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Computation of Drought Effects on Yield and Quality of Wheat (*Triticum aestivum* L.) Via Reckoning of Morpho-Physiological Responses

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ABSTRACT

Drought stress considerably affects the growth, yield as well as quality traits of wheat. Thus, the assessment of drought stress on the growth of wheat plants is very crucial to identify superior genotypes. This research explored how drought stress affects wheat grain yield and associated traits. Ten wheat genotypes were evaluated under both fully irrigated conditions and drought conditions, where only one irrigation was provided after rouni. Data on growth, yield, and protein content were collected for analysis. There were highly significant differences (P<0.01) observed among the genotypes for all the recorded parameters. Drought stress led to a significant decrease in the number of days to 50% heading and maturity, as well as in plant height (cm), Productive tillers/plant, Normalized difference vegetative index at anthesis (NDVI), chlorophyll index (SPAD), thousand grain weight (g), and grain yield (kg ha^{-1}). On the other hand, protein content amplifies under drought conditions. Correlation analysis revealed a significant positive relationship between yield and several traits, including thousand grain weight, productive tillers per plant, protein content, normalized difference vegetative index at anthesis, flag leaf area, and chlorophyll SPAD. Notably, protein content exhibited a positive correlation with yield under drought stress, but a negative correlation under irrigated conditions. Bi-plot analysis indicated that genotypes HYT-70-16 and V-17086 were identified as superior performers in drought conditions for yield and related traits. These identified genotypes, i.e HYT-70-16 and V-17086 can be leveraged in future wheat breeding programs to incorporate desirable traits for developing drought-tolerant wheat varieties.

Keywords: drought, protein, yield, chlorophyll, wheat.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the second most commonly cultivated cereal crop all over the globe, it primarily belongs to Southwestern Asia. It is now being cultivated all over the world (Rahman et al., 2008). It is also entitled as king of cereals because of its huge consumption throughout the globe. Almost one-third of the population of the globe utilizes wheat as a staple food (Ahmad et al., 2023; Li et al., 2023). Wheat grain gives about 69% carbohydrates, 2.5% fat and 9.4% protein, (Ahmad et al., 2022; Liang et al., 2023).

Often wheat crop faces several stresses (biotic and abiotic) in field conditions which significantly reduced the yield by affecting plant growth and development (Saddiq et al., 2021). Drought stress is considered to be one of the most crucial abiotic stress which significantly injures the plant by affecting its growth and development at different stages

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(Wasaya et al., 2021; Ahmad et al., 2022). Drought can also initiate physiological and molecular illnesses in plants by producing an excess amount of reactive oxygen species. It can also negatively affect the different morpho-physiological characteristics of the wheat crop which include chlorophyll contents, stomatal oscillation, plant height, leaf area, etc. (Ahmad et al., 2021; Yang et al., 2019). The contents of wheat quality parameters i.e. protein (gliadins and glutenin), fiber etc. were found to be altered by drought stress, in earlier reports which ultimately reduces the bread making quality of wheat (Rakszegi et al., 2019; Ma et al., 2023).

Recent studies confirmed that the climate change scenario is adversely affecting wheat production all over the globe due to water shortage and heat stress. Similarly, this weather changing situations also affecting the wheat production in Pakistan (Javed et al., 2022; Sun et al., 2024). In Pakistan, during 2020-2021 the cultivated area of wheat was 9,168 thousand hectares, with a net production of 27,464 thousand tonnes and 2,996 (kg/ha.) average grain yield (Economic Survey of Pakistan, 2021). According to a report the estimated requirement of wheat production in Pakistan was about 30 million tons during 2022 but was not surpassed 26 million tons because of the major yield limiting factors drought and heat. Data of different studies showed that Pakistan is prevailing in the list of most affected countries due to the climate change (Bhatti, 2022; Zhao et al., 2023; Chen et al., 2024). The overall economy of Pakistan is greatly related to agriculture sector. The fluctuating patterns of rains are responsible for floods and drought in different regions of the country. The existing water limiting conditions significantly affect wheat production. Wheat is the major food crop of Pakistan. Many studies concluded that the existing climate change conditions are causing decline in wheat production, which is alarming the researcher as the demand of consumption is accelerating day by day (Waseem et al., 2022; Yi et al., 2022). There is a great need to establish such wheat genotypes which have the ability to produce good in the rising water limiting conditions of the country to replace the existing varieties who are vulnerable to different biotic and abiotic stresses (Javed et al., 2022; Du et al., 2024).

The concept of this study is to explore the potential of newly developed wheat genotypes under the drought stress, while estimating the drought effects on vital yield and quality contributing parameters. The identified superior bread wheat genotypes will be exploited in future wheat breeding aiming on establishment of best drought tolerant wheat genotypes which can deliver ideal yield and good quality characters under the climate change scenario.

