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Assessment of Durum Wheat Genotypes by Drought Tolerance Indices under Drought and Normal Condition

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ABSTRACT

Background: Drought is a major problem reducing agronomic crop production worldwide. Increasing the genetic potential of yield in water deficit condition is one of the major objectives of durum wheat breeding programs in world.

Methods: In this study, 20 genotypes of durum wheat (*Triticum durum* Desf.) were assessed in both water-stressed and well-watered environments for 2 years *i.e.* 2017-18 to 2018-19 *rabi* season. In each environment, each genotype was sown in four rows of 2.5-meter length and 20 cm apart using a randomized complete block design with two replications. Eight drought tolerance indices were applied based on grain yield in drought stress (Ys) and normal irrigation (Yp) conditions. Highly significant differences for yield (Yp and Ys) and all drought tolerance indices were observed indicating differences in genotypes for genes controlling yield and drought tolerance indices.

Result: High yield values in non-stress and stress environments were exhibited by genotypes GW 1339 (8254.29 kg ha^{-1}, 2970.83 kg ha^{-1}) followed by GW 2017-864 (7512.50 kg ha^{-1} 2756.25 kg ha^{-1}) and HI 8737(7186.47 kg ha^{-1}, 2845.83 kg ha^{-1}). It is remarkable that the genotypes GW 1339, GW 2017-864 and HI 8737 had high performances in both stressed and non-stressed conditions for grain yield. The maximum value of STI (0.576), HARM (4329.06) GMP (4922.03), MP (5612.56) and YI (1.28) indices was manifested by genotype GW 1339. Based on different drought indices, genotypes GW 1339, GW 2017-864 and HI 8737were found promising for drought tolerant than the other genotypes. The STI, HARM, GMP and MP indices, which were strong positive and significantly correlated to the grain yields in both favorable and drought stress environments, were introduced as the best indices, indicating effectiveness of these indices in identifying high yielding lines under drought stress as well as non-stress conditions. Association studies indicated that there was a positive and non-significant correlation between (Yp) and (Ys) was observed. The SSI index exhibited a negative correlation with the yield (Ys) under stress environment. Results of association studies showed that STI, HARM, GMP and MP indices were able to discriminate between drought-sensitive and drought-tolerant durum wheat genotypes. Principal components analysis showed two components which explained 99% variation.

Key words: Bi-plot, Drought stress, Grain yield, Principal component, Tolerance indices.

INTRODUCTION

Wheat is the most important crop in the world and it is cultivating in about 220.19 million hectares around the world. Wheat demand is increasing with the continuous increase in human population and it is expected to reach up to 40% in 2030. Mottaleb *et al.* (2023). However, the world's wheat consumption is expected to expand beyond production raising concerns about future food security. In India, during 2018-19 *rabi* season, wheat was cultivated in 29.55 mha constituting 24.35 per cent of the total crop acreage and production in 2018-19 has made a landmark achievement by producing 101.20 mt by registering another record in average national productivity *i.e.* 3424 kg/ha. (Anonymous, 2019). Drought (water deficits) and heat (high temperatures) stress are the major abiotic constraints, under the current and climate change scenario in future.

Reforming drought tolerance in wheat species is one of the most important solutions to fight the drought. It makes identifying drought tolerant genotypes difficult. Use of high yielding genotypes having drought tolerance is an efficient approach to lessen its damaging effects. With declining resources of water and escalating intensity of drought, loss of yield is a dangerous alarm in these regions. However, attaining drought tolerance exclusively yield depended is complex due to its intricate heritability. Likewise, choosing genotypes having tolerant genes is a tricky task (Mitra, 2001). Alternatively, some statistical parameters as well as drought tolerance indices could be employed to compare the changes in grain yield in normal and drought conditions for the assortment of genotypes of high yields and drought tolerance. They have been widely used for screening drought-tolerant genotypes in durum wheat (Patel *et al.,* 2019). On the other side, performance increase in water shortage condition requires identifying drought-tolerant

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genotypes and management affairs to maximize accessible water. Thus, improvement of drought tolerance in crops is a major objective of most crop breeding programs, particularly in arid and semi-arid areas of the world. To characterize, detect and evaluate the response of the population and differentiate drought resistance genotypes, several selection indices have been suggested based on a mathematical relationship between irrigated conditions and drought conditions (Sadeghzadeh Ahari *et al.,* 2009). Thus, the aim of this study was to evaluate the efficiency of several drought tolerant indices for screening and identification of drought tolerant durum wheat genotypes.

