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SCREENING OF DROUGHT TOLERANCE WHEAT (*TRITICUM AESTIVUM L.*) GENOTYPES FOR YIELD TRAITS USING TOLERANCE INDICES

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Abstract

Drought is a major environmental stress that negatively impacts wheat growth and significantly reduces its productivity. In this study, 31 advanced wheat lines, along with four check varieties, were evaluated under both normal and drought stress conditions using an alpha lattice design with three replications at The University of Agriculture, Peshawar, Pakistan, during the Rabi crop season of 2017-18. Data were collected on six yield parameters: spikes per square meter, spike length, grains per spike, grain weight per spike, thousand-grain weight, and grain yield (kg/ha). Eight drought tolerance indices were calculated for grain yield, including Tolerance Index (TOL), Stress Susceptibility Index (SSI), Stress Tolerance Index (STI), Geometric Mean Productivity (GMP), Mean Productivity (MP), Harmonic Mean (HM), Yield Index (YI), and Yield Stability Index (YSI). Significant differences ($P \leq 0.01$) were observed among genotypes for spikes per square meter, spike length, grains per spike, grain weight per spike, thousand-grain weight, and grain yield across both conditions. The genotype × environment interaction also showed significant variation ($P \leq 0.01$) for grains per spike, grain weight per spike, thousand-grain weight, and grain yield, indicating that the genotypes performed inconsistently across different environments. Under both normal and drought conditions, grain yield showed significant positive correlations with STI, GMP, MP, HM, and YSI, suggesting that these indices are reliable for identifying drought-tolerant genotypes. Based on high values of GMP, MP, HM, and overall performance, the genotypes CIM-206, CIM-205, CIM-134, and CIM-130 were identified as more drought-tolerant and high-yielding, making them suitable for both normal and drought conditions. These genotypes are recommended for use in future wheat breeding programs aimed at developing drought-tolerant varieties in Pakistan.

Key words: Drought tolerance, genotypes, *Triticum aestivum*, Yield traits, Phenotypic evaluation

Introduction

Wheat (*Triticum aestivum* L.) is a highly self-pollinated crop belongs to family *Poaceae* with chromosome number 2n=6x=42, AABBDD. It is a principal cereal in several countries of the world and most consumed food cereal in Pakistan (Akram *et al.,* 2008). Additionally, it plays a significant role in the global economy and is traded more than any other crop (Awulachew, 2020).It is considered to be originated in South East Asia. In Pakistan's agriculture during the year 2022–2023, its contribution is 8.2% to value addition and 1.9% to GDP (https://www.finance.gov.pk 2022-23). In the province of Khyber Pakhtunkhwa, wheat is cultivated on more than 52% area as rain-fed crop and its average yield is very low due to unavailability of appropriate wheat varieties for the area's climate and its appropriate time of sowing (Mukhtarullah *et al*., 2016). Globally, wheat was grown on an area of 222.11 million hectares with production of 779.76 million tons (USDA, 2021-22). Pakistan is the placed in 7th largest wheat producing country with 3.38% share in global wheat production during growing year 2021-22 (USDA, 2021-22). Its area under cultivation was increase to 9.04 million hectares while production stood at 27.63 million tones with a yield of 3056 kg/ha as compared with 8.97 million hectares, production of 26.20 million tones and 2920 kg/ha respectively during 2021–2022. Area, production and yield changed up to 0.7%, 5.4% and 4.7% respectively in the year 2022–2023 (https://www.finance.gov.pk 2022-23).

Since 1900, scarcity of water affects more than 11 million causalities and affect more than 2 billion people (4th UN World Water Development Report, 2012); while heat stress is reported to affect 1.2 billion people globally (Li, Li, *et al.,* 2020; Li, Yuan, *et al.,* 2020). Drought is an important abiotic stress which negatively affects crop growth and development. The impact and severity of drought stress depend on the crop developmental stage, the duration and intensity of the drought, and the genetic makeup of a cultivar (Tanin *et al.,* 2022; Ramesh *et al.,* 2024). Progressive global climatic change and increasing shortage of water resources are influencing wheat production greatly (Chaudhary *et al*, 2016). Drought limits plant growth and crops production more than any other environmental stresses (zhu, 2002). Drought is the most common environmental stress affecting 32% of 99 million hectares under wheat cultivation in developing countries and at least 60 million hectares under wheat cultivation in under developed countries (Rajaram 2007).

The main goal of wheat breeders is to developed drought tolerance varieties which performed well in rainfed/drought stress region. Understanding plant responses to drought is of great importance and also a fundamental part of making crops stress tolerant (Farshadfar *et al.,* 2013). Several drought indices have been used for screening drought tolerant genotypes based on yield under normal and drought stress conditions. Such as : Tolerance index (TOL) (Rosielle and Hamblin, 1981), mean productivity (MP) (Rosielle and Hamblin, 1981), geometric mean productivity (GMP) (Fernandez, 1992),harmonic mean (HM) (Bidinger and Mahalakshmi, 1987),stress susceptibility index (SSI)(Fischer and Maurer, 1978), stress tolerance index (STI) (Fernandez, 1992), yield index (YI) (Gavuzzi *et al.,* 1997), yield stability index (YSI) (Bouslam and Schapaugh, 1984) and Relative stress index (RSI) (Bouslam and Schapaugh, 1984). The main goal of the present study is to find out drought tolerance wheat genotypes for future breeding program and for rainfed wheat growing areas in Pakistan.