MATERIAL AND METHODS

Experimental Location

Here we performed an experiment at Wheat Research Institute (WRI), Faisalabad, Punjab, Pakistan (East: 73°74, Lat: 30°31.5 North with elevation of 184 m) during 2020-2021 and 2021-2022. The soil of site was sandy loam. The meteorological data during different stages of crop during 2020-2022 is presented in Figure 1.

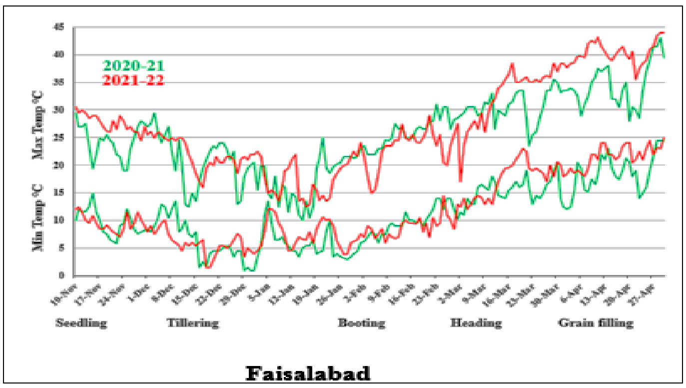

Figure 1. Weather statistics during 2020-2021 and 2021-2022 wheat crop season

Plant Material

In this study ten newly developed advanced lines of bread wheat were selected for the testing against normal and drought stress (Table 1). In normal conditions the crop was given four irrigations at different crop stages i.e. pre-sowing, tillering, booting and grain filling, while under drought stress only two irrigations were given at the time of rouni (Pre-sowing irrigation) and tillering stage as shown in Figure 2.

Table 1. List of wheat genotypes used in the experiment

S. No.	V-Code	Parentage
1.	V-20665	NR390/V-03042
2.	V-20662	MILAN/KAUZ//PRINIA/3/BAV92/5/TRAP#1/BOW//VEE#5/SARA/3/ZHE JIANG 4/4/DUCULA/6/DHRAWAR-DRY
3.	V-20654	WAXWING/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ(12001)/5/SOKOLL/EXCALIBUR
4.	V-20670	NR399/6/TRCH/SRTU/5/KAUZ//ALTAR 84/AOS/3/MILAN/KAUZ/4/HUITES
5.	V-17086	T.DICOCCONC19309/AE.SQARROSSA(409)//MUTUS/3/2*MUTUS
6.	V-20609	CHAKWAL-50//INQ.91/FRET-2
7.	V-20673	MANTHAR/6/FRET2/KUKUNA//FRET2/3/TAM200/TUI /5/FRET2*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ
8.	V-20621	MILLAT.11/CK.50
9.	V-20671	MANTHAR/6/FRET2/KUKUNA//FRET2/3/TAM200/TUI/5/FRET2 *2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ
10.	HYT-70-16	BORL14//BECARD/QUAIU#1