MATERIALS AND METHODS

Plant material and experimental setup

Twenty durum wheat (*Triticum durum* Desf.) genotypes were used in the study based on their reputed differences in yield performance under irrigated and non-irrigated conditions (Table 1). Experiments were conducted at the research farm, Wheat Research Station, Vijapur (latitude 23.350 N, longitude 072.550 E and altitude 126 m above sea level) in *rabi* seasons of 2017-18 to 2018-19 (two cropping years). The annual average temperature of the study area was 28.6°C and 12.6°C (Fig 1) with maximum and minimum temperatures, respectively, with the soil type classified as sandy loam soil with a pH of 7.74. During both the crop seasons no rainfall was received, so experiment was conducted in truly natural drought conditions. Each genotype was sown in four rows 2.5-meter in length and 20 cm apart, with a seed rate of 150 kg/ha in a randomized complete block design replicated twice. Standard agronomic practices were adopted to raise a good crop.

Estimation of drought tolerant indices

Drought tolerance indices were calculated using following formulas:

1. Stress susceptibility index (SSI) = $1 - \dfrac{Ysi/Ypi}{SI}$

$$SI = 1- \frac{Ys}{Yp}$$ (Fischer and Maurer, 1978)

2. Stress tolerance index (STI) = $\dfrac{Ypi \times Ysi}{Yp2}$ (Fernandez, 1992)

3. Tolerance index (TOL) = Ypi - Ysi (Rosielle and Hamblin, 1981)

4. Geometric mean productivity (GMP) = $\sqrt{(Ypi \times Ysi)}$ (Fernandez, 1992)

5. Mean productivity (MP) = $\dfrac{YPi + YSi}{2}$ (Rosielle and Hambling, 1981)

6. Harmonic mean (HARM) = $\dfrac{2\ (Ypi \times Ysi)}{Ypi+Ysi}$

7. Yield index (YI) = $\dfrac{Ysi}{Ys}$ (Gavuzzi *et al.,* 1997; Lin *et al.,* 1986)

8. Yield stability index (YSI) = $\dfrac{Ysi}{Ypi}$ (Bouslama and Schapaugh, 1984)

Where,

Ysi and Ypi = Yields of a given genotype under stress and optimum condition, respectively.

Ys and Yp = Average yield of all genotypes under stress and optimal conditions, respectively.

Stress intensity (SI) = 0.65

Statistical analysis

Analysis of variance was performed for each index according to Steel and Torrie (1980) by the computer program MSTATC software. Principal component analysis (PCA) was used to classify the screening methods as well as the genotypes. Correlation was also used to identify tolerant and high-yielding genotypes using IRRI Star software, based on principal component analysis.

RESULTS AND DISCUSSION

Pooled analysis of variance

The results of pooled analysis of variance in normal and drought stress conditions and stress tolerance indices showed significant differences among the genotypes for Ys, Yp and stress tolerance indices (Table 2). These results indicate presence of high genetic variation among genotypes, which could be a useful source for the selection of drought-tolerant genotypes. Kumar *et al.* (2021) and Mumtaz and Khan (2023) also reported significant differences between studied genotypes of wheat .