MATERIALS AND METHODS:

The present experiment was conducted in the experimental field of department of Plant Breeding and Genetics at "The University of Agriculture, Peshawar Pakistan" during Rabi crop season 2017-18. The experimental material consisted of thirty-five wheat genotypes including thirty-one wheat advanced lines and four checks grown under two different environments (normal and drought stress) on November 29, 2017. Both experiments were laid out in Alpha lattice design with three replications. Each replication was sub divided into 5 blocks each having 7 genotypes. Each genotype was planted in four rows of five meter length with 25 cm row to row distance. Standard and uniform agronomic practices were applied to all entries from sowing till the time of harvesting. Data was recorded on six yields parameters; spike m^{-2}, spike length, grains $spike^{-1}$, grain weight $spike^{-1}$, thousand grain weight and gain yield (kg ha^{-1}).

Stress selection Indices: A number of drought tolerance/susceptible indices were calculated under both normal and drought conditions, using the following formulas:

Tolerance Index (TOL) = $(Yp - Ys)$ (Rosielle and Hamblin 1981) (1)

Stress susceptibility index (SSI) = $\frac{1 - (Ys/Yp)}{1 - (\bar{Y}s/\bar{Y}p)}$ (Fischer and Maurer; 1978) (2)

Stress tolerance index (STI) = $\frac{Yp \times Ys}{(\bar{Y}p)^2}$ (Fernandez 1992) (3)

Geometric mean productivity (GMP) = $\sqrt{Yp \times Ys}$ (Fernandez; 1992) (4)

Mean productivity (MP) = $\frac{Yp + Ys}{2}$ (Rosielle and Hamblin 1981) (5)

Yp = Yield under normal condition
Ys = Yield under drought stress condition
$\bar{Y}p$ = Mean yield of all genotypes under normal condition
$\bar{Y}s$ = Mean yield of all genotypes under drought condition

Heritability (Broad sense)

Heritability across environments was calculated for various traits following the procedure of Singh and Chaudery (1997).

Where,
Genetic variance (Vg) = (GMS – EMS)/re
Phenotypic variance (Vp) = Vg + G × EMS – (EMS/r) + EMS
Heritability (broad sense) = (Genetic variance)/(Phenotypic variance)
Heritability (broad sense) = Vg/(Vg +Ve) = Vg/Vp
Where,
h2BS = broad sense heritability for a trait

Vg = genetic variance
Ve = environmental variance
Vp = phenotypic variance

According to Stansfield (1986), heritability estimate were grouped into:
(<20%) : Low
(20-50%) : Moderate
(>50%) : High

Correlation (r):
Correlations were computed following Singh and Chaudery (1997):

Statistical analysis: To estimate variation among the population, statistical approach (SAS, 2009) was used as outlined for alpha lattice design. Variance components (Vg, Ve and VP) were computed from the mean squares of the ANNOVA to estimate broad sense heritability under each environment.

Table a. List of 35 wheat genotypes studied for yield traits and tolerance indices.

S.No	Genotypes	Pedigree
1	CIM-113	WAXWING/KIRITATI/6/PVN//CAR422/ANA/5/BOW/CROW//BUC/PVN/3/YR/4/TRAP#1/7/SERI.1B//KAUZ/HEVO/3/AMAD*2/4/KIRITATI/8/ATTILA*2/PBW65*2/4/BOW/NKT//CBRD/3/CBRD
2	CIM-114	WAXWING/KIRITATI/6/PVN//CAR422/ANA/5/BOW/CROW//BUC/PVN/3/YR/4/TRAP#1/7/SERI.1B//KAUZ/HEVO/3/AMAD*2/4/KIRITATI/8/ATTILA*2/PBW65*2/4/BOW/NKT//CBRD/3/CBRD
3	CIM-116	WAXWING/KIRITATI/6/PVN//CAR422/ANA/5/BOW/CROW//BUC/PVN/3/YR/4/TRAP#1/7/SERI.1B//KAUZ/HEVO/3/AMAD*2/4/KIRITATI/8/ATTILA*2/PBW65*2/4/BOW/NKT//CBRD/3/CBRD
4	CIM-121	BAV92//IRENA/KAUZ/3/HUITES/4/DOLL/7/PBW343*2/KUKUNA/5/KAUZ//ALTAR 84/AOS/3/PASTOR/4/TILHI/6/PBW343/8/BAV92//IRENA/KAUZ/3/HUITES/4/DOLL
5	CIM-124	ELVIRA/CHIBIA//DIAMONDBIRD/4/2*MARCHOUCH*4/SAADA/3/2*FRET2/KUKUNA//FRET2
6	CIM-125	ATTILA*2/PBW65/5/CNO79//PF70354/MUS/3/PASTOR/4/BAV92/6/TRCH/SRTU//KACHU/7/UP2338*2/KKTS*2//YANAC
7	CIM-126	ATTILA*2/PBW65/5/CNO79//PF70354/MUS/3/PASTOR/4/BAV92/6/TRCH/SRTU//KACHU/7/UP2338*2/KKTS*2//YANAC
8	CIM-130	ROLF07/SAUAL*2/5/SERI.1B//KAUZ/HEVO/3/AMAD*2/4/KIRITATI
9	CIM-131	ROLF07/SAUAL*2/5/SERI.1B//KAUZ/HEVO/3/AMAD*2/4/KIRITATI
10	CIM-133	TACUPETOF2001/BRAMBLING/5/NAC/TH.AC//3*PVN/3/MIRLO/BUC/4/2*PASTOR*2/6/TRCH/SRTU//KACHU

