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Original article

Grain yield, chlorophyll and protein contents of elite wheat genotypes under drought stress

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ABSTRACT

Background: Drought stress at different growth stages significantly alters growth, yield, and quality traits of wheat. However, great variability exists among genotypes regarding their response to drought stress. Therefore, determining the impacts of drought stress on yield and quality traits would help to select the superior genotypes.
Methods: This study investigated the effects of drought stress on wheat grain yield, chlorophyll, and protein contents. Fourteen (14) recently developed elite bread wheat (*Triticum aestivum* L.) genotypes were used in this study for evaluation under irrigated (full irrigation) and drought conditions (half of normal irrigation). The data relating to growth, yield and protein contents were recorded.
Results: Significant differences ($P \leq 0.01$) were noted among genotypes for all recorded traits. Drought stress significantly reduced the days to 50 % heading, days to 50 % maturity, grain filling, plant height (cm), number of spikes per m^2, chlorophyll index (SPAD), peduncle length (cm), number of grains spike^{-1}, thousand grain weight (g) and grain yield (kg ha^{-1}). However, protein contents were increased under drought stress. Correlation analysis showed significant positive association of grain yield with thousand grain weight, number of spikes per m^2, spike length, chlorophyll index, grain filling period and number of grains spike^{-1} under both irrigated and drought stress conditions. The protein contents expressed positive and negative relationship with yield under drought stress and irrigated conditions, respectively. Bioplot analysis revealed that genotype 'V-19618′ and 'V-19600′ proved superior under drought conditions regarding grain yield and related traits, while genotype 'V-19574′ proved better under both irrigated and drought conditions.
Conclusions: These identified genotypes, i.e., 'V-19618′ and 'V-19600′ can be utilized in future wheat breeding programs to induce desirable characters for producing drought tolerant wheat genotypes.

1. Introduction

Wheat (*Triticum aestivum* L.) is considered as major crop among cereals all over the globe. It belongs to family Poaceae with chromosome 2n = 42 (Giraldo et al., 2019). Wheat is considered as an essential part of daily human diet in different geographic regions of the world. Nearly 35 % of the global population consumes wheat as staple food. More than two-third of the global wheat production is used as food, whereas one-fifth is utilized as livestock feed

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(Grote et al., 2021). Wheat is a vital food source as it provides carbohydrates, fats, protein, fiber, zinc, calcium, and vitamin E etc. (Irge, 2017).

In Pakistan, wheat is cultivated as a major cereal crop, and it contributes 1.6 % towards GDP and 8.9 % share in overall agriculture. During 2020–21 ~ 27.29 million tons wheat was produced from 9.17 million hectares in Pakistan (GOP, 2019). Globally wheat production was 780 million tons during 2021 (FAO, 2021). Wheat is consumed as staple food in Pakistan (Gul et al., 2021). Recently, wheat production has been greatly affected by climate change around the globe with the increasing unavailability of water resources. Pakistan is ranked in top ten countries which are more vulnerable to climate change (Ahmad et al., 2015). Therefore, the impacts of climate change would be quite significant on crop production in Pakistan (Kamitewoko, 2021).

Climate change is emerging as a significant threat to crop production. As the global population is growing day by day, food security is becoming the major issue of the world and setting a big challenge for the scientist to overcome this problem. Similarly, climate change is creating significant threats to fulfill the consumption demand of wheat under boosting number of population and concomitant urbanization (Anwar et al., 2020). The changing climatic is not only affecting the intensity of rainfall, but also the amount of rainfall per annum. Many areas of the country receiving < 250 mm rainfall annually (Baigal, 2016).

The grain protein concentration of wheat can be greatly influenced by abiotic stresses, which would alter baking quality (Zorb et al., 2018). Drought stress significantly affects the composition of wheat grain, including protein, gliadins, glutenin and fiber (Rakszegi et al., 2019). Wheat grain yield is a complex quantitatively inherited trait. It may be readily affected by biotic and abiotic stresses. About 25 % wheat grain yield can be enhanced by developing stress (biotic and abiotic) tolerant genotypes (Gill et al., 2004). Unfavorable environmental conditions and abiotic stresses negatively affect grain yield, resulting in considerable economic losses (Mahpara et al., 2012). Grain yield can be improved by improving source-sink association (Lawlor and Paul, 2014). Progress in grain yield can be achieved by improving crop varieties with optimum planting time. Several wheat varieties have been developed and introduced in Pakistan; however, new high-yielding cultivars are still needed to combat biotic and abiotic stresses (Sabri et al., 2020). The wheat grain yield can be estimated via its linked characteristics, i.e., number of tillers, 1000-grain weight, spike length, and number of spikelets spike^{-1} etc. (Li et al., 2020).

The purpose of present study was to evaluate the recently developed wheat genotypes under drought stress for identifying the key traits to aid future screening process for improving grain yield. It was hypothesized that recently developed genotypes will significantly differ in their response to drought stress and stress-free conditions. The genotypes with superior performance under drought stress would be recommended for future breeding programs to develop drought-tolerant genotypes.

2. Materials and Methods

2.1. Experimental site

A field experiment was performed during 2019–20 at Wheat Research Institute (WRI), Faisalabad, Pakistan (31.405286 °N, 73.048130 °E with an elevation of 184 m above sea level). The texture of soil of experimental site was sandy clay loam. The soil characteristics of the experimental site are presented in Fig. 5. The maximum total rain fall was noted during the month of March 2020 which was 143 mm as shown in Fig. 4.