Mean values of drought tolerance indices

To study suitable stress tolerance indices for the selection of genotypes under drought stress condition, the yield of genotypes under both normal and stress conditions were recorded for calculating different sensitivity and tolerance indices (Table 3). Studies revealed that in wheat, the effect of drought stress is more pronounced during the reproductive stage (Nezhadahmadi *et al.,* 2013). In our study, 11 (55%) accessions from the study panel revealed a GY-SSI value of <1, indicating drought tolerance, whereas 09 (45%) showed a GY-SSI higher than 1, implying that these genotypes are drought susceptible. This suggests that in this study, drought stress was moderate but enough to facilitate the selection of drought-tolerant accessions. Moderate drought stress was reported as recommended to select drought-tolerant wheat lines (Ali and El-Sadek, 2016). In the non-stress condition (Yp) the highest values for grain yield was recorded for genotype GW 1339 (8254.29 kg ha^{-1}) followed by GW 2017-877(7839.58 kg ha^{-1}) and GW 2017-864 (7512.50 kg ha^{-1}), while genotype GW 2017-870 (5158.33 kg ha^{-1}) followed by GW 2015-699(5462.50 kg ha^{-1}) and GW 2017-874(5564.58 kg ha^{-1}) had the lower grain yield in that order. On the other hand, under drought stress condition (Ys) the highest grain yield was observed

Table 1: Name of durum wheat genotypes used for drought tolerance assessment.

Genotype	Pedigree
GW 2015-703	AKAKI 4/ACO 89//RASCON 19/3/PDW 228
GW 2015-699	ZHONG-ZUO/ACO 89//GW 1139/3/GW 1220
GW 1348	ERP'S'. GEN (2). YEN (2). FEGI'S'/GW 1113//DBPY 2003-2
GW 1349	HI 8671 / HI 8498
GW 1339	DDW 04/4/MEMO/YAV//AVK/3/RD 214
GW 2017-876	JD 03-32/GW 1139// HI 1189
GW 2017-877	JD 2001-32/IC 95290//P 5551/P 5469
GW 2017-886	DBPY 04-2/HI 8691
GW 2017-883	DDW 04/HI 8691
GW 2017-858	ALTAR 84/5/CHEN'S'/MABU/3/GME 189/HUI'S'//LDSMUT/TEAL'S'/4/MPO 1036
GW 2017-864	ZHONG-2UC/3/P 5551/P 5469//MACS 3038/4/GW 1256
GW 2017-874	GW 1193/VD 2004-13
GW 2017-870	GW 1104/DW 20//GW 1249
GW 2017-865	CINTA 1/MACS 3446
GW 2017-854	AJAIA 12/F3 LOCAL//RD 214/3/HI 8012//V 86/HI 8371
GW 2017-878	DBPY 2005-04/VD 2005-13
GW 2017-866	PDW 306/3/IWP 5061/GW 1021//GW 1115/4/IWP 5061/GW 1021//GW 1115
GDW 1255	WH 922 // NI 8757 / GW 1053
HI 8498	RAJ 6070 / RAJ 911
HI 8737	HI 8177 / HI 8158 // HI 8498

Table 2: Pooled analysis of variance of Yp, Ys and drought tolerance indices for 20 durum wheat genotypes.

Drought tolerance indices	Environment (df = 1)	Genotype (df = 19)	GXE (df = 19)	Pooled error (df = 38)
YS	551,397.566	489,547.396***	343,756.957**	118,703.254
YP	44,910,138.399	2,693,274.589***	1,114,904.130*	528,760.753
STI	0.077	0.031***	0.017**	0.006
TO	35,508,834.803	2,389,883.647***	1,498,852.231**	556,031.188
HARM	2,965,038.456	730,551.251***	399,849.802*	179,407.283
GM	6,786,251.946	779,065.050***	324,883.037*	161,146.000
MP	13,853,348.794	993,936.143***	354,629.539*	184,723.102
SSI	0.000	0.038***	0.032**	0.010
YSI	0.060	0.016***	0.013***	0.004
YI	0.000	0.096***	0.065**	0.023

*: Significant at p<0.05; **: significant at p<0.01; ***: significant at p<0.001.