S.No	Genotypes	Pedigree
11	CIM-134	TACUPETOF2001/BRAMBLING/5/NAC/TH.AC//3*PVN/3/MIRLO/BUC/4/2*PASTOR*2/6/TRCH/SRTU//KACHU
12	CIM-135	TACUPETOF2001/BRAMBLING/5/NAC/TH.AC//3*PVN/3/MIRLO/BUC/4/2*PASTOR*2/6/WAXWING/SRTU//WAXWING/KIRITATI
13	CIM-137	TACUPETOF2001/BRAMBLING/5/NAC/TH.AC//3*PVN/3/MIRLO/BUC/4/2*PASTOR*2/6/WAXWING/SRTU//WAXWING/KIRITATI
14	CIM-139	TACUPETOF2001/BRAMBLING/5/NAC/TH.AC//3*PVN/3/MIRLO/BUC/4/2*PASTOR*2/6/WAXWING/SRTU//WAXWING/KIRITATI
15	CIM-144	KACHU/SAUAL*2/5/SERI.1B//KAUZ/HEVO/3/AMAD*2/4/KIRITATI
16	CIM-145	KACHU/SAUAL*2/5/SERI.1B//KAUZ/HEVO/3/AMAD*2/4/KIRITATI
17	CIM-147	KACHU/SAUAL*2/8/ATTILA*2/PBW65/6/PVN//CAR422/ANA/5/BOW/CROW//BUC/PVN/3/YR/4/TRAP#1/7/ATTILA/2*PASTOR
18	CIM-148	KACHU/SAUAL*2/8/ATTILA*2/PBW65/6/PVN//CAR422/ANA/5/BOW/CROW//BUC/PVN/3/YR/4/TRAP#1/7/ATTILA/2*PASTOR
19	CIM-149	KACHU/SAUAL*2/8/ATTILA*2/PBW65/6/PVN//CAR422/ANA/5/BOW/CROW//BUC/PVN/3/YR/4/TRAP#1/7/ATTILA/2*PASTOR
20	CIM-150	KACHU/SAUAL/4/VARIS/MISR2, EGY/3/FRET2/KUKUNA//FRET2/5/KACHU/SAUAL
21	CIM-155	SAUAL/MUTUS*2/3/TRCH/SRTU//KACHU
22	CIM-159	SAUAL/MUTUS*2/3/TRCH/SCMU//KACHU
23	CIM-160	SAUAL/MUTUS*2/3/TRCH/SRWU//KACHU
24	CIM-163	SAUAL/MUTUS*2//PICAFLOR #1
25	CIM-171	ATTILA/3*BCN//BAV92/3/TILHI/5/BAV92/3/PRL/SARA//TSI/VEE#5/4/CROC_1/AE.SQUARROSA(224)//2*OPATA*2/6/HUW234+LR34/PRINIA//UP2338*2/VIVITSI
26	CIM-181	FRET2*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ/5/TNMU/6/FRET2*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ*2/7/TRCH/SRTU//KACHU
27	CIM-194	BL2800/5/SERI.1B//KAUZ/HEVO/3/AMAD*2/4/KIRITATI/6/KINGBIRD#1//INQALAB 91*2/TUKURU
28	CIM-197	BCN/RIALTO//2*MUNAL #1
29	CIM-202	SOKOLL/3/PASTOR//HXL7573/2*BAU/4/SOKOLL//PBW343*2/KUKUNA/3/ATTILA/PASTOR
30	CIM-205	PASTOR//HXL7573/2*BAU/3/SOKOLL/WBLL1/4/OR 9437534/SOKOLL//SOKOLL

S.No	Genotypes	Pedigree
31	CIM-206	PASTOR//HXL7573/2*BAU/3/SOKOLL/WBLL1/5/CROC_1/AE.SQUARROSA (213)//PGO/3/CMH81.38/2*KAUZ/4/BERKUT/6/W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1
32	Insaf	Check-1
33	Benazir	Check-2
34	Ghanimat	Check-3
35	Pirsabak-05	Check-4

Wheat, rainfall and temperature:

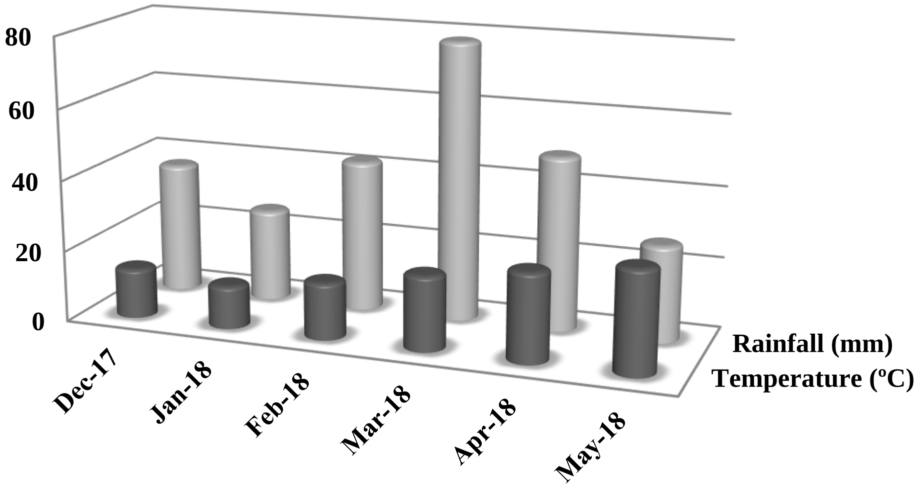
Wheat crop growth and rainfall: Rainfall plays a vital role in the determination of annual wheat production in Pakistan. Before sowing and shooting to grain filling phase rainfall proved to be fruitful but before planting and after germination and at the time of physiological maturity it has drastic effect on the crop and decline in the overall yield occur.

Rainfall during the crop season 2017-18: Rainfall accounting 37 mm was reported for 6 days in December from germination to mid growing stages. 26 mm for 4 days in January while 4 days with 47.7 mm in February. 78.4 mm was reported for 10 days in March from shooting phase to early maturity. March was proved to be the wettest month of the whole season. During flowering in the month of April rainfall accounting 48.9 mm for 10 days badly suffered the crop growth at pollination stage. While in the month of May 27 mm was reported for 6 days which result in drastic influence on wheat crop (Figure 1).

Temperature and wheat crop growth: Wheat crop completely dependent upon temperature from emergence to grain filling stage till physiological maturity. It is the most important climatic factor that effects the growth of wheat crop. Therefore, three temperature values are important for wheat plant growth.

1. Biological zero: Ranges between 0ºC and 5ºC. Below its plant growth stops.
2. Optimum temperature: At 25ºC maximum plant growth occurs.
3. Maximum temperature: Ranges from 30-32 ºC. Exceeding limit plant growth may stop (Mavi and Graeme, 2005).

Temperature during crop season of 2017-18: Day time and mean daily high temperature remained mostly normal from emergence till heading stage. While in month of April maximum temperature (30ºC) was recorded which badly affected the critical growth stages of the wheat crop across the environments and result in non-significant G × E interaction for most of the traits **(Figure 1).**



	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18
■ Temperature (ºC)	14	12	16	21	25	29
□ Rainfall (mm)	37	26	42.7	78.4	48.9	27

Figure 1. Metrological data of Peshawar from December 2017 to May 2018.

Statistical analysis: Combined analysis of variance revealed highly significant differences ($P \leq 0.01$) among environments, genotypes and genotype x environment interaction on grains spike^{-1}, grains weight spike^{-1}, thousand grains weight and grain yield, while spike m^2 and spike length revealed non-significant interaction (Table 1). Significant genotype × environment interactions for the traits exhibited inconsistent performance of genotypes over two environments.

Results and discussions:

1.0 Grain yield (kg ha^{-1}) as affected by normal and drought stress conditions.

Grain yield (kg ha^1) under normal condition was ranged from 1250 kg ha^{-1} to 3143.30 kg ha^{-1}, with mean of 1936.43 kg ha^{-1}, while it ranged from 920 kg ha^{-1} to 2904.7 kg ha^{-1}, with a mean of 1678.834 kg ha^{-1} under drought condition (Table 2). Genotype CIM-134 was ranked the highest yielding (3143.3 kg ha^{-1}) genotype under normal conditions followed by CIM-125 (2824.70 kg ha^{-1}, CIM-135 (2559.30 kg ha^{-1}) and CIM-137 (2528.00 kg ha^{-1}), however the lowest yield were produced by genotypes CIM-149 (1250.00 kg ha^{-1}), CIM-197 (1277.30 kg ha^{-1}) and CIM-144 (1287.30 kg ha^{-1}), respectively (Table 3). Similarly, under drought condition, high grain yield was produced by genotype CIM-206 (2904.7 kg ha^{-1}) and was latter followed by other three genotype CIM-130, CIM-144 and CIM-205 with grain yield of 2710.7 kg ha^{-1}, 2672 kg ha^{-1} and 2518.7 kg ha^{-1}, while lowest yield producing genotypes were CIM-126

(920 kg ha^{-1}), CIM-121 (966.7 kg ha^{-1}) and CIM-131 (974 kg ha^{-1}) (Table 2). Ahakpaz *et al*., (2020) and Ayed *et al*., (2021) also revealed yield loss in drought stress environment.