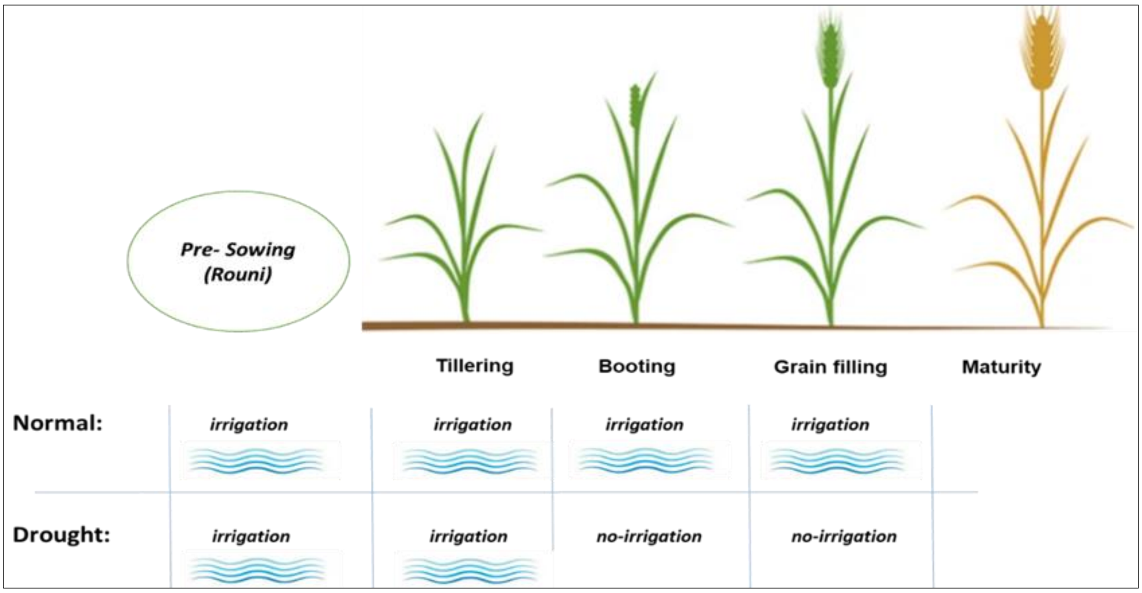

Figure 2. Stages of crop on which irrigation was applied

Experimental Design

Ten newly developed bread wheat genotypes were used in this experimental study followed by randomized complete block design (RCBD) with three repetitions. All the recommended agronomic and cultural practices have been retained in the course of the crop season. Different plants traits were recorded in filed during the both crop season i.e days to 50% heading, productive tillers/plant, flag leaf area (cm^2), Canopy temperature at grain filling, normalized difference vegetation index (NDVI) at anthesis, spike length (cm), plant height (cm), days to 50% maturity, yield ($kgha^{-1}$), Chlorophyll (expressed in SPAD units), protein contents and thousand grain weight (g).

Data Analysis

All the measured plant traits were analyzed by using Statistix-8.1 software; however the means values of recorded data were compared at 5% probability. Pearson's correlation method was adopted for the assessment of relationship among the recorded traits (Javed et al., 2022). The PCA analysis was executed using R-studio software.

RESULTS AND DISCUSSION

Analysis of variance and Means Comparison of data depicted significant variation among the measured characters which confirmed the existence of possible genetic variation among the genotypes for all the recorded parameters (Table 2).

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

SOV	Condition	df	DH	NPT	FL	CT	NDVI	SL	PH	DM	GY	Ch	PC	TGW
Replications	Normal	2	0.700	1.225	0.078	0.014	0.00007	0.0003	0.448	0.133	0.004	0.075	0.002	0.020
	Rainfed		0.508	0.008	0.062	0.024	0.00006	0.0006	1.600	0.700	0.002	0.433	0.027	0.009
Treatments	Normal	9	5.227	17.033	48.149	0.715	0.00376	1.1834	48.692	4.981	0.672	2.300	0.218	60.288
	Rainfed		12.157	8.670	38.333	0.688	0.00360	0.6093	23.182	9.578	0.543	8.149	0.227	15.500
Error	Normal	18	0.219	0.281	0.009	0.004	0.00002	0.0052	0.037	0.254	0.004	0.195	0.001	0.011
	Rainfed		0.129	0.212	0.104	0.025	0.00005	0.0034	0.220	0.256	0.004	0.119	0.001	0.002
CV (%)	Normal		0.42	3.06	0.23	0.31	0.55	0.53	0.18	0.36	1.35	0.85	0.25	0.28
	Rainfed		0.41	3.23	0.84	0.67	0.96	0.45	0.48	0.37	1.58	0.71	0.21	0.11

**Significant at $P \leq 0.01$; DH = Days to 50% heading, NPT = Productive tillers/plant, FL = Flag leaf Area (cm^2), CT = Canopy temperature at grain filling, NDVI = Normalized difference vegetative index at anthesis, SL = Spike length (cm), PH = Plant height (cm), DM = Days to 50% maturity, Y = Yield ($kgha^{-1}$), Ch = Chlorophyll SPAD, PC = Protein Contents, TGW = Thousand grain weight (g).

ANOVA and Comparison of Means

The mean performance of all the studied traits under normal and drought conditions is presented in Table 3. In normal/irrigated conditions day to 50% heading (DH) ranged from 109.2-113.0 days. For spike appearance, genotypes V-20670, V-20662, V-20673 and V-20621 took lesser number of days in comparison to other genotypes. While, under drought conditions the DH varied from 86.2-92.0 days and early heading was noted in genotypes V-17086, V-20621 and V-20654.

