D-G}	2^{M}	34^{G-I}	6.88^{J-M}	30.53^{A}	2.8^{S}	3.93^{KL}	2.83^{GH}	44.99^{DE}	45.87^{F-H}	14.28^{AB}	30.33^{AB}	5.9^{AB}	7.56^{L-O}	3.2^{NO}	16.36^{QR}	61.47^{HI}	8.7^{E-H}	12^{BC}	29.37^{G-I}	11.83^{BC}
MAXPAK	3.81^{G-M}	9.45^{H-J}	7.92^{H-J}	3.6^{E}	25.8^{QR}	5.58ST	27.63^{D-G}	4.4^{MN}	7.93^{A-F}	2.73^{H}	34.77^{G-J}	43.44^{I-M}	11.88^{D-G}	28.13^{CD}	2.9^{E}	9.79^{CD}	3.6^{LM}	24.04^{OP}	57.52^{L-N}	5.4^{U}	12^{BC}	29.23^{H-K}	10.14^{G-I}
WEEBIL	3.48^{J-M}	6.89^{L}	7.36^{I-K}	2.4^{KL}	24.8^{R}	7.87^{EF}	29.64^{A-C}	4.2^{NO}	6.93^{E-I}	3.73^{D}	39.00^{E-G}	42.92^{J-N}	10.87^{F-I}	28.4^{CD}	4.9^{C}	9.69^{C-E}	3.4^{MN}	14.39^{R}	58.52^{KL}	7.2^{O-Q}	14^{AB}	27.58^{MN}	8.67^{KL}
PARWAZ	3.81^{G-M}	9.56^{H-J}	11.45^{A-D}	2.4^{KL}	29.6^{MN}	5.99^{O-S}	25.98^{GH}	4.1^{OP}	8.65^{A-C}	4.86^{C}	27.29^{M-Q}	51.73^{AB}	8.18^{NO}	27.99^{CD}	6.2^{A}	7.49^{M-O}	4.7^{C-E}	43.48^{D-F}	67.84^{AB}	9.3^{CD}	12^{BC}	29.34^{G-J}	10.73^{EF}
PRL	4.36^{C-J}	5.21^{M}	5.73^{K}	2.8^{HI}	40.4^{A}	6.53^{L-O}	28.14^{C-E}	5.6^{FG}	8.30^{A-E}	3.86^{D}	28.28^{K-O}	41.61^{M-P}	9.03^{J-N}	28.65^{CD}	5.2^{C}	7.73^{L-N}	4.9^{BC}	36.12^{J-L}	57.41^{L-N}	8.5^{F-I}	14^{AB}	25.45^{P}	8.25^{L-N}
LLR-23	4.03^{D-M}	8.19^{J-L}	7.92^{H-J}	3.2^{FG}	34.9^{D-H}	5.47ST	21.65^{K-M}	4.6^{LM}	8.26^{A-E}	3.73^{D}	26.90^{M-Q}	42.85^{K-N}	10.47^{G-J}	25.41^{E}	5.9^{AB}	9.19^{E-H}	3.8^{J-L}	44.05^{DE}	61.76^{G-I}	6.4^{R-T}	12^{BC}	30.3^{DE}	8.14^{L-O}
CHANAB-70	4.81^{A-F}	9.44^{H-J}	9.62^{FG}	4.2^{AB}	36.4^{B-E}	6.46^{M-O}	24.24^{I}	6.2^{B}	8.96^{AB}	2.86^{GH}	25.42^{N-R}	46.94^{E-G}	8.96^{J-O}	25.04^{EF}	3.2^{E}	7.09^{OP}	4.1^{G-I}	26.40^{NO}	62.74^{F-H}	7.5^{M-P}	12^{BC}	32.68^{C}	12.57^{A}
FROTANA	4.91^{A-E}	10.12^{F-I}	10.38^{C-F}	2.7^{IJ}	34.9^{D-H}	7.07^{H-K}	15.14^{Q}	3.9^{PQ}	6.28^{G-J}	4.95^{BC}	33.72^{G-L}	42.27^{L-O}	14.42^{A}	20.99^{H}	3.05^{E}	7.54^{M-O}	4.35^{FG}	36.03^{J-M}	57.97^{LM}	9^{C-F}	15^{AB}	27.99^{M}	10.38^{F-H}
WC-6	4.47^{C-I}	11.32^{B-G}	10.53^{C-F}	4.2^{AB}	37.6^{B}	7.08^{H-K}	22.42^{J-L}	4.65^{K-M}	6.96^{E-I}	3.86^{D}	31.79^{H-M}	41.62^{M-P}	12.58^{C-E}	23.55^{FG}	3.2^{E}	5.89^{Q}	4.1^{G-I}	38.16^{G-L}	57.42^{L-N}	8^{I-M}	12^{BC}	29.7^{F-I}	10.95^{E}