1.1 Other agronomic yield traits as affected by normal and drought stress conditions.

Mean of other agronomic traits (spike m^{-2}, spike length, grains spike^{-1}, grain weight spike^{-1} and thousand grain weight) are present in (Table 2). There was variation in genotypic performance for the traits under normal and drought stress conditions. Mean for spike m^{-2} under normal and drought stress conditions was 157 (spike m^{2}) and 151 (spike m^{2}). Maximum number of spike m^{--2} under normal condition was produced by genotype CIM-139 (200) and was followed by other genotypes CIM-145 (195), CIM-144 (194) and CIM-135 (189), moreover the top performing genotypes in respect under drought condition were CIM-114, CIM-116, CIM-205 and CIM-131with spike m^{-2} of 197, 194, 179 and 176, respectively (Table 2). Under normal conditions, genotypes such as CIM-134, CIM-125 and Insaf with values of 11.3 cm, 11.2 cm and 10.9 cm revealed maximum spike length, while mean of all genotypes was 9.37 cm (Table 3). Similarly under drought condition mean for spike length was ranged between 8 cm to 11. 3 cm, while maximum spike length was produced by genotypes CIM-137, (11.3 cm), CIM-130 (11.2 cm) and CIM-181(11.1 cm) (Table 3). In respect to grains spike^{-1}, desirable genotypes were CIM-205 (58), CIM-144 (57) and CIM-134 (56) under normal, and the genotype CIM-155 (57) was ranked with maximum number of grains spike^{-1} and was latter followed by other genotypes respectively CIM-114, CIM-147 and CIM-205 with grains spike^{-1} (56 each), respectively. Maximum grains weight spike^{-1} was produced by genotypes CIM-134 (2.72 gm), CIM-137 (2.69 gm) and CIM-125 (2.68 gm) while the mean value of 2.49 gm was recorded under normal condition. 1000 gw is an important trait which directly associated with yields. In normal environment mean value ranged from 42.4 to 49.9 gm, genotypes CIM-160, CIM-137 and CIM-134 attained better 1000-gw with values of 49.9 gm, 49.3 gm and 48.2 gm. Similarly in drought condition the highest 1000-gw was taken by genotypes CIM-144 (46.8 gm), CIM-147 (44.8 gm) and CIM-206 (44.7 gm) (Table 2).

1.2 Association of grain yield and drought tolerance indices

Drought tolerance indices are important criteria in identifying genotypes tolerant to drought (Ballesta *et al*.2019). The index TOL was calculated as difference in grain yield under normal and drought condition, so higher value of TOL, showing higher yield reduction under stress environment, while least TOL values taken genotypes indicated more stability. For grain yield, maximum TOL was recorded by genotype CIM-125 (1635.4) followed by other genotypes CIM-126 (1280.7), CIM-134 (1278.6) and CIM-121 (1273.3) (Table 3). Moreover least TOL was revealed for genotypes CIM-144 (-1384.7) and CIM-149 (-676), expressed that these are stable genotypes. Genotypes which revealing SSI <1 are considering more resistant to drought condition. Desirable SSI genotypes with minimum values were CIM-144, CIM-149 and CIM-145, respectively. The genotype CIM-206 displayed maximum values for

STI (1.91), GMP (2677.46), MP (2686.35), and HM (2668.60), specifying it as the most stable and tolerant genotype across the two environments. Similarly, genotypes CIM-205, CIM-134, CIM-130 and CIM-137 also expressed the desired levels of STI, GMP, MP and STI (Table 3). The YI value is calculated based on the yield of a genotype to the mean yield of all the tested genotypes under drought environments. The favoured genotypes with maximum YI values are CIM-206 (1.73), CIM-130 (1.61), CIM-144 (1.59) and CIM-205 (1.50) had considered as most tolerant, whereas less tolerance genotypes were CIM-126, CIM-121 and CIM-131. The YSI estimation is calculated on relative yield of genotypes under stress to their yield under non-stress conditions. High value of YSI pertained genotype, will have a high yield under stress and non-stress environments. YSI values, greater than one exhibited effective and showed better genotype under drought than normal environment. According to YSI, the desirable genotypes were; CIM-144 (2.08), CIM-149 (1.54) and CIM-145 (1.39), however, genotypes CIM-126 and CIM-125 with same value of (0.42 each) were as sensitive to drought environment (Table 3). Anwaar *et al.,* (2020), Farshadfar *et al.,* (2012), Ayalew *et al.,* (2016), Mursalova *et al.,* (2015) also demonstrated that these indices are the desirable for identifying of superior genotypes in drought stress environments.

1.3 Correlation between grain yield and tolerance indices

Grain yield under normal condition (Yp) showed non-significant correlation with yield in drought conditions (Ys) ($r=0.09$; $p >= 0.05$) (Table 4). There were positive significant correlations between Yp and all drought tolerance indices expect YI, YSI and Ys. Highly significant positive association was recorded between yields under normal conditions (Yp) $r = 0.66$ with TOL, $r = 0.60$ with SSI, $r = 0.67$ with STI, $r = 0.68$ with GMP, $r = 0.73$ with MP and $r = 0.62$ with HM (Table 5). Similarly in drought environment, grain yield (Ys) was positively correlated with STI ($r = 0.78$), GMP ($r = 0.78$), MP (0.75), HM ($r =0.81$), YI ($r =1.00$) and with YSI ($r =0.70$). All these studies inspected the selection criteria effectiveness for evaluating plant drought tolerance and reported that STI, GMP, MP and HM are more suitable to screen tolerance as they showed high positive correlation with grain yield under drought than normal conditions. Our studied results exhibited positive significant correlation between STI, GMP and MP in both normal and drought and conditions shows that their effects are stronger and making these indices the most suitable criteria for selection of genotypes under drought environment. Moreover in present study, highly significant positive correlation was recorded between MP and GMP ($r = 0.99$), MP with HM ($r = 0.97$) and MP with YI ($r = 0.75$) (Table 5). High values of MP distinguish high-yielding drought tolerant wheat genotypes. All these studies exhibited positive correlation between grain yield (both normal and drought conditions) with MP and GMP which revealed that these indices had straight correlation with high yielding tolerant wheat genotypes under drought environments (Table 4). Lal *et al.,* (2024), Balmaceda *et al.,* (2023), Dunareanu *et al.,* (2023) and Anwaar *et al.,* (2020) also recorded positive correlation of grain yield with GMP, MP and HM under normal and drought stress environments.