Number of Productive tillers per plant (NPT) under irrigated conditions ranged from 14.2-20.8 tillers per plant. Genotypes HYT-70-16, V-17086 and V-20673 were found with maximum NPT among all the genotypes. On the other hand, in drought conditions NPT ranged from12.2-16.8 tillers per plant, and genotypes V-20621, V-20609 and V-17086 were produced maximum NPT as compared to other genotypes. Under irrigated conditions Flag leaf area (FL) varied from 35.9-48 cm^2, and the genotypes HYT-70-16, V-17086 and V-20673 were with a larger leaf area than other genotypes. But, in case of drought conditions the FL was ranged from 32.9-45.7 cm^2 and the genotypes V-20609, V-20621 and HYT-70-16 were noticed with huge FL. The range of canopy temperature (CT) was 20.0 to 21.4 and the genotypes HYT-70-16, V-20673 and V-17086 kept their canopy cooler as compared to other genotypes, while in case of drought stress CT varied from 22.9 to 24.7 and the genotypes V-20609 and HYT-70-16 were found with cooler canopies under drought stress. The Normalized difference vegetation index (NDVI) in case of drought stress ranged from 0.70 to 0.80. The genotype V-20609 showed maximum NDVI in drought stress while in irrigated conditions the variation was from 0.72 to 0.82 and genotype HYT-70-16 was with maximum NDVI under irrigated conditions. The Spike length (SL) ranged from 12.3 to 14.3 in irrigated conditions and genotype V-17086 came in front with larger SL under normal conditions, on the other hand under drought stress the SL varied from 12.3 to 13.5 and the genotype HYT-100-74 was noted with longest spike under drought stress. The Plant height (PH) varied from 95.2 to 102.7 cm under drought conditions and genotype V-20621 was found to be shortest and genotype V-20654 found tallest under drought. While, in case of irrigated conditions PH ranged from 96.7 to 111.8 cm and the genotype V-20671 was found shortest and genotype V-20670 found tallest under drought. The Days to 50% maturity (DM) ranged from 133.2 to 138.7 under drought stress and the genotype V-20621 found early maturity. While in case of irrigated conditions DM ranged 137.7 to 142 and the genotype V-20621 found early in irrigated conditions. The grain yield (GY) ranged from 4.3 to 5.7 tons/ha, while under drought stress GY varied from 3.7 to 4.5 tons/ha, the genotype HYT-70-16 came in front as a yield topper under both the conditions. The chlorophyll contents (Ch) varied from 45.3 to 51.2 under drought stress and the genotype V-20609 showed maximum chlorophyll contents under drought stress, while under irrigated conditions, Ch ranged from 52.8 to 53 and the genotype V-20665 showed maximum chlorophyll contents under irrigated conditions. The protein contents (PC) under drought conditions ranged from 15.0 to 15.9 and the genotype V-20609 showed maximum PC under drought stress. While, under irrigated conditions PC ranged from 14.5 to 15.4 and the genotype V-20654 exhibited maximum PC. The thousand grain weight (TGW) ranged from 30.9 to 44.2 g under normal conditions and the genotype V-20665 showed maximum TGW, while in case of drought stress TGW ranged from 32.4 to 39.2 and the genotype V-17086 maximum TGW.

Among environmental stresses, drought stress is a key factor that can considerably reduce yields by influencing crop development and production (Javed et al., 2022). In Wheat drought stress causes damaging effects on physiological and agronomic characteristics (Bănică et al., 2008; Ahmad et al., 2022). The average genotype records for wheat during drought and irrigation circumstances showed a drop in grain yield and its associated characteristics Javed et al. (2022) and Ahmad et al. (2022) also informed same tendency. But, under drought situations, protein level in grain showed a positive jump. Previous research also covered the impact of drought stress on yield reduction (Etminan et al., 2019).

Table 3. Means values of yield and quality traits of different wheat genotypes under irrigated and drought conditions