WC-7	4.47^{C-I}	10.94^{B-H}	7.25^{I-K}	3^{GH}	34.8^{E-H}	5.83^{P-T}	20.96^{L-N}	5.3^{HI}	7.26^{C-I}	2.73^{H}	49.76^{CD}	39.92^{P-R}	10.83^{F-I}	24.31^{E-G}	4.9^{C}	7.99^{K-M}	3.4^{MN}	43.87^{DE}	55.52^{O-Q}	8.3^{G-J}	16^{A}	33.57^{B}	11.86^{BC}
WC-8	4.24^{C-K}	9.54^{H-J}	10.62^{B-F}	4.4^{A}	36.5^{B-D}	9.07^{B}	16.88^{P}	4.2^{NO}	5.63^{IJ}	3.86^{D}	47.65^{D}	38.34^{R}	11.57^{D-H}	18.11^{K}	3.2^{E}	7.28^{NO}	4.7^{C-E}	62.49^{A}	56.87^{M-O}	7.8^{J-N}	12^{BC}	30.72^{D}	12.23^{AB}
WC-9	3.15^{M}	12.32^{A-C}	11.42^{A-D}	3^{GH}	37.6^{B}	7.55^{E-I}	26.74^{E-G}	5.4^{GH}	8.63^{A-C}	4.86^{C}	32.97^{G-M}	43.85^{I-L}	10.05^{H-L}	28.36^{CD}	4.2^{D}	5.88^{Q}	4.7^{C-E}	40.42^{D-K}	59.65^{JK}	6.8^{QR}	10^{C}	30.61^{D}	11.84^{BC}
WC-10	3.16^{M}	12.54^{AB}	11.84^{A-C}	3^{GH}	32.9^{IJ}	3.78^{V}	16.64^{PQ}	3.8^{Q}	8.48^{A-E}	3.73^{D}	20.38^{R-U}	48.92^{CD}	8.78^{K-O}	19.87^{H-J}	4.9^{C}	9.45^{D-G}	3.4^{MN}	37.72^{H-L}	64.52^{CD}	9.9^{AB}	14^{AB}	28.75^{KL}	9.47^{J}
WC-22	4.03^{D-M}	12.21^{A-C}	9.84^{D-G}	4^{BC}	32.6^{IJ}	7.88^{EF}	24.62^{HI}	6.8^{A}	7.63^{B-G}	4.86^{C}	31.09^{H-N}	53.23^{A}	10.38^{G-K}	25.41^{E}	3.2^{E}	7.29^{NO}	4.5^{EF}	38.41^{F-L}	67.42^{B}	6.6^{RS}	12^{BC}	26.41^{O}	8.68^{KL}
WC-23	3.87^{F-M}	12.35^{A-C}	9.17^{F-H}	2.8^{HI}	35.7^{C-F}	7.83^{EF}	28.66^{B-D}	3.4^{R}	5.96^{H-J}	3.86^{D}	49.42^{CD}	44.73^{H-K}	7.33^{O}	29.45^{BC}	3.2^{E}	7.16^{O}	4.1^{G-I}	56.09^{B}	60.53^{IJ}	9.2^{C-E}	14^{AB}	28.8^{J-L}	9.66^{IJ}
WC-24	3.92^{F-M}	10.84^{C-H}	7.58^{H-J}	3.6^{E}	35.9^{C-F}	7.78^{E-G}	22.01^{J-L}	4.8^{KL}	6.93^{E-I}	3.73^{D}	39.23^{E-G}	46.35^{F-H}	7.78^{NO}	25.24^{E}	2.9^{E}	10.59^{B}	3.2^{NO}	45.20^{CD}	61.95^{G-I}	7.3^{N-Q}	14^{AB}	27.29^{N}	11.14^{DE}
WC-25	4.25^{C-K}	12.98^{A}	10.45^{C-F}	2^{M}	37^{BC}	5.88^{P-T}	27.91^{D-F}	5.9^{C-E}	8.45^{A-E}	2.83^{GH}	14.46^{U-W}	41.92^{M-O}	10.52^{G-J}	28.78^{B-D}	2.9^{E}	8.99^{GH}	4.7^{C-E}	41.99^{D-I}	57.52^{L-N}	7.2^{O-Q}	12^{BC}	33.33^{B}	12.36^{AB}
WC-26	4.56^{A-H}	11.67^{A-G}	9.95^{D-G}	2.4^{KL}	29.467^{M-O}	5.55ST	16.63^{PQ}	4.4^{MN}	8.96^{AB}	3.86^{D}	36.31^{GH}	40.52^{O-Q}	8.56^{L-O}	18.38^{JK}	4.2^{D}	9.06^{F-H}	4.5^{EF}	39.20^{E-L}	56.32^{N-P}	7.7^{K-O}	10^{C}	33.13^{BC}	12.57^{A}