2.2. Experimental design and treatments

A set of 14 genotypes of bread wheat was used in the study to investigate their behavior under irrigated and drought conditions. The variety code and parentage of fourteen genotypes elaborated in Table 1. Randomized complete block design (RCBD) was adopted with three replications in this study. The plot size for each entry was $5\ m \times 1.62\ m$ ($8.1\ m^2$). All the recommended cultural and agronomic practices were adopted. The data relating to days to 50 % heading, days to 50 % maturity, grain filling duration, plant height (cm), number of spikes per m^2, chlorophyll index (SPAD), peduncle length (cm), spike length (cm), number of grains spike^{-1}, number of spikelet spike^{-1}, thousand grain weight (g), protein content (%) and grain yield kg ha^{-1} were recorded.

2.3. Statistical analysis

The recorded data of all the traits were analyzed using Statistix software (Version 8.1.) The means value of all the treatments were compared using Tukey's HSD test at 5 % probability level (Steel et al., 1997). Pearson's correlation was estimated for the identification of best correlated yield trait. Principal component analysis was performed as discussed by Curry et al. (1983) and followed by Abbas et al. (2022).

3. Results and discussion

3.1. Analysis of variance and means comparison of data

Highly significant differences were found among all genotypes for studied traits (Table 2). These significant differences among

Table 1
List of Wheat genotypes used in the experiment.

Code	Genotype	Parentage	Type
V1	V-19503	SHORTENED SR26 TRANSLOCATION//2*WBLL1*2/KKTS/3/BECARD	**Adv. line**
V2	V-19504	MUTUS*2/KINGBIRD #1/3/KSW/SAUAL//SAUAL	**Adv. line**
V3	V-19521	WBLL1/KUKUNA//TACUPETO F2001/3/BAJ #1*2/4/BORL14	**Adv. line**
V4	V-19531	VALK/4/WBLL1*2/BRAMBLING/3/KIRITATI//PBW65/2*SERI.1B/6/WBLL1/4/BOW/NKT//CBRD/3/CBRD/5/WBLL1*2/TUKURU	**Adv. line**
V5	V-19542	BECARD/FRNCLN//BORL14	**Adv. line**
V6	V-19550	ATTILA*2/PBW65//PIHA/3/ATTILA/2*PASTOR*2/6/CNO79//PF70354/MUS/3/PASTOR/4/BAV92*2/5/HAR311	**Adv. line**
V7	V-19554	NELOKI*2//KACHU/KIRITATI	**Adv. line**
V8	V-19565	FRET2*2/BRAMBLING//BECARD/3/WBLL1*2/BRAMBLING*2/4/BECARD/QUAIU #1	**Adv. line**
V9	V-19566	INIA CHURRINCHE/KIRITATI*2//KACHU/KINDE	**Adv. line**
V10	V-19574	IQBAL2000/DHARABI-09	**Adv. line**
V11	V-19589	MILAN//PRL/2*PASTOR/4/CROC1/AE.SQUARROSA(2 1 3)//PGO/3/BAV92/6/SERI.1B*2/3/KAUZ*2/BOW//KAUZ/5/CNO79//PF70354/MUS	**Adv. line**
V12	V-19600	BABAX/LR43//BABAX/6/MOR/VEE#5//DUCULA/3/DUCULA/4/MILAN/5/BAU/MILAN/7/SKAUZ/BAV92/8/WBLLI*2/VIVITSI/3/T.DICOCCOMP194624/AE.SQ	**Adv. line**
V13	V-19602	BABAX/LR43//BABAX/6/MOR/VEE#5//DUCULA/3/DUCULA/4/MILAN/5/BAU/MILAN/7/SKAUZ/BAV92/8/WBLLI*2/VIVITSI/3/T.DICOCCOMP194624/AE.SQ	**Adv. line**
V14	V-19618	QUAIU#1/3/T.DICOCCON194625/AE.SQUARROSA(3 7 2)//3*PASTOR /4/QUAIU#2/5/KRITATI//2*PRL/2*PASTOR	**Adv. line**

Table 2
Analysis of variance (ANOVA) for yield and Quality traits of different wheat genotypes under Irrigated and drought conditions.

SOV	Condition	df	DH	DG	DM	PH	NS	CC	PL	SL	GS	SP	GW	PC	GY
Replications	**Irrigated**	2	7.1	0.3	6.0	5.8	0.1	0.9	2.5	0.2	7.14	0.2	3.0	0.3	9245.0
	Drought		5.8	27.2	7.9	34.6	33.2	10.3	0.6	0.1	2.2	0.1	0.9	0.03	1107.0
Treatments	**Irrigated**	14	9.3**	6.5**	4.5**	95.2**	4717.5**	7.9**	23.2**	0.6**	47.9**	3.7**	39.8**	0.6**	948202.0**
	Drought		9.1**	13.9**	8.9**	163.6**	5341.7**	4.9**	6.3**	0.8**	44.6**	3.3**	65.5**	0.6**	325831.0**
Error	**Irrigated**	28	0.9	2.7	1.7	4.2	4.9	1.9	0.3	0.1	1.9	0.2	0.4	0.01	5590.0
	Drought		2.4	4.6	2.1	3.0	3.6	1.9	0.3	0.01	0.6	0.2	0.2	0.02	2957.0
CV (%)	**Irrigated**		0.9	4.5	0.9	2.1	0.4	2.8	2.9	4.9	3.4	2.5	1.4	0.5	1.5
	Drought		1.4	6.4	1.0	1.9	0.7	2.7	4.2	1.6	2.7	2.9	1.2	1.1	1.9

**Significant at P ≤ 0.01; DH = days to 50 % heading, DG = grains filling duration (days), DM = days to 50 % maturity, PH = plant height (cm), NS = number of spike per m^2, CC = chlorophyll index (SPAD), PL = peduncle length (cm), SL = spike length (cm), GS = number of grains $spike^{-1}$, SP = number of spikelets $spike^{-1}$, GW = 1000 grain weight (g), PC = protein content (%), GY = grain yield (kg ha^{-1}).

all traits indicated the presence of great variability that can play a vital role in grain yield enhancement of bread wheat in different breeding programs. The range of coefficient of variance was 0.4 to 4.9 % in irrigated conditions, while 0.7 to 6.4 % in drought conditions.