Genotype	Condition	DH	NPT	FL	CT	NDVI	SL	PH	DM	GY	Ch	PC	TGW
V-20665	Normal	110.2 cd	17.3 d	44.8 c	20.6 e	0.80 c	13.5 b	105.3 cd	139.7 bc	4.9 d	53.0 a	14.6 f	44.2 a
	Drought	89.5 b	13.2 c	38.8 c	23.7 bc	0.75 de	13.1 c	98.2 cd	135.7 cd	3.7 cd	48.3 de	15.3 d	33.4 f
V-20662	Normal	109.8 cd	15.0 e	42.5 e	20.7 de	0.77 d	13.2 c	107.8 b	139.5 bc	4.6 e	52.2 a-d	15.0 c	33.3 g
	Drought	88.8 bc	13.3 c	39.2 c	23.7 bc	0.75 de	13.2 bc	100.2 b	138.7 a	3.9 c	49.2 cd	15.5 c	34.3 e
V-20654	Normal	113.0 a	14.2 e	35.9 h	21.4 a	0.72 f	12.2 e	103.8 e	142.0 a	4.3 f	50.5 e	15.4 a	36.3 f
	Drought	86.5 ef	12.2 c	33.9 e	24.7 a	0.70 f	12.2 f	102.7 a	134.2 ef	3.3 e	45.3 f	15.0 f	32.4 h
V-20670	Normal	109.2 d	15.3 e	38.4 g	21.1 b	0.73 e	13.6 b	111.8 a	137.8 de	4.4 ef	50.8 e	15.3 b	32.8 h
	Drought	92.0 a	15.0 b	37.3 d	23.6 bcd	0.78 bc	12.4 ef	102.2 a	138.7 a	4.2 b	49.5 bc	15.6 bc	36.3 d
V-17086	Normal	111.0 bc	19.7 ab	47.9 a	20.1 fg	0.82 a	14.3 a	105.8 c	140.2 bc	5.5 b	51.5 c-e	14.9 de	30.9 i
	Drought	86.2 f	15.5 ab	38.4 c	23.8 bc	0.76 cd	13.4 ab	97.0 de	136.3 bc	4.3 b	47.7 e	15.5 c	36.9 c
V-20609	Normal	110.2 cd	19.2 bc	46.4 b	20.2 f	0.80 b	13.5 b	105.2 d	139.2 cd	5.2 c	52.8 ab	14.5 f	41.8 b
	Drought	88.0 cd	16.3 ab	45.7 a	22.9 e	0.80 a	13.3 bc	95.5 f	134.8 de	4.6 a	51.2 a	15.9 a	39.2 a
V-20673	Normal	109.8 cd	19.2 bc	46.4 b	20.1 fg	0.81 ab	14.2 a	107.3 b	139.7 bc	5.3 c	51.2 de	14.9 cd	38.8 d
	Drought	87.7 d	12.3 c	32.9 e	23.9 b	0.70	13.3 ab	96.3 ef	137.2 b	3.6 d	48.2 de	15.2 e	33.2 g
V-20621	Normal	109.8 cd	17.7 cd	43.4 d	21.0 bc	0.77 d	13.2 c	103.8 e	137.7 e	4.9 d	51.7 b-e	14.9 cd	41.2 c
	Drought	86.2 f	16.8 a	41.4 b	23.1 de	0.79 ab	12.5 de	95.2 f	133.2 f	4.4 a	49.2 cd	15.8 a	37.4 b
V-20671	Normal	112.7 a	14.7 e	41.9 f	20.9 cd	0.77 d	13.0 d	96.7 g	140.8 ab	4.6 e	51.2 de	14.9 c	37.9 e
	Drought	87.3 de	12.8 c	38.6 c	23.9 b	0.73 e	12.7 d	99.3 bc	135.8 bcd	3.8 c	47.3 e	15.3 d	33.4 f
HYT-70-16	Normal	111.8 ab	20.8 a	48.0 a	20.0 g	0.82 a	14.3 a	101.1 f	140.2 bc	5.7 a	52.7 abc	14.8 e	41.9 b
	Drought	91.0 a	15.2 b	39.4 c	23.3 cde	0.78 abc	13.5 a	95.5 f	136.5 bc	4.5 a	50.3 ab	15.7 b	37.0 c
Range	*Normal*	*109.2-113*	*14.2-20.8*	*35.9-48*	*20.0-21.4*	*0.72-0.82*	*12.3-14.3*	*96.7-111.8*	*137.7-142*	*4.3-5.7*	*52.8-53*	*14.5-15.4*	*30.9-44.2*
	Drought	*86.2-92.0*	*12.2-16.8*	*32.9-45.7*	*22.9-24.7*	*0.70-0.80*	*12.3-13.5*	*95.2-102.7*	*133.2-138.7*	*3.7-4.5*	*45.3-51.2*	*15.0-15.9*	*32.4-39.2*

Traits Relationship Studies

The affiliation among recorded parameters in each environment (drought and irrigated) was evaluated by using of Pearson`s correlation as followed by Anwaar et al. (2020). Under drought environment the yield expressed the highly significant positive association with thousand grain weight, Productive tillers/plant, Protein contents, Normalized difference vegetative index at anthesis, Flag leaf Area and Chlorophyll SPAD. Javed et al. (2022) also noticed positive association in wheat of yield with thousand grain weight, Productive tillers/plant. While Petcu et al. (2011) and Nasirzadeh et al. (2021) also confirmed the higher value of chlorophyll in wheat is the indication of better grain yield. The significant but negative correlation of grain yield was found with Canopy temperature, plant height and days to 50% maturity under drought stress, while non-significant but positive association was observed with days to 50% heading and spike length. Similar outcomes have also been described by Javed et al. (2022). The relationship of TGW, chlorophyll contents, normalized difference vegetative index, flag leaf area, spike length and Productive tillers/plant had highly significant positive association with grain yield under irrigated conditions. While Canopy temperature and Protein contents showed highly significant and negative relationship with grain yield. Days to 50% heading, Days to 50% maturity and plant height showed negative and non-significant association with the grain yield.

Principal Component Analysis (PCA)

PCA divided all variances into several factors that are helpful in making plans for usage of appropriate germplasms in crop improvement (Shah et al., 2022). The bi-plot explains the relationship among various recorded characters and wheat genotypes. The bi-plot of PCA-1 and PCA-2 for drought (Figure 3) and irrigated condition (Figure 4) shows the associations between different indices. Among criteria under drought and irrigated conditions first component showed 80.7% variation, while second component showed 80.7% variation.