Key: At seedling stage: (coleoptile length (cm) "Col.S", shoot length (cm) "SL.S", root length (cm) "RL.S", no. of roots "NOR. S"), At tillering stage: (shoot length (cm) "SL.T", root length (cm) "RL.T", leaf area (cm^2) "LA.T", no. of tillers "NOT.T", no. of crown roots "NOCR.T", no. of seminal roots "NOSR.T", root to shoot ratio "RSR.T"), At heading stage: (shoot length (cm) "SL.H", root length (cm) "RL.H", leaf area (cm^2) "LA.H", no. of tillers "NOT.H", no. of crown roots "NOCR.H", no. of seminal roots "NOSR.H", root to shoot ratio "RSR.H"), At maturity stage: (plant height (cm) "PH.M", spike length (cm) "SPL.M", Number of spikelets "NOS.M", 1000 grain weight (g) "TGW", Yield per plant (g) "YPP".

and positive correlation with the leaf area recorded at the heading, while it showed a significant but negative correlation with the number of seminal roots (tillering) and number of seminal roots (heading). The leaf area (heading) showed a significant but negative correlation with the number of seminal roots recorded at the tillering as well as at the heading stage. (Figure 1a).

Under drought condition

A significant and positive correlation between the number of seminal roots and the number of tillers at the heading stage was observed. The number of seminal roots also showed a significant positive correlation with number of tillers at heading stage and spike length as well as with the number of seminal roots, shoot length and number of crown roots recorded at the tillering stage. Moreover, this trait had a significant but positive association with root length taken at seedling stage. The number of tillers at the heading stage was observed positively correlated with the number of crown roots noted at the tillering stage. However, the number of crown roots (tillering) showed a negative correlation with coleoptile length (seedling) and root length at heading stage. A positive correlation was observed between root-to-shoot ratio (tillering) and root-to-shoot ratio (heading). Shoot length at tillering stage had a negative association with shoot length and number of crown roots at heading as well as with plant height. The number of seminal roots (tillering)was negatively correlated with leaf area at tillering stage and also with number of crown roots and leaf area taken at heading stage. Shoot length (seedling) was positively associated with root length at seedling stage, while negatively correlated with number of tillers at heading stage. Seedling root length showed a positive correlation with spike length. Root length (heading) had positive correlation with root length (tillering). Root length (tillering) was positively correlated with both leaf area (tillering) and leaf area (heading). Leaf area noted at the tillering stage had a positive correlation with the number of spikes, spike length and leaf area (heading). A highly significant and positive correlation was observed between Thousand-grain weight and yield per plant (Figure 1b).