The response of each bread wheat genotype for all the parameters under study under irrigated and drought conditions is presented in Table 3. In irrigated conditions, days to 50 % heading (DH) ranged from 112.0 to 119.0 days. The genotypes 'V-19618′, 'V-19574′ and 'V-19504′ took lesser number of days for spike appearance compared to the rest of the genotypes included in the study. Under drought conditions, DH ranged from 109.0 to 115.0 days and genotypes 'V-19600′, 'V-19589′ and 'V-19531′ resulted in early heading. Grain filling duration (days) varied from 34 to 39 in irrigated conditions with genotypes 'V-19550′ and 'V-19602′ taking lesser days to fill the grain. Grain filling duration (days) ranged from 29.0 to 37.0 days under drought stress with the genotypes 'V-19550′ and 'V-19554′ took less days to fill the grain. Significant variability was noted for days to 50 % maturity (DM) under both conditions. The DM varied between 150.0 and 154.0 and 142.0 to 148.0 days under irrigated and drought conditions, respectively. Genotype 'V-19618′ under irrigated conditions and 'V-19554′ under drought conditions proved early maturing. Plant height (PH) ranged from 85.0 to 106.0 and 79.0 to 103.0 cm under irrigated and drought conditions, respectively. Genotype 'V-19600′ was the shortest and 'V-19602′ was the tallest. Significant variation was found for number of tillers per m^2. Number of tillers per m^2 ranged from 459.0 to 570.0 and 229.3 to 362.3 under irrigated and drought conditions, respectively. Genotype 'V-19554′ under irrigated condition and 'V-19602′ under drought conditions produced the highest number of number of tillers per m^2. The chlorophyll index (SPAD) varied from 47.0 to 52.0 and 50.0 to 54.0 in irrigated and drought conditions, respectively. Genotype 'V-19554′ under irrigated and 'V-19574′ under drought conditions resulted in the highest chlorophyll index. Under irrigated conditions peduncle length ranged from 14.7 to 23.8 cm and under drought condition it ranged from 11.5 to 16.0 cm. Genotype 'V-19574′ had the highest peduncle length under both conditions.

Spike length varied from 5.3 to 6.9 cm under irrigated conditions and genotype 'V-19550′ produced the longest spikes. On the other hand, spike length under drought conditions ranged from 5.2 to 6.8 cm and genotype 'V-19618′ produced the longest spike. Number of grains $spike^{-1}$ varied from 34.0 to 50.0 and 21 to 35.3 under irrigated and drought conditions, respectively. Genotype '19600′ produced the highest number of grains among all genotypes under both irrigated and drought conditions. The number of spikelets per $spike^{-1}$ varied from 14.0 to 17.7 under irrigated and 14.3 to 17.7 under drought conditions. Under both conditions genotype 'V-19600′ produced the higehst number of spikelets per $spike^{-1}$. Under irrigated condition thousand grain weight ranged from 36.6 to 47.9 g, while under drought it ranged from 26.4 to 40.6 g. Genotype 'V-19565′ under irrigated conditions and 'V-19618′ under drought conditions produced the heaviest thousand grains. Protein contents ranged from 12.5 to 14.0 % and 14.8 to 16.1 % under irrigated and drought conditions, respectively. Genotypes 'V-19618′ had the highest protein content under both environments. Grain yield ranged between 3352 and 5550 kg ha^{-1} under irrigated conditions, while it varied from 2276 to 3416 kg ha^{-1} under drought conditions. Genotype 'V-19554′ under irrigated conditions and 'V-19618′ under drought stress produced the highest grain yield.

Drought stress is a major factor among other environmental stresses which can cause significant yield losses by affecting crop growth and productivity (Pour-Aboughadareh et al., 2019). Generally, drought stress leaves negative effects on physiological and agronomic characters in wheat crop (Qaseem et al., 2019). The mean data (Table 3) of wheat genotypes under irrigated and drought conditions indicated a decline in yield and related traits. Gaju et al. (2009) and Pour-Aboughadareh et al. (2020) also reported similar trend. However, protein contents under both the conditions observed a positive jump under drought stress (Kilic and Yağbasanlar, 2010). Previous studies also discussed reduction in grain yield due to drought stress (Etminan et al., 2019).

3.2. Association between measured traits

The association among recorded traits under both environments was assessed using Pearson's correlation as adopted by Pour-Aboughadareh et al. (2020). Under drought conditions, grain yield showed highly significant positive correlation with thousand grain weight, number of spikes per m^2, and spike length. On the other hand, chlorophyll index, grain filling duration, and number of grains $spike^{-1}$ showed significant positive relation with grain yield. Baye et al. (2020) also reported positive correlation of grain yield with grain filling period, grains $spike^{-1}$ and thousand grain weight in wheat. The higher value of chlorophyll index is prediction of good grain yield in wheat (Islam et al., 2014). The non-significant and positive correlation was found among days to 50 % maturity, protein content, peduncle length and spikelets per $spike^{-1}$ with grain yield under drought condition, while non-significant negative relationship of grain yield was observed with plant height (Fig. 1). Days to 50 % heading expressed significant but negative correlation with grain yield under drought condition. Similar findings have also been explained by Mecha et al. (2017).

In irrigated condition the relationship of chlorophyll index, thousand grain weight, number of spikes per m^2 and peduncle length had highly significant positive correlation with grain yield, while grain filling period and number of grains $spike^{-1}$ expressed significant positive correlation with grain yield. Spike length and number of spikelets $spike^{-1}$ showed non-significant and positive correlation, while days to 50 % maturity, protein contents (%) and

Table 3
Means values of yield and quality traits of different wheat genotypes under Irrigated and Drought conditions.