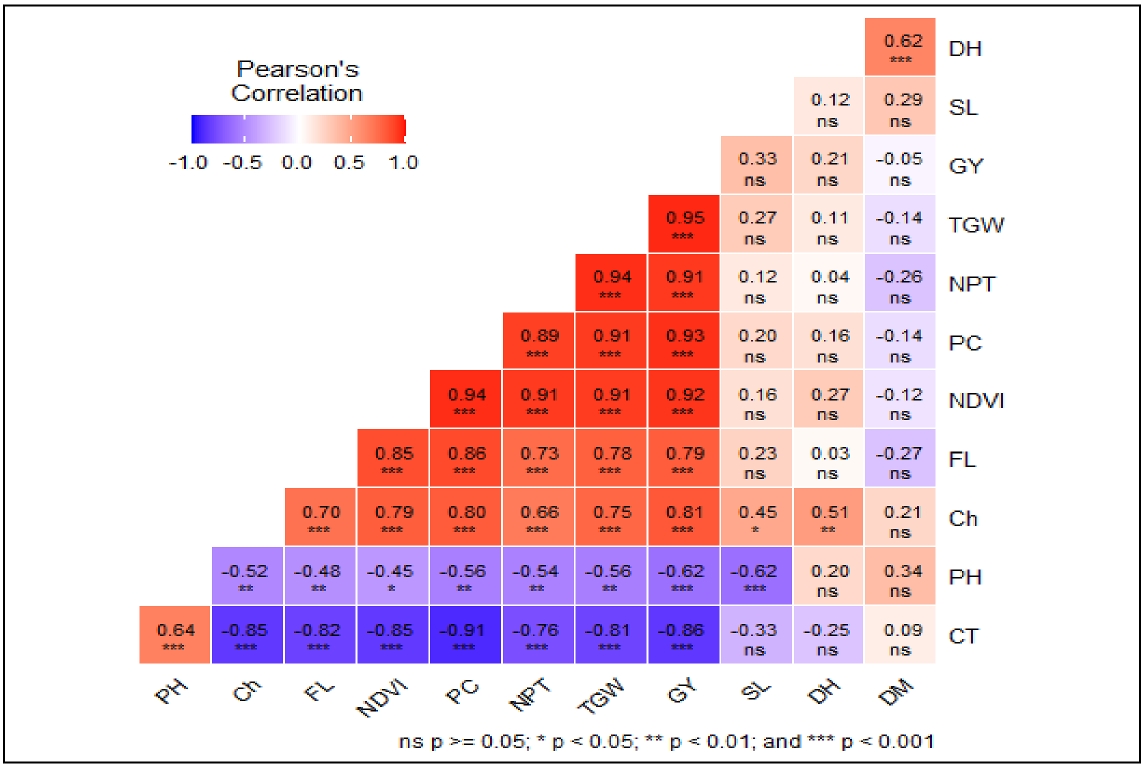

Figure 3. Pearson's Correlation under drought conditions

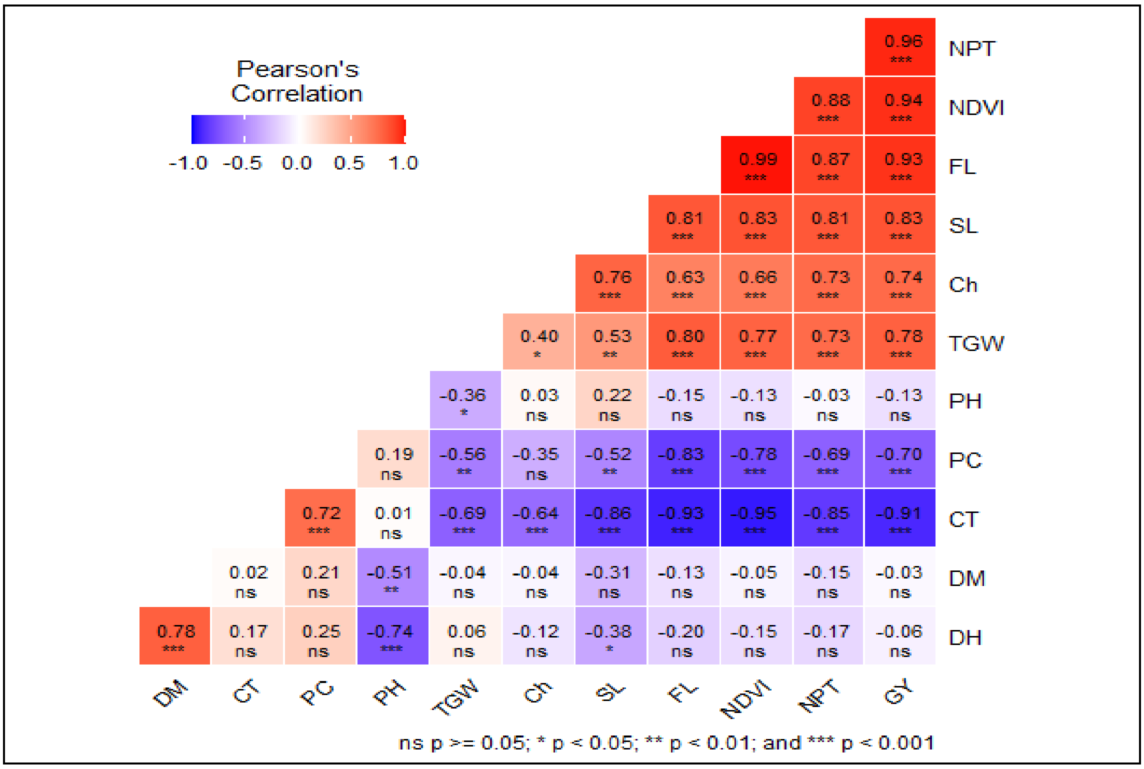

Figure 4. Pearson's Correlation under normal conditions

Under drought stress, PCA bi-plot showed positive association of grain yield with normalized difference vegetative index at anthesis, thousand grain weight, protein contents, flag leaf area, productive tillers/plant, chlorophyll contents, spike length, days to 50% heading (Figure 5). While negative correlation of yield was observed with DM, PH and CT at grain filling. Genotypes HYT-70-16 and V-17086 were shown superlative genotypes in drought conditions for yield and its associated parameters. While the PCA bi-plot under irrigated conditions showed positive correlation of yield with Thousand grain weight, Normalized difference vegetative index at anthesis, chlorophyll contents, flag leaf area, productive tillers/plant and spike length (Figure 6). However, negative association of grain yield was noticed with plant height, protein contents and canopy temperature at grain filling. The Genotypes HYT-70-16, V-17086, V-20609 and V-20673 were found preeminent genotypes in irrigated conditions for grain yield and its associated traits.