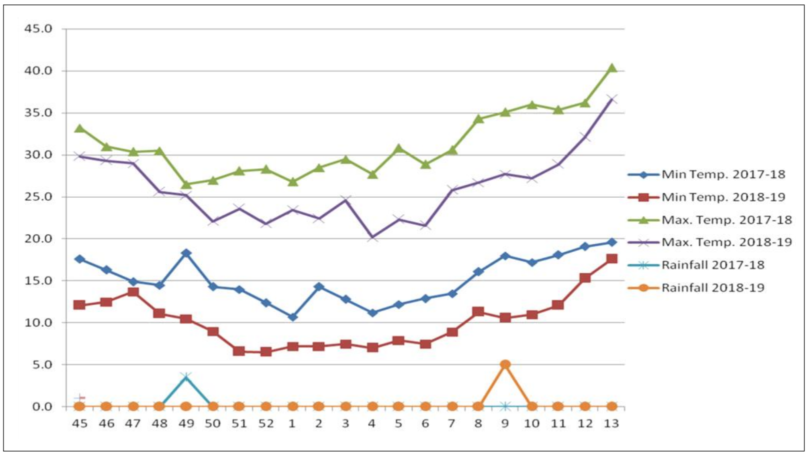

Fig 1: Minimum and maximum temperature and rainfall of last two years recorded at Wheat Research Station, Vijapur (2017-18 to 2018-19).

by genotype GW 1339 (2970.83 kg ha^{-1}) followed by GW 2017-878(2889.58 kg ha^{-1}) and HI 8737(2845.83 kg ha^{-1}). Genotypes GW 2017-866(1881.25 kg ha^{-1}) followed by GW 2017-854 (1900.00 kg ha^{-1}) and GW 1349(1947.92 kg ha^{-1}) recorded lower grain yield.

Genotypes GW 2017-878(2854.25), GW 2017-870 (3020.83) and GW 2015-699(3216.67) were found more tolerant based on TOL, in which lower values of TOL identified tolerant genotypes (Table 3). GW 2017-878(2889.58 kg ha^{-1}) had the second-highest grain yield in drought stress condition. Therefore, it is obvious that TOL index has been relatively successful in stress conditions to select the genotypes which had the high grain yield and lead the selection towards more efficient and tolerant genotypes.

The stress intensity (SI) value was 0.65 which provides an opportunity to evaluate durum wheat genotypes under severe stress conditions. Based on the SSI, the genotypes GW 2017-878(0.75), GW 2017-870 (0.85) and HI 8737(0.88) were identified as drought tolerance genotypes, while the genotypes GW 2017-877(1.13) and GW 2017-854(1.11) displayed the higher values of SSI (Table 3). Ghafari (2008) stated that genotype evaluation through SSI, categorizes experimental materials according to tolerance and stress sensitivity. Through this index, tolerant and sensitive genotypes can be specified without regarding their performance potential.

According to the MP, the genotypes GW 1339 (5612.56), GW 2017-864(5134.38) and HI 8737(5016.15) were found drought tolerance genotypes and the genotypes GW 2017-870(3647.92), GW 2015-699(3854.17) and GW 2017-874 (3859.38) were identified as drought susceptible ones in stressed condition (Table 3). MP is based on the arithmetic means and therefore, it may have an upward bias due to a relatively larger difference between Ypi and Ysi-. Generally higher MP value is an indicator of genotypes with higher yield potential. So, the MP index leads the selection towards more efficient genotypes in both stress and non-stress conditions. Among the tested genotypes, genotype GW 1339 (2970.83 kg ha^{-1}, 8254.29 kg ha^{-1}) had the highest grain yield in stress and non-stress condition. Verma and Singh (2023) also reported GW 1339 as high yielding genotype in central zone of India. The results of this study corresponded to the results of Shirinzadeh *et al.* (2009).

GMP values recorded were highest in genotype GW 1339 (4922.03) followed by GW 2017-864(4530.32) and HI 8737(4434.88). In terms of harmonic mean (HARM), the genotypes GW 1339(4329.06), HI 8737(4013.79) and GW 2017-864(4005.17) were identified as drought tolerant genotypes, while the other remained remaining genotypes showed lower values of HM (Table 3). The results of both GMP and HM indices were completely similar. It seems that this similarity is due to the nature of their calculating formulas and so it is logical to use one of them in future studies. Results for MP, GMP and HARM were following the findings of Mirzaei *et al.* (2014).