Condition	Genotype	DH	DG	DM	PH	NS	CC	PL	SL	GS	SP	GW	PC	GY
	V-19503	114.0CD	38.0AB	152.0ABC	95.0DE	459.0 K	50.0ABC	15.3IJ	6.0CD	39.0D	16.3CD	38.4H	13.4C	4395.0F
	V-19504	113.0 DE	37.0ABC	150.0C	101.0BC	496.0 G	49.0BCD	20.0D	5.5EF	38.0D	16.7BCD	42.5D	13.6B	5075.0CD
	V-19521	114.0CD	37.0ABC	151.0BC	105.0A	480.0 I	48.0CD	17.3FG	6.6AB	39.0D	17.0ABC	40.5EF	13.0E	4720.0E
	V-19531	113.0 DE	39.0A	152.0ABC	98.0CD	524.0 D	50.0ABC	21.0C	5.9CDE	42.0C	15.0E	45.9B	12.7F	5227.0B
	V-19542	114.0CD	37.0ABC	151.0BC	103.0AB	490.7H	48.0CD	19.0E	6.1BCD	39.0D	16.3CD	43.9C	13.6B	5007.0D
	V-19550	116.0B	34.0D	150.0C	99.0C	460.0 K	50.0ABC	15.8HI	6.9A	44.0BC	16.0D	39.3GH	13.5BC	4625.0E
	V-19554	114.0CD	39.0A	153.0AB	93.0E	570.0 A	52.0A	23.8A	6.3ABC	46.0B	16.0D	47.6A	12.5G	5550.0A
Irrigated	V-19565	114.0CD	36.0BCD	150.0C	94.0E	560.0B	51.5A	22.0B	5.7DEF	38.0D	16.3CD	47.9A	13.9A	5537.0A
	V-19566	115.0 BC	37.0ABC	152.0ABC	93.0E	489.3H	50.0ABC	18.0F	5.3F	39.0D	15.0E	41.4E	13.6B	4957.0D
	V-19574	112.0 E	39.0A	151.0BC	95.0DE	500.0F	51.0AB	20.5CD	5.8CDE	43.0C	17.3AB	44.2C	13.2D	5167.0BC
	V-19589	115.0 BC	37.0ABC	152.0ABC	94.0E	470.0 J	49.0BCD	16.7GH	5.8CDE	39.0D	14.3EF	39.8FG	12.7F	4632.0E
	V-19600	114.0CD	38.0AB	152.0ABC	85.0F	510.0 E	52.0A	20.9C	5.8CDE	50.0A	17.7A	44.6C	13.2D	5187.0BC
	V-19602	119.0 A	35.0CD	154.0A	106.0A	430.0 L	47.0D	14.7 J	5.3F	34.0E	14.0F	36.6I	13.4C	3352.0G
	V-19618	112.0 E	38.0AB	150.0C	100.0BC	540.0C	52.0A	21.4BC	5.7DEF	42.0C	15.0E	47.3A	14.0A	5280.0B
Range		112–119	34–39	150–154	85–106	459–570	47–52	14.7–23.8	5.3–6.9	34–50	14–17.7	36.6–47.9	12.5–14	3352–5550
LSD		1.7	2.8	2.2	3.5	3.7	2.3	0.9	0.5	2.3	0.7	1.0	0.1	125.5
	V-19503	113.0ABC	34.0ABCD	147.0AB	90.0D	304.0C	52.0ABC	12.0G	6.3C	28.0F	16.0DE	38.7C	15.1DEF	3231.7B
	V-19504	110.0DE	34.0ABCD	144.0CDE	102.0A	290.3E	53.0AB	15.5AB	6.1C	30.3CD	16.7BCD	34.7E	15.3D	2854.0D
	V-19521	112.0BCD	32.5BCDE	144.5CD	97.0B	253.0I	51.0BC	15.0BC	5.5GH	24.7H	17.0ABC	28.5 J	15.0EFG	2552.0FG
	V-19531	110.0DE	36.0AB	146.0ABC	85.0EF	254.7I	54.0A	14.0DE	5.7FG	26.7G	15.0FG	29.3I	14.8G	2628.0F
	V-19542	112.0BCD	32.5BCDE	144.5CD	92.0CD	229.3 J	52.0ABC	14.5CD	5.43H	28.7EF	15.3EF	27.8 K	15.1DEF	2497.7GH
	V-19550	114.0AB	29.0E	143.0DE	87.0E	214.3 K	53.0AB	12.0G	5.2I	31.0C	16.3CD	26.4L	14.9FG	2276.3I
Drought	V-19554	110.0DE	32.0CDE	142.0E	81.0G	283.0F	53.0AB	12.0G	5.9D	29.0EF	16.0DE	33.6F	15.2DE	2805.0DE
	V-19565	112.0BCD	35.0ABC	147.0AB	92.0CD	276.7G	53.0AB	13.0F	5.8EF	24.3H	16.0DE	32.6G	15.8BC	2728.0E
	V-19566	112.0BCD	31.0DE	143.0DE	84.0F	262.0H	52.0ABC	11.5G	5.6G	24.3H	14.7FG	30.3H	16.1A	2621.7F
	V-19574	111.0CDE	33.5ABCD	144.5CD	86.0EF	347.3B	54.0A	16.0A	6.7B	33.0B	17.3AB	39.5B	15.0EFG	3240.0B
	V-19589	110.0DE	36.0AB	146.0ABC	84.0F	280.3F	51.0BC	13.0F	5.9DE	29.7DE	14.7FG	33.3F	14.8G	2765.0DE
	V-19600	109.0E	37.0A	146.0ABC	79.0G	294.0D	54.0A	13.5EF	6.2C	35.3A	17.7A	35.8D	15.3D	2965.7C
	V-19602	115.0A	33.0BCD	148.0A	103.0A	230.3 J	50.0C	15.0BC	5.4HI	21.0I	14.3G	27.5 K	15.7C	2441.3H
	V-19618	110.0DE	35.0ABC	145.0BCD	94.0C	362.3A	54.0A	14.0DE	6.8A	31.0C	15.3EF	40.6A	16.0AB	3416.7A
Range		109–115	29–37	142–148	79–103	229.3–362.3	50–54	11.5–16	5.2–6.8	21–35.3	14.3–17.7	26.4–40.6	14.8–16.1	2276.3–3416.7
LSD		2.6	3.6	2.5	2.9	3.1	2.4	0.9	0.3	1.3	0.8	0.7	0.3	91.3