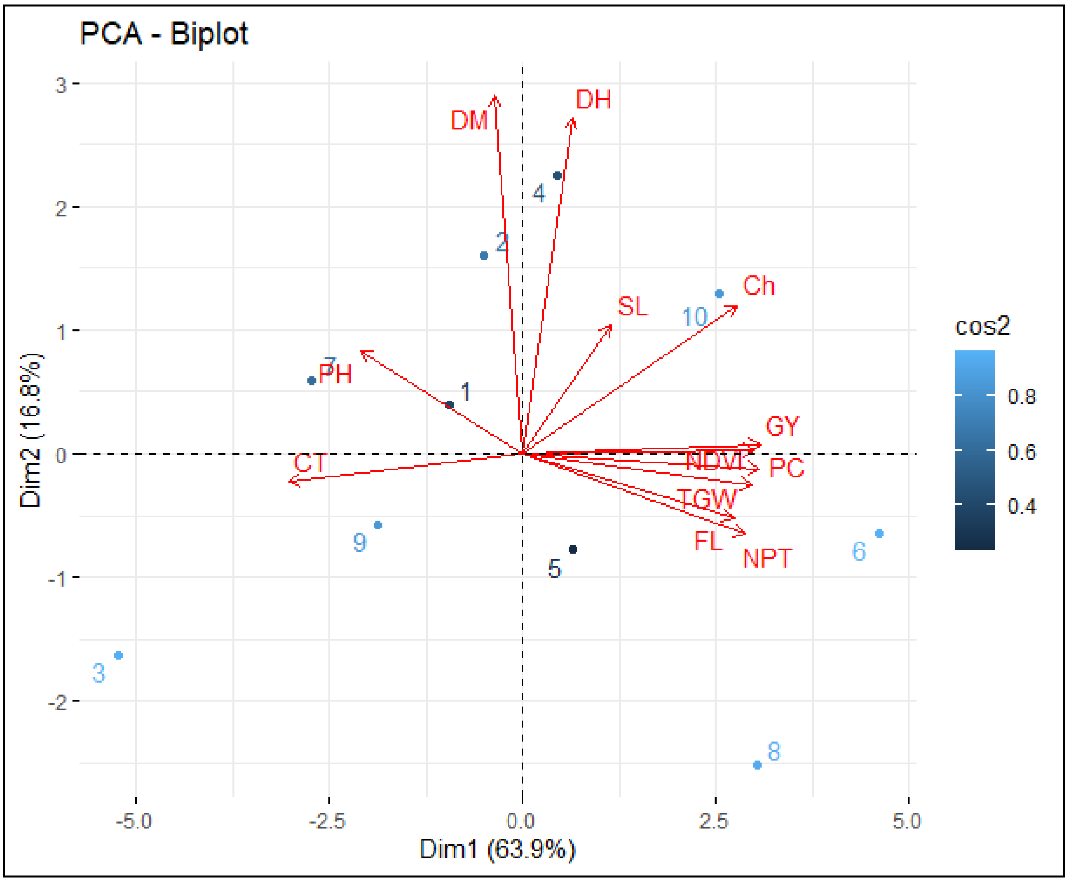

Figure 5. PCA-1 under drought conditions

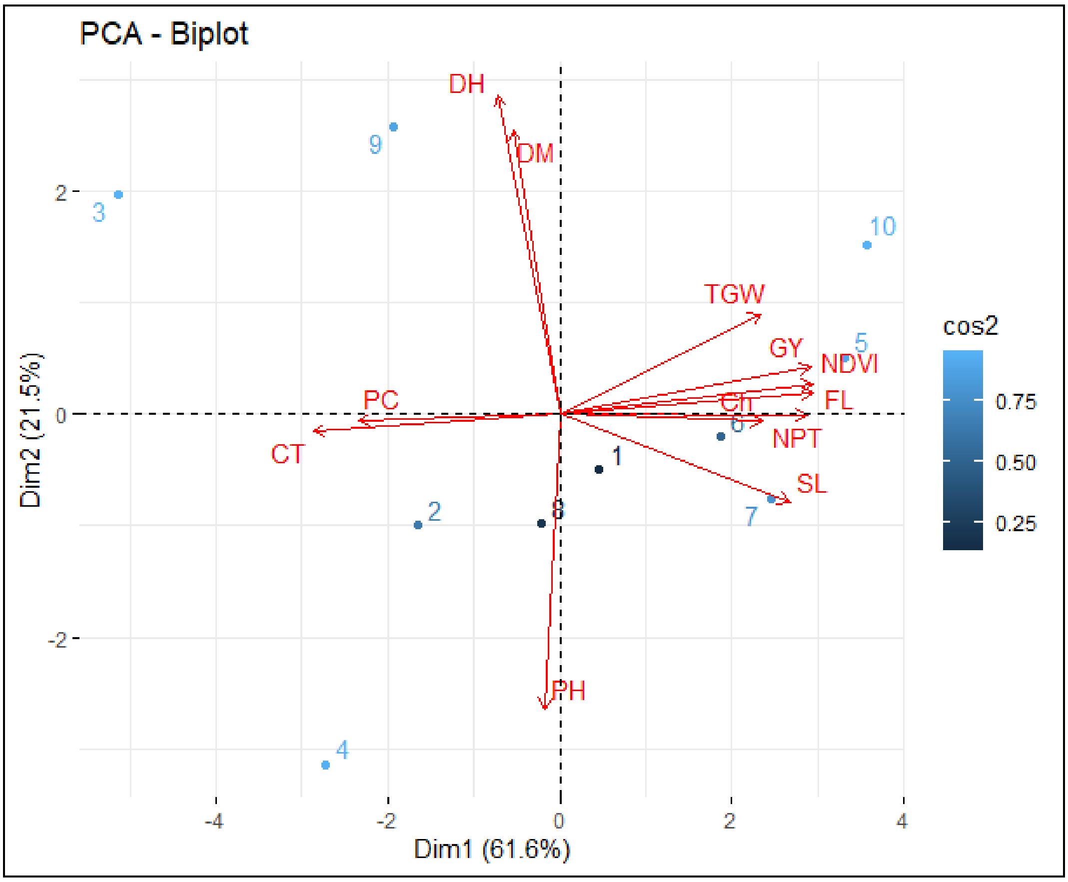

Figure 6. PCA-2 under irrigated conditions

CONCLUSIONS

The present results explain that drought stress significantly affected yield and other morphological traits of wheat genotypes. Significant variation was detected in traits, indicating that these genotypes could be valuable for wheat breeding programs focusing on improvement of drought tolerance. The positive correlation between thousand grain weight, NDVI at anthesis, chlorophyll content, flag leaf area, productive tillers per plant, and spike length with grain yield suggests that these wheat genotypes performed effectively under drought stress conditions.

Protein content showed a negative correlation with yield under irrigated conditions, but it increased when the plants were exposed to drought stress. Of all the genotypes tested, HYT-70-16 and V-17086 exhibited the best performance in terms of grain yield and related traits under both irrigated and drought conditions. It is suitable for use in drought-prone areas and for breeding drought-tolerant varieties.

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