PCA-Biplot Analysis

The PCA's first and second components justified 28.5% and 28.6% variation under control and drought stress condition, respectively (Figure 2a & 2b). Chakwal-50 is positioned far in the top right quadrant, suggesting it is distinct from other genotypes and heavily influenced by traits i.e., no. of tillers, no. of seminal roots at heading, no. crown roots at tillering and root length at seedling stage. LLR-25 and LLR-22 are positioned in the right quadrant, showing the close association with no. of tillers and root length at seedling stage under drought condition, respectively. The Lasani-8, WC-26 and WC-8 are positioned in the lower-right quadrant of the biplot, indicating their distinctness and a strong influence by specific traits including coleoptile length at seedling, no. of seminal roots at tillering, shoot length at seedling, 1000-grain weight and yield per plant. This distinct grouping reflects their divergence from other genotypes in the study based on these traits (Figure 2b).

Hence, PCA revealed that genotypes i.e., Chakwal-50, Lasani-08, WC-26 and WC-08 are strongly associated with key drought-resilient traits under drought stress (Figure 2b). PCA bi-plot analysis revealed the positive association of yield per plant with attributes like coleoptile length and shoot length at seedling stage, no. of crown roots, root length, root-to-shoot ratio, shoot length at tillering stage, root-to-shoot ratio at heading and 1000-grain weight at maturity under drought stress condition (Figure 2b)