DH = days to 50 % heading, DG = grains filling duration (days), DM = days to 50 % maturity, PH = plant height (cm), NS = number of spike per m^2, CC = chlorophyll index (SPAD), PL = peduncle length (cm), SL = spike length (cm), GS = number of grains $spike^{-1}$, SP = number of spikelets $spike^{-1}$, GW = 1000 grain weight (g), PC = protein content (%), GY = grain yield (kg ha^{-1}).

	CC	DG	DH	DM	GS	GW	GY	NS	PC	PH	PL	SL	SP
CC	1	0.47	-0.56*	-0.24	0.73**	0.72**	0.74**	0.75**	0.04	-0.74**	0.71**	0.05	0.32
DG	0.26	1	-0.73**	0.16	0.42	0.54*	0.55*	0.53*	-0.43	-0.39	0.59*	-0.06	0.26
DH	-0.59*	-0.63*	1	0.56*	-0.39	-0.69**	-0.80**	-0.62*	-0.03	0.27	-0.63*	-0.14	-0.50
DM	-0.29	0.61	0.24	1	-0.07	-0.33	-0.49	-0.26	-0.56*	-0.09	-0.19	-0.28	-0.41
GS	0.67**	0.25	-0.60*	-0.29	1	0.47	0.56*	0.45	-0.31	-0.68**	0.53*	0.40	0.49
GW	0.49*	0.49*	-0.51*	0.09	0.55*	1	0.90**	0.97**	0.04	-0.36	0.95**	0.02	0.27
GY	0.48*	0.51*	-0.49*	0.13	0.49*	0.99**	1	0.89**	-0.02	-0.49	0.87**	0.18	0.45
NS	0.53*	0.48*	-0.55*	0.04	0.49*	0.97**	0.97**	1	-0.04	-0.39	0.94**	0.04	0.23
PC	-0.02	-0.08	0.13	0.03	-0.35	0.16*	0.18	0.22	1	0.19	-0.12	-0.31	0.05
PH	-0.44	-0.10	0.45	0.33	-0.48	-0.16	-0.13	-0.13	0.25	1	-0.42	0.10	-0.30
PL	0.01	0.33	-0.10	0.30	0.07	0.09*	0.13	0.19	-0.15	0.56*	1	-0.05	0.32
SL	0.58	0.47	-0.54*	0.04	0.57*	0.97**	0.97**	0.99**	0.17	-0.14	0.21	1	0.39
SP	0.47	0.11	-0.31	-0.18	0.61*	0.35	0.29	0.31	-0.29	-0.16	0.26	0.33	1

Highly significant positive correlation
Significant positive correlation
Highly Significant negative correlation
Significant negative correlation
Non- Significant positive correlation
Non- Significant negative correlation

Fig. 1. Phenotypic Correlation of wheat genotypes for yield and quality traits in Drought conditions (below diagonal) and Irrigated (above diagonal). CC = chlorophyll index (SPAD), DG = grains filling duration (days), DH = days to 50 % heading, DM = days to 50 % maturity, GS = number of grains spike^{-1}, GW = 1000 grain weight (g), GY = grain yield (kg ha^{-1}), NS = number of spike per m^2, PC = protein content (%), PH = plant height (cm), PL = peduncle length (cm), SL = spike length (cm), SP = number of spikelet spike^{-1},

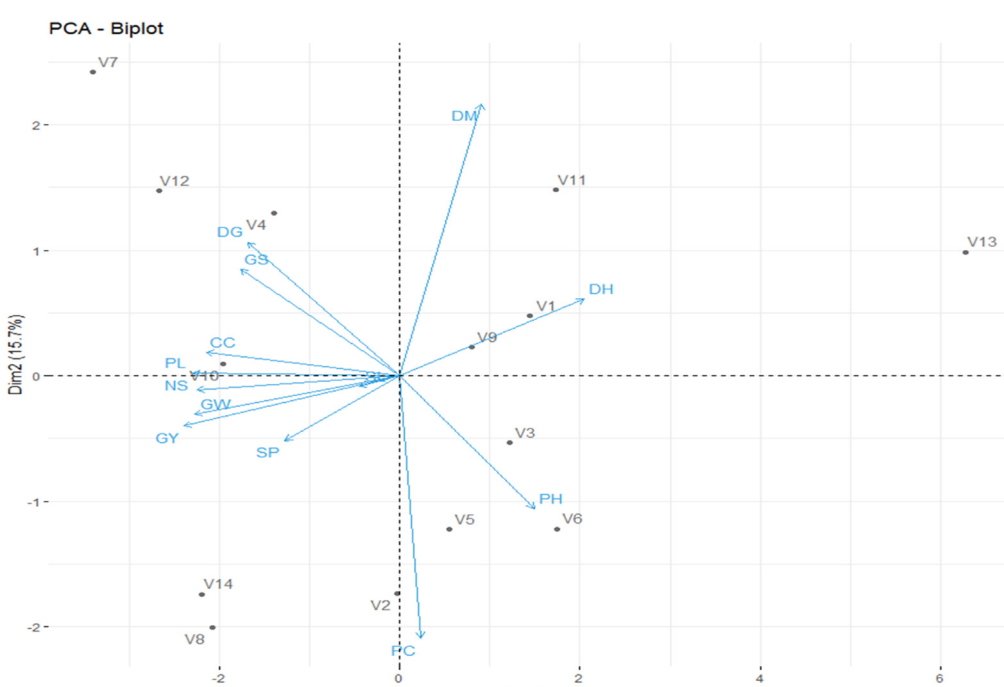

Fig. 2. PCA biplot of wheat Genotypes under irrigated conditions. V1 = V-19503, V2 = V-19504, V3 = V-19521, V4 = V-19531, V5 = V-19542, V6 = V-19550, V7 = V-19554, V8 = V-19565, V9 = V-19566, V10 = V-19574, V11 = V-19589, V12 = V-19600, V13 = V-19602, V14 = V-19618.

plant height showed non-significant but negative relationship with grain yield.