1.4 Heritability estimate

Under both, normal and drought conditions, moderate heritability estimate were recorded for most of the studied traits (Table 5). In normal environment heritability estimate for different traits were; spike m^2 (16%), spike length (43%), grains $spike^{-1}$ (48%), grain weight $spike^{-1}$ (38%), thousand grain weight (39%) and grain yield (37%). Similarly in drought condition the said values were observed; spike m^{-2}, spike length, grains $spike^{-1}$, grain weight $spike^{-1}$, thousand grain weight and gain yield, values are 19%, 63%, 61%, 40%, 32% and 45%, respectively (Table 5).

Table 1. Pooled analysis of 35 wheat genotypes evaluated under normal and drought stress environments.

Traits	Environment df =1	Reps w/n envt df =4	Blks w/n(envt x reps) df = 24	Genotypes df = 34	G X E df = 34	Error df = 112	CV
SM^2	86.78^{ns}	42003.5	1913.64	2455.97**	668.12^{ns}	1186.83	22.95
SL	4.45**	1.32	0.3	0.87**	0.16^{ns}	0.23	5.26
GPS	63.74**	46.01	4.95	9.37**	8.51**	1.78	2.47
GWPS	2.02**	0.08	0.02	0.09**	0.08**	0.03	7.61
TGW	1639.12**	12.14	9.28	18.42**	14.10**	6.89	6.13
GY	3484297.6**	5470636.5	175818.2	778420.9**	612060.8**	227001.4	26.35

**, * = significant at 1 % and 5 % probability level, ns = Non significant

SM^2 = Spike per meter square, SL = Spike length, GPS = Grains spike^{-1}, GWPS = Grains weight spike^{-1}, TGW= Thousand grains weight, GY = Grain yield

Table 2. Means for 6 yield traits of 35 wheat genotypes evaluated under normal and drought stress environments.

Genotypes	SM^2 (no)		SL (cm)		GPS (no)		GWPS (no)		1000 GW (gm)		GY (kg ha^{-1})	
	N	D	N	D	N	D	N	D	N	D	N	D
CIM-113	177	153	8.6	8.3	54	52	2.32	2.22	44.10	38.20	1511.30	1330.00
CIM-114	167	197	9.1	9.1	54	56	2.56	2.46	44.50	40.30	2080.00	1620.70
CIM-116	166	194	8.6	8.7	52	52	2.38	2.19	43.90	38.00	1805.30	1094.00
CIM-121	131	139	10.3	8	54	52	2.56	2.29	45.20	38.10	2240.00	966.70
CIM-124	140	172	9.8	9.5	55	51	2.64	2.24	45.30	41.70	2168.70	1294.00
CIM-125	133	159	11.2	8.7	54	54	2.68	2.30	44.00	35.60	2824.70	1189.30
CIM-126	111	131	10.3	8.2	54	48	2.66	2.07	45.40	39.00	2200.70	920.00
CIM-130	143	135	10.3	11.2	55	51	2.51	2.29	47.70	39.00	2092.70	2710.70
CIM-131	126	176	9.7	8.3	51	51	2.19	2.19	44.10	42.30	1672.70	974.00
CIM-133	138	166	9.5	8.1	54	54	2.44	2.23	44.20	39.40	1693.30	1278.70
CIM-134	166	128	11.3	9.4	56	51	2.72	2.37	48.20	43.70	3143.30	1864.70
CIM-135	189	171	9.6	10.1	52	52	2.51	2.20	47.80	42.30	2559.30	1704.00
CIM-137	178	148	9.5	11.3	55	55	2.69	2.45	49.30	34.80	2528.00	2092.70
CIM-139	200	152	8.7	9.6	56	52	2.56	2.38	48.10	38.90	2132.00	1589.30