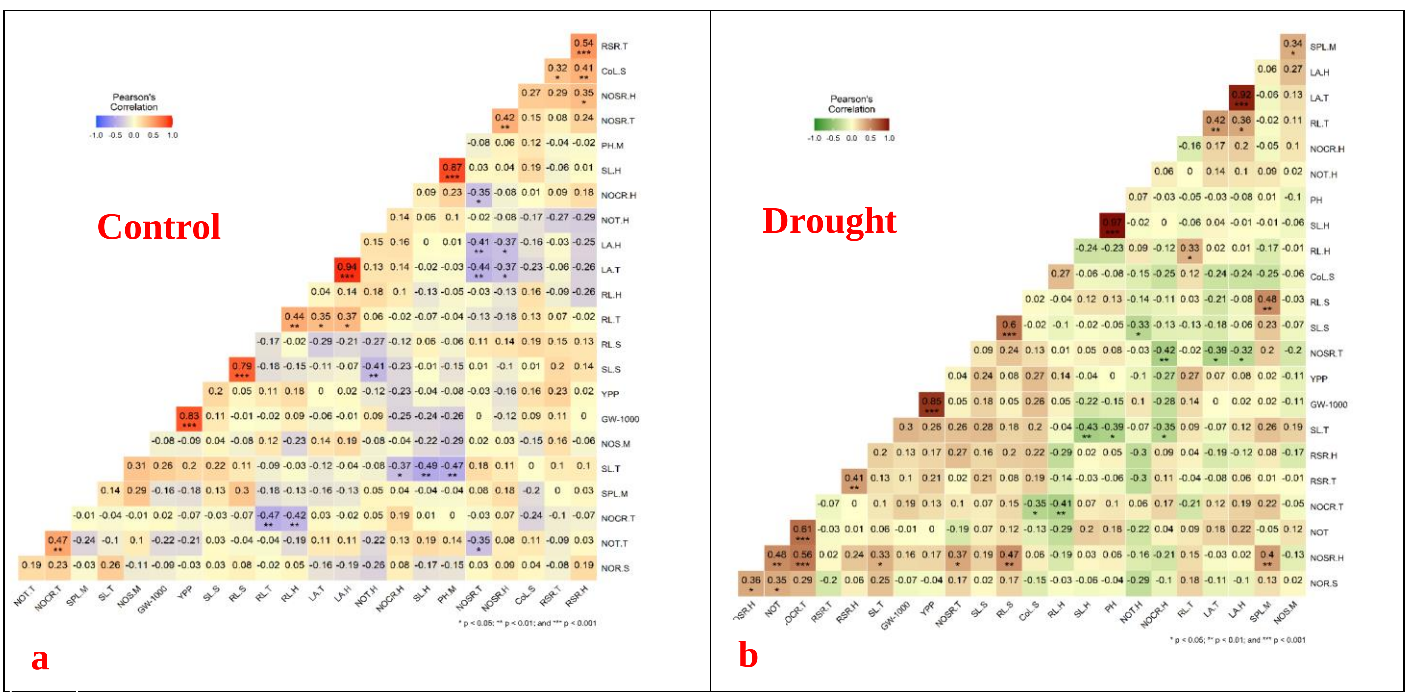

Figure 1. Pearson's Correlation of (a) control and (b) drought stress effect on different variables under study.

Analyzing morphological determinants for yield that respond to water stress proved to be useful in the screening of wheat genotypes under drought condition. Elongated functional roots can enhance the ability of plants to absorb water and nutrients which ensures the survival of plants under drought condition. The roots play a vital role in altering wheat plant physiology and shoot morphology by affecting the absorption of nutrients and water (Kareem et al., 2022). The same phenomenon was observed during this investigation and also reported earlier by many scientists, at the seedling stage, Seher-06, LLR-25 and LLR-9 showed maximum mean values for root length under drought stress while at the tillering stage, Seher-06, WC-8 and Auqab-2000 performed best under drought stress condition by keeping their highest root length. At the heading stage, Lasani-08 showed a good response to water stress by increasing its roots. Drought stress limits the development/growth of horizontal root system (crown roots), where seminal roots help plants to survive as they can still grow and find water (Manschadi et al., 2006). The roots that go deep into the soil layers are seminal, while the number and length of seminal roots can be used as an important parameter to study drought tolerance as genetic variation has been reported in wheat for this trait (Bengough et al., 2004). In the current study, parameters such as root length and number of