3.3. Principal component analysis

Principal component analysis (PCA) separated the total variance into several factors which are useful for conservation and manipulation of genetic resources and planning for utilization of appropriate germplasms in crop improvement (Zaman et al., 2014). The biplot expressed the association among different measured traits and wheat genotypes. Biplot vectors closer to each-other showed the correlation between those traits and the genotypes close to a specific trait vector represents the best performance of the wheat genotypes for that particular plant trait (Zulkiffal et al., 2018).

The biplot of PCA1 and PCA2 for irrigated (Fig. 2) and drought condition (Fig. 3) indicates the relationships between different indices. Differentiation indices in different groups was found due to PCA1 and PCA2 under both the conditions. The first and second components justified 65.4 % and 62.6 % variation between the criteria under irrigated and drought conditions, respectively.

The PCA biplot under irrigated conditions (Fig. 2) revealed positive association of grain yield with chlorophyll index, thousand

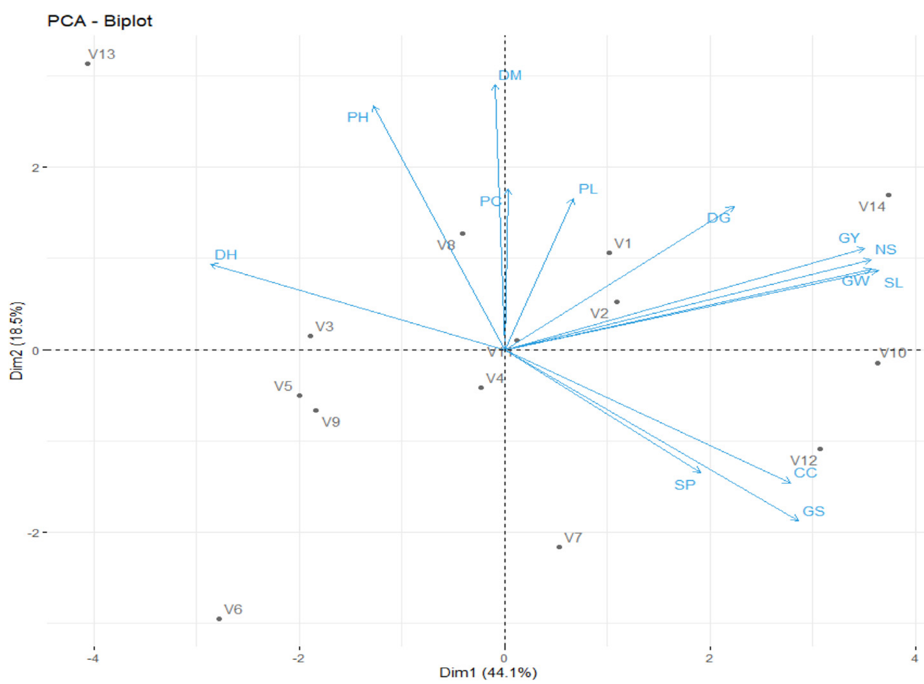

Fig. 3. PCA biplot of wheat genotypes under drought conditions. V1 = V-19503, V2 = V-19504, V3 = V-19521, V4 = V-19531, V5 = V-19542, V6 = V-19550, V7 = V-19554, V8 = V-19565, V9 = V-19566, V10 = V-19574, V11 = V-19589, V12 = V-19600, V13 = V-19602, V14 = V-19618.