CIM-144	194	164	8.5	10.8	57	51	2.56	2.34	47.70	46.80	1287.30	2672.00
CIM-145	195	155	9.3	9.8	55	53	2.40	2.22	46.10	42.10	1422.00	1980.70
CIM-147	160	146	9.3	10.5	54	56	2.57	2.34	46.40	44.80	2106.70	1796.00
CIM-148	160	156	9.8	9.8	55	55	2.50	2.43	45.90	43.40	2092.70	1982.00
CIM-149	147	139	8.2	10.2	55	53	2.48	2.22	44.40	42.50	1250.00	1926.00
CIM-150	135	125	8.1	9.7	55	55	2.39	2.34	44.50	38.50	1304.70	1544.00
CIM-155	156	132	8.4	10.4	53	57	2.42	2.52	45.00	39.80	1571.30	2057.30
CIM-159	145	115	10.4	8.7	54	52	2.34	2.32	45.40	39.00	2042.70	1492.00
CIM-160	145	141	8.7	9	53	51	2.50	2.38	49.90	38.80	1731.30	1155.30
CIM-163	166	162	10.2	9.6	55	53	2.49	2.37	45.60	38.50	2178.70	1110.70
CIM-171	143	126	8.2	10.3	54	54	2.44	2.31	45.10	36.10	1549.30	1784.00
CIM-181	142	117	8.2	11.1	55	55	2.48	2.36	46.60	38.40	1679.30	1595.70
CIM-194	138	144	9.9	9.7	53	53	2.36	2.29	44.60	37.10	1341.30	1451.30
CIM-197	152	151	8.5	8.9	54	52	2.35	2.32	46.00	36.80	1277.30	1476.00
CIM-202	169	159	9.3	9.3	55	55	2.60	2.36	44.70	38.80	2338.70	1795.30
CIM-205	183	179	10.2	10.9	58	56	2.32	2.48	43.80	42.80	2495.30	2518.70
CIM-206	173	173	10.5	10.8	55	55	2.58	2.54	45.60	44.70	2468.00	2904.70
Benazir	149	134	8.1	8.5	54	54	2.40	2.26	42.40	41.80	1592.00	1516.00
Ghanimat	174	130	8.2	9.4	51	51	2.55	2.29	44.30	38.20	1461.30	1556.00
Insaf	156	146	10.9	8.5	54	56	2.36	2.32	44.50	39.70	2287.30	1880.00
PS-05	148	164	8.6	9.4	54	56	2.58	2.45	44.80	39.50	1646.00	1936.70
Mean	**157**	**151**	**9.37**	**9.54**	**54**	**53**	**2.49**	**2.32**	**45.57**	**39.98**	**1936**	**1679**

N = Normal environment, D = Drought stress environment
SM^2 = Spike per meter square; SL = Spike length; GPS = Grains $spike^{-1}$, GWPS = Grains weight $spike^{-1}$, TGW= Thousand grains weight; GY = Grain yield

Table 3. Means of grain yield and drought tolerance indices under normal and drought stress environments.

Genotypes	Yp	Ys	TOL	SSI	STI	GMP	MP	HM	YI	YSI
CIM-113	1511.30	1330.00	181.30	0.90	0.54	1417.75	1420.65	1414.87	0.79	0.88
CIM-114	2080.00	1620.70	459.30	1.66	0.90	1836.04	1850.35	1821.85	0.97	0.78
CIM-116	1805.30	1094.00	711.30	2.96	0.53	1405.35	1449.65	1362.40	0.65	0.61
CIM-121	2240.00	966.70	1273.30	4.27	0.58	1471.53	1603.35	1350.55	0.58	0.43
CIM-124	2168.70	1294.00	874.70	3.03	0.75	1675.20	1731.35	1620.87	0.77	0.60
CIM-125	2824.70	1189.30	1635.40	4.35	0.90	1832.87	2007.00	1673.85	0.71	0.42
CIM-126	2200.70	920.00	1280.70	4.37	0.54	1422.90	1560.35	1297.56	0.55	0.42
CIM-130	2092.70	2710.70	-618.00	-2.22	1.51	2381.74	2401.70	2361.94	1.61	1.30
CIM-131	1672.70	974.00	698.70	3.14	0.43	1276.41	1323.35	1231.13	0.58	0.58
CIM-133	1693.30	1278.70	414.60	1.84	0.58	1471.47	1486.00	1457.08	0.76	0.76
CIM-134	3143.30	1864.70	1278.60	3.06	1.56	2421.01	2504.00	2340.78	1.11	0.59
CIM-135	2559.30	1704.00	855.30	2.51	1.16	2088.31	2131.65	2045.86	1.01	0.67
CIM-137	2528.00	2092.70	435.30	1.29	1.41	2300.08	2310.35	2289.85	1.25	0.83
CIM-139	2132.00	1589.30	542.70	1.91	0.90	1840.76	1860.65	1821.08	0.95	0.75
CIM-144	1287.30	2672.00	-1384.70	-8.09	0.92	1854.63	1979.65	1737.51	1.59	2.08
CIM-145	1422.00	1980.70	-558.70	-2.95	0.75	1678.26	1701.35	1655.48	1.18	1.39
CIM-147	2106.70	1796.00	310.70	1.11	1.01	1945.16	1951.35	1938.98	1.07	0.85
CIM-148	2092.70	1982.00	110.70	0.40	1.11	2036.60	2037.35	2035.85	1.18	0.95
CIM-149	1250.00	1926.00	-676.00	-4.07	0.64	1551.61	1588.00	1516.06	1.15	1.54
CIM-150	1304.70	1544.00	-239.30	-1.38	0.54	1419.32	1424.35	1414.30	0.92	1.18
CIM-155	1571.30	2057.30	-486.00	-2.33	0.86	1797.95	1814.30	1781.75	1.23	1.31
CIM-159	2042.70	1492.00	550.70	2.03	0.81	1745.77	1767.35	1724.45	0.89	0.73
CIM-160	1731.30	1155.30	576.00	2.50	0.53	1414.27	1443.30	1385.83	0.69	0.67
CIM-163	2178.70	1110.70	1068.00	3.68	0.65	1555.60	1644.70	1471.32	0.66	0.51
CIM-171	1549.30	1784.00	-234.70	-1.14	0.74	1662.51	1666.65	1658.39	1.06	1.15
CIM-181	1679.30	1595.70	83.60	0.37	0.71	1636.97	1637.50	1636.43	0.95	0.95
CIM-194	1341.30	1451.30	-110.00	-0.62	0.52	1395.22	1396.30	1394.13	0.86	1.08