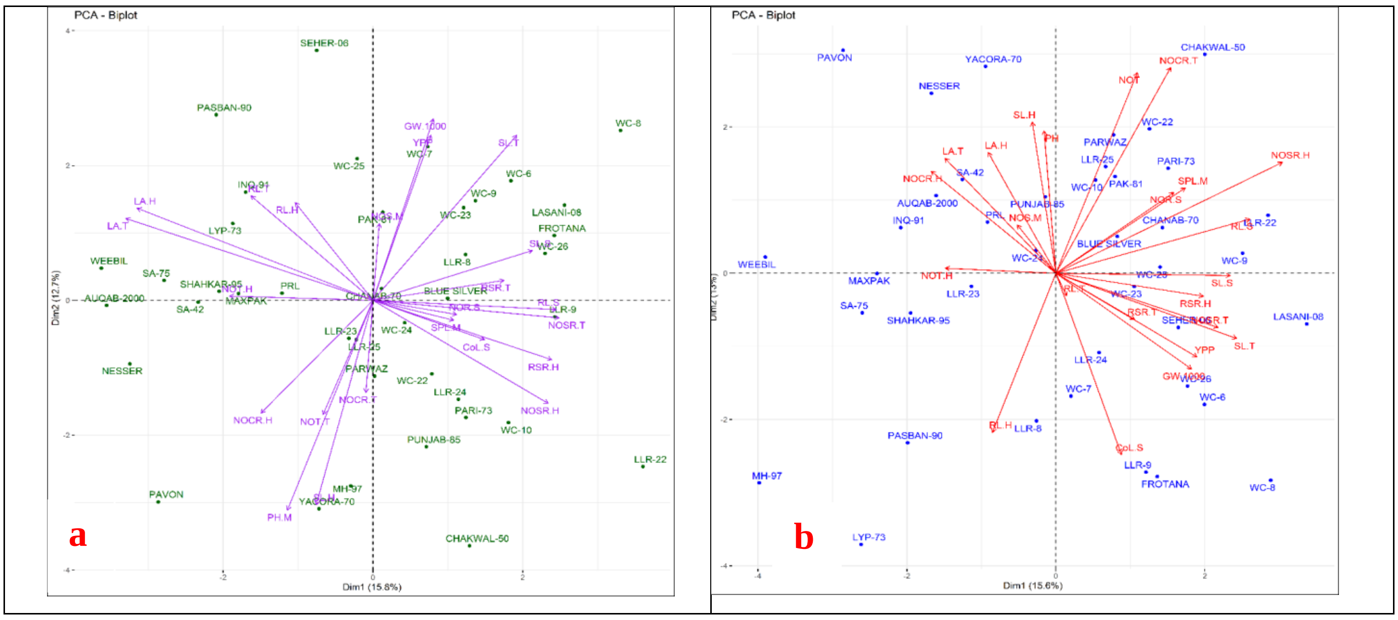

Figure 2. PCA bi-plot analysis depicts genotypes and variables into different quadrants based on the trait's association under (a) control and (b) drought stress condition.

seminal roots were found crucial to determine water stress condition. An increase in the mean values for seminal roots and root-to-shoot ratio was observed under drought condition whereas a decline in the number of crown roots, number of tillers and shoot length was observed under water stress. It indicates that it is hard for a plant to maintain a strong airy portion (shoot and tillers) under drought condition. It is regarded as a water economy strategy by plants to cope the water scarcity condition by reducing canopy area (Farooq et al., 2019). This adaptation helps plants to keep a balance between water absorbed by roots and in plant tissues (Shao et al., 2009; Farooq et al., 2019).

The long root system also helps plants increase tillering and grain yield. The relationship between root length and yield is closely tied to the root system's physiological and morphological characteristics (Yang et al., 2023). In this study, positive correlation of yield with root length, no. of seminal roots, no. of crown roots and 1000 grain weight was also observed.

The deep roots of wheat are considered very important for plants to show tolerance to drought stress, especially during tillering and maturity (Zhou et al., 2022). Most of the genotypes having high values for root length can be observed away from the origin in the PCA biplot (Figure. 2b), depicting the reliability of the results. Yield in wheat is influenced by traits such as 1000-grain weight and tillering. Root traits, particularly under stress, enhance water and nutrient uptake, contributing to yield stability. High-yielding cultivars balance root-shoot systems and adapt efficiently to environmental condition (Tshikunde et al., 2019). The identified genotypes Chakwal-50 and Lasani-08 showing deeper roots under drought can be utilized for the development of drought-tolerant lines holding deep root systems. Based on PCA analysis, genotypes Lasani-8, WC-8 and Chakwal-50 were showed greater distance from the origin and found at the vertex of triangle under drought along with best performance regarding yield and other parameters taken at different stages, Maqbool et al., *2010* also discussed similar findings. The genotypes WC-8 and LLR-22 performed well under control condition (Figure. 2a).

PCA-biplot proved to be useful in isolating appropriate drought-tolerant and high-yielding genotypes (Khalili et al., 2012). The importance of a biplot can be illustrated by its character of displaying relationships among various indices under drought condition. In addition, it demonstrates an outline of these indices mainly those that are away from the origin. In conclusion, the present study explored the drought-tolerant genotypes based on modifications in the morphological attributes under drought stress condition. It also revealed the genetic diversity among wheat genotypes based on the expression of the recorded traits.

CONCLUSION

Drought adversely affects plant growth. During this study, the length and number of roots along with other morphological traits at all growth stages are proved to be helpful under drought stress condition where the plants have to maintain their yield as well. Screening can be done at early stages such as seedling as well as in later stages; tillering, heading stage and maturity. Chakwal-50, Lasani-08, WC-8 and LLR-22 showed the best performance regarding root parameters under drought and can maintain good vegetative portions and good yield. Furthermore, Genotypes LLR-25 (12.73g/plant), Lasani-08 (12.69g/plant) and WC-26 (12.57 g/plant) showed the best performance in terms of yield under drought condition. In conclusion, this study recommends these genotypes for direct sowing in farmer fields under drought condition and can further be used for wheat breeding programs to develop drought-tolerant varieties.

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