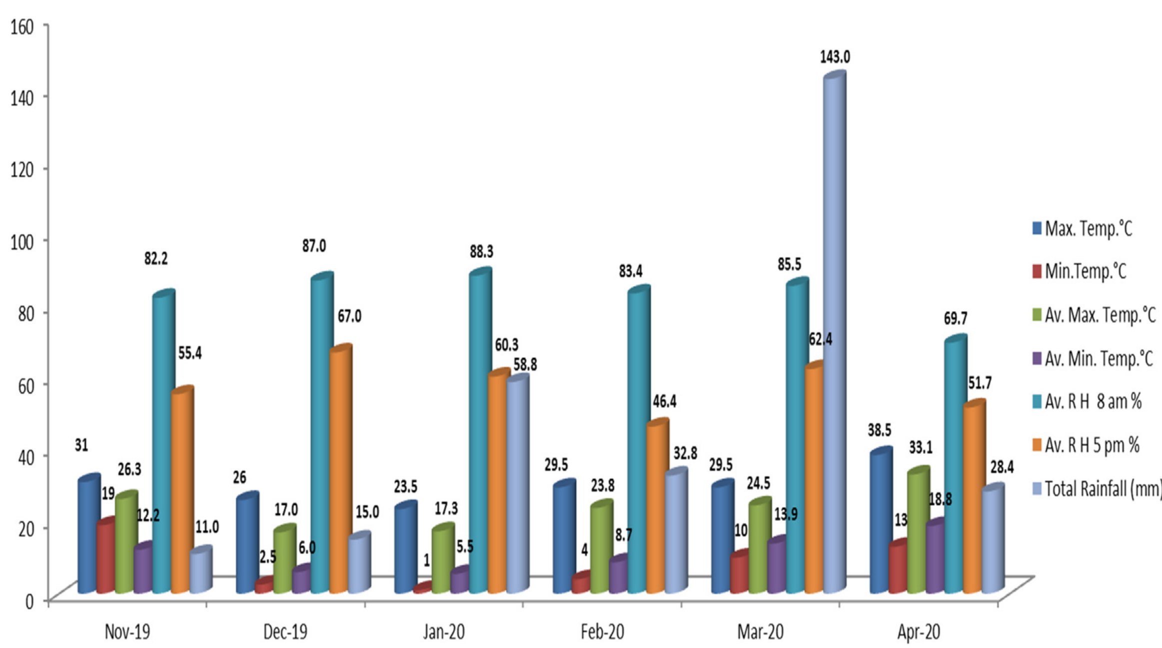

Fig. 4. Meteorological data of the experimental site during 2019–20.

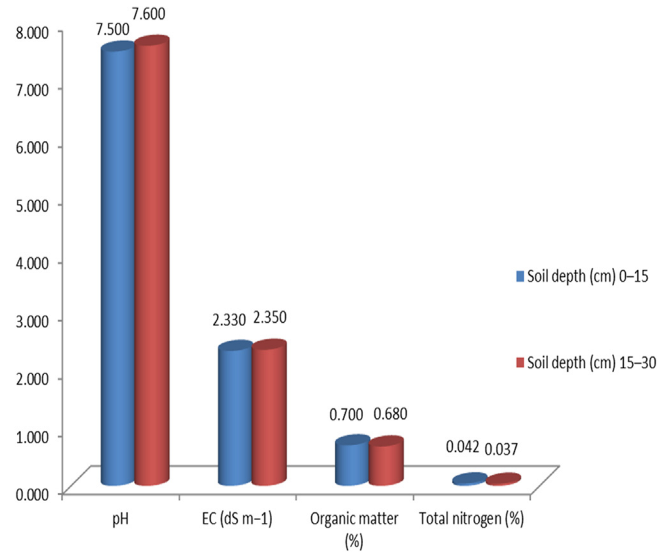

Fig. 5. Characteristics of soil of the field trial site.

grain weight, number of spikes per m^2, peduncle length, grain filling duration, number of grains $spike^{-1}$, spike length (cm) and number of spikelets $spike^{-1}$. However, plant height (cm), protein contents (%), days to 50 % maturity and 50 % heading expressed negative relationship with grain yield. Genotype 'V-19574′ proved the best genotype under irrigated conditions regarding grain yield and related traits.

Under drought stress, PCA biplot showed positive relationship of grain yield with thousand grain weight, number of spikes per m^2, spike length (cm), chlorophyll index, grain filling period and number of grains $spike^{-1}$. On the other hand, negative relationship was found regarding days to 50 % heading and 50 % maturity, protein content, peduncle length, and number of spikelets $spike^{-1}$. Genotypes 'V-19618′, 'V-19574′ and 'V-19600′ proved best genotypes under drought conditions regarding grain yield and related traits.

4. Conclusion

The current findings revealed that wheat genotypes were considerably affected by drought stress for grain yield and morpho-physiological traits. There was notable variation was found in the recorded traits and these genotypes may be considered for wheat breeding programs for drought tolerance. As seen in the current results, positive relationship of thousand grain weight, number of spikes per m^2, spike length, chlorophyll index, grain filling duration and number of grains $spike^{-1}$ with grain yield made the wheat genotypes to perform better in drought stressed environment. The protein content was negatively associated with yield in irrigated conditions but increase in these contents was recorded under drought stress. Among all tested genotypes, 'V-19574′ proved better under both (irrigated and drought) conditions regarding grain yield and its contributing traits. It can be utilized in drought prone environment for cultivation and to develop drought tolerant varieties.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

K. Abbasa, Z. Hussainb, M. Hussaina, F. Rahimc, N. Ashrafd, Q. Khane, G. Razaf, A. Alig, D. M. Khanh, U. Khalilh, N. Irshad. 2022. Statistical modeling for analyzing grain yield of durum wheat under rainfed conditions in Azad Jammu Kashmir, Pakistan. Brazil J. Biol., 2022, vol. 82, e240199 Doi: 10.1590/1519-6984.240199.

Ahmad, A., Ashfaq, M., Rasul, G., Wajid, S.A., Khaliq, T., Rasul, F., Saeed, U., Rahman, M.H., Hussain, J., Baig, I.A., 2015. Impact of climate change on the rice–wheat cropping system of Pakistan. In: Rosenzweig, C., Hillel, D. (Eds.), Handbook of Climate Change and Agroecosystems: The Agricultural Model Intercomparison and Improvement Project Integrated Crop and Economic Assessments. Imperial College Press, London, pp. 219–258.

Anwar, A., Younis, M., Ullah, I., 2020. Impact of urbanization and economic growth on CO2 emission: A case of far east Asian countries. Int. J. Environ. Res. 17, 2531. https://doi.org/10.3390/ijerph17072531.

Birhanu Mecha, Sentayehu Alamerew, Alemayehu Assefa, Ermias Assefa, Dargicho Dutamo. 2017. Correlation and path coefficient studies of yield and yield associated traits in bread wheat (Triticum aestivum L.) Genotypes. Adv. Plants Agric. Res. 2017;6(5):128-136. DOI: 10.15406/apar.2017.06.00226.

Baigal, P.M., 27 April, 2016. accessed. https://www.thethirdpole.net/en/climate/climate- change-brings-severe-risks-to-northern-pakistan/2016.

Curry, S., Cooper, R., Mccallum, W., Pocock, P., Papakostopoulos, D., Skidmore, S., Newton, P., 1983. The principal components of auditory target detection. Adv. Psychol. 10, 79–117. https://doi.org/10.1016/S0166-4115(08)62035-X.