CIM-197	1277.30	1476.00	-198.70	-1.17	0.50	1373.06	1376.65	1369.48	0.88	1.16
CIM-202	2338.70	1795.30	543.40	1.75	1.12	2049.07	2067.00	2031.29	1.07	0.77
CIM-205	2495.30	2518.70	-23.40	-0.07	1.68	2506.97	2507.00	2506.95	1.50	1.01
CIM-206	2468.00	2904.70	-436.70	-1.33	1.91	2677.46	2686.35	2668.60	1.73	1.18
Benazir	1592.00	1516.00	76.00	0.36	0.64	1553.54	1554.00	1553.07	0.90	0.95
Ghanimat	1461.30	1556.00	-94.70	-0.49	0.61	1507.91	1508.65	1507.16	0.93	1.06
Insaf	2287.30	1880.00	407.30	1.34	1.15	2073.67	2083.65	2063.75	1.12	0.82
PS-05	1646.00	1936.70	-290.70	-1.33	0.85	1785.44	1791.35	1779.56	1.15	1.18

Yp = yield in normal conditions; Ys = yield in drought stress conditions; TOL = tolerance index; SSI = stress susceptibility index; STI = stress tolerance index; GMP = geometric mean productivity; MP =mean productivity; HM = harmonic mean; YI = yield index; YSI = yield stability index

Table 4. Pearson Correlation coefficients between yield under normal (Yp) and drought stress (Ys) conditions and drought tolerance indices.

	Yp	**Ys**	**TOL**	**SSI**	**STI**	**GMP**	**MP**	**HM**	**YI**	**YSI**
Yp	1.000									
Ys	0.09^{ns}	1.000								
TOL	0.66***	-0.69***	1.000							
SSI	0.60***	-0.70***	0.97***	1.000						
STI	0.67***	0.78***	-0.10^{ns}	-0.12^{ns}	1.000					
GMP	0.68***	0.78***	-0.10^{ns}	-0.13^{ns}	1.00***	1.000				
MP	0.73***	0.75***	-0.04^{ns}	-0.09^{ns}	0.99***	0.99***	1.000			
HM	0.62***	0.81***	-0.16^{ns}	-0.16^{ns}	0.99***	0.99***	0.97***	1.000		
YI	0.09^{ns}	1.00***	-0.69***	-0.70***	0.78***	0.78***	0.75***	0.81***	1.000	
YSI	-0.60***	0.70***	-0.97***	-1.00***	0.12^{ns}	0.13^{ns}	0.09^{ns}	0.16^{ns}	0.70***	1.000

ns = non-significant; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$

Table 5. Heritability estimates for various traits under normal and drought stress environments.

	Normal			Drought		
Traits	**Vg**	**Ve**	**h^2 (%)**	**Vg**	**Ve**	**h^2 (%)**
SM^2	245.7	1316.16	16	146.77	630.5	19
SL	0.11	0.15	43	0.15	0.09	63
GPS	1.07	1.15	48	3.71	2.4	61
GWPS	0.03	0.05	38	0.01	0.01	40
TGW	1.6	2.52	39	4.31	9.26	32
GYLD	142404.7	243121.5	37	169755	210881.4	45

SM^2 = Spike per meter square, SL = Spike length, GPS = Grains spike^{-1}, GWPS = Grains weight spike^{-1}, TGW= Thousand grains weight, GY = Grain yield,

Conclusion:

Statistical analysis exhibited highly significantly differences ($P \leq 0.01$) among genotypes across both the environments for spike m^{-2}, spike length, grains spike^{-1}, grain weight spike^{-1}, thousand grain weight and gain yield, however, genotype × environment interaction showed highly significant variation ($P \leq 0.01$) for grains spike^{-1}, grains weight spike^{-1}, thousand grain weight and grain yield, which displayed inconsistent performance of genotypes for various yield traits over two environments. Under normal and drought stress environments, significant positive correlation of grain yield was observed with indices; STI, GMP, MP, HM and YSI and expressed as most suitable for predicting tolerance indices under drought environment. Base on high values of GMP, MP, HM and mean performances , the genotypes CIM-206, CIM-205, CIM-134 and CIM-130 were found more tolerant and higher yielding and suitable for both normal and drought environments. These genotypes/pure lines should be used in future drought wheat breeding program for development of drought tolerant varieties in Pakistan.

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