Dejene Disasa Irge, 2017. Chemical Composition and Nutritional Quality of Wheat, Teff Eragrostis tef (Zucc) Trotter), Barley *(Hordeum vulgar*e L.) and Rice (Oryza sativa) -A Review. Food Sci. Qual. Manage. 59, 6–11.

Etminan, A., Pour-Aboughadareh, A., Mohammadi, R., Shoshtari, L., Yousefiazarkhanian, M., Moradkhani, H., 2019. Determining the best drought tolerance indices using artificial neural network (ANN): Insight into application of intelligent agriculture in agronomy and plant breeding. Cereal Res. Commun. 47, 170–181.

Gaju, O., Reynolds, M., Sparkes, D., Foulkes, M., 2009. Relationships between large-spike phenotype, grain number, and yield potential in spring wheat. Crop Sci. 49, 961–973.

Gill, S., Loprinzi, C.L., Sargent, D.J., Thomé, S.D., Alberts, S.R., Haller, D.G., Benedetti, J., Francini, G., Shepherd, L.E., Francois Seitz, J., Labianca, R., Chen, W., Cha, S.S., Heldebrant, M.P., Goldberg, R.M., 2004. Pooled analysis of fluorouracil-based adjuvant therapy for stage II and III colon cancer: who benefits and by how much. J. Clin. Oncol. 22 (10), 1797–1806.

Giraldo, P., Benavente, E., Manzano-Agugliaro, F., Gimenez, E., 2019. Worldwide Research Trends on Wheat and Barley: A Bibliometric Comparative Analysis. Agronomy. 9, 1–18.

Government of Pakistan. 2019. Economic survey of Pakistan. Statistics of Pakistan.Ministry of National Food Security and Research (Economic Wing), Islamabad.

Grote, U., Fasse, A., Nguyen, T.T., Erenstein, O., 2021. Food Security and the Dynamics of Wheat and Maize Value Chains in Africa and Asia. Front. Sustain. Food Syst. 4, (4). https://doi.org/10.3389/fsufs.2020.617009 617009.

Gul, A., Chandio, A.A., Siyal, S.A., Rehman, A., Xiumin, W., 2021. How climate change is impacting the major yield crops of Pakistan? an exploration from long-and short-run estimation. Environ. Sci. Pollut. Res., 1–15

Kamitewoko, E., 2021. Impact of Climate Change on Food Crop Production in Congo Brazzaville. Modern Econ. 12 (11), 1686–1702.

Kilic, H., Yağbasanlar, T., 2010. The effect of drought stress on grain yield, yield components and some quality traits of durum wheat (Triticum turgidum ssp. durum) cultivars. Notulae Botanicae Horti Agrobotanici Cluj-Napoca 38 (1), 164–170.

Lawlor, D.W., Paul, M.J., 2014. Source/sink interactions underpin crop yield: the case for trehalose 6-phosphate/SnRK1 in improvement of wheat. Front. Plant Sci. 5, 418.

Li, J., Wen, S., Fan, C., Zhang, M., Tian, S., Kang, W., Zhao, W., Bi, C., Wang, Q., Lu, S., Guo, W., Ni, Z., Xie, C., Sun, Q., You, M., 2020. Characterization of a major quantitative trait locus on the short arm of chromosome 4B for spike number per unit area in common wheat (*Triticum aestivum* L.). Theor. Appl. Genet. 133 (7), 2259–2269.

Mahpara, S., Farooq, J., Ali, Z., Petrescu-Mag, I.V., Hussain, F., 2012. Assessment of genetic distance among wheat genotypes through RAPD markers. Adv. Agric. Bot. 4, 31–35.

Alireza Pour-Aboughadareh 1, Reza Mohammadi 2, Alireza Etminan 3, Lia Shooshtari 4, Neda Maleki-Tabrizi 5 and Peter Poczai.2020. Effects of Drought Stress on Some Agronomic and Morpho-Physiological Traits in Durum Wheat Genotypes. Sustainability. 12, 5610; doi:10.3390/su12145610 pp. 1-14.

Pour-Aboughadareh, A., Omidi, M., Naghavi, M.R., Etminan, A., Mehrabi, A.A., Poczai, P., Bayat, H., 2019. Effect of water deficit stress on seedling biomass and physio-

chemical characteristics in different species of wheat possessing the D genome. Agronomy 9, 522.
Qaseem, M.F., Qureshi, R., Shaheen, H., 2019. Heat and their combination on the growth, yield and physiology of diverse wheat (Triticum aestivum L.) genotypes varying in sensitivity to heat and drought stress. Sci. Rep. 9, 6955.
Rakszegi, M., Darkó, É., Lovegrove, A., Molnár, I., Láng, L., Bedő, Z., et al., 2019. Drought stress affects the protein and dietary fiber content of whole meal wheat flour in wheat/Aegilops addition lines. PLoS ONE 14 (2), 1–19. https://doi.org/10.1371/journal.pone.0211892.
Sabri, R.S., Rafii, M.Y., Ismail, M.R., Yusuff, O., Chukwu, S.C., Hasan, N., 2020. Assessment of agro-morphologic performance, genetic parameters and clustering pattern of newly developed blast resistant rice lines tested in four environments. Agronomy 10, 1098.
Steel, R.G.D.; Torrie, J.H.; Dickey, D.A. Principles and Procedures of Statistics. A Biometrical Approach; McGraw Hill Book Co.: New York, NY, USA, 1997; pp. 400–428.
Zaman, M., Siddquie, N.A., RahmanM, A.MY., Islam, M.J., 2014. Divergence analysis of drought tolerant. Bangladesh Journal of Agriculture Research 39, 385–396.
Zorb, C., Ludewig, U., Hawkesford, M.J., 2018. Perspective on wheat yield and quality with reduced nitrogen supply. Trends Plant Sci. 23, 1029–1037.