The higher values for stress tolerance index (STI) were observed for genotypes GW 1339(0.576), GW 2017-864(0.481) and HI 8737(0.457) in that order and genotypes GW 2017-870 (0.240) and GW 2017-866(0.254) had the lower stress tolerance index (STI). The high values of STI in these genotypes indicated high drought tolerance and high potential yield. Mevlut and Sait (2011) reported relatively similar ranks for the genotypes observed by GMP and MP parameters as well as STI, which suggests that these three parameters are similar for screening drought-tolerant genotypes.

In case of the yield index (YI), the genotypes GW 1339 (1.28), HI 8737(1.23) and GW 2017-878(1.23) were recognized as more drought tolerant genotypes (Table 3). The higher value for YSI was observed in genotypes GW 2017-878(0.52), GW 2017-870 (0.44) and GW 2015-699(0.42) (Table 3). The genotypes with high YSI are expected to have high yield under stressed and low yield under non-stressed conditions (Mohammadi *et al.,* 2010). Genotype GW 2017-878(2889.58 kg ha^{-1}) had a high yield in stress condition, but it didn't have high yield in normal condition.

Correlation analysis

Albeit selection based on a combination of indices may provide a more useful criterion for improving drought tolerance, however, correlation analysis between grain yield and drought tolerance indices can be a good criterion for screening the best genotypes and indices. Thus, a suitable index must be significantly correlated with grain yield under both the conditions (Mitra, 2001). A positive and non-significant correlation between (Yp) and (Ys) indicates that the yield under stress condition (Ys) has no significant correlation with the yield under non-stress environment (Yp). This indicates high stress intensity. Similar results were earlier reported by (Alefsi David *et al.,* 2020).

A positive correlation between Yp and SSI (r=0.53), Yp and TOL (r=0.90) and a negative correlation between Ys (drought stress) and SSI (r= - 0.59), Ys (drought stress) and TOL (r= -0.08) (Table 4) suggest that selection based on SSI and TOL will result in reduced yield under irrigated conditions. Especially, negative correlation between SSI and Ys was expected because genotypes that suffer less yield loss from irrigated to drought conditions also tend to have high yield in stressful environments. SSI identified some genotypes such as GW 2017-878, GW 2017-870 and GW 2015-699 as stress-resistant though they did not have outstanding yield performance in stress primarily because of their low potential yield (Table 3). On the other hand, the correlation between Yp and SSI was negligible (r= 0.53). The Ys was significantly correlated ($P<0.01$) with all indices except TOL, whereas Yp was highly significantly correlated with all indices except YI. Highly correlated indices with both the Ys and Yp are most appropriate for identifying stress tolerant cultivars.

Both Yp and Ys were significant and positively correlated ($P<0.05$) and ($P<0.01$) with, STI (r=0.77 and 0.84),

Table 3: Mean values of drought tolerance indices of durum wheat genotypes under stress and non-stress conditions.

Code	Ys	Yp	STI	TOL	HARM	GMP	MP	SSI	YSI	YI
1	2010.42 (17)	6127.08 (15)	0.275 (15)	4116.67 (5)	3013.43 (16)	3498.44 (15)	4068.75 (16)	1.03 (13)	0.33 (12)	0.86 (17)
2	2245.83 (9)	5462.50 (19)	0.272 (16)	3216.67 (3)	3175.28 (14)	3497.50 (16)	3854.17 (19)	0.90 (4)	0.42 (3)	0.96 (9)
3	2114.58 (16)	7107.08 (8)	0.326 (13)	4992.50 (17)	3237.24 (13)	3857.83 (13)	4610.83 (11)	1.08 (17)	0.30 (16)	0.90 (16)
4	1947.92 (18)	6368.75 (14)	0.263 (17)	4420.83 (10)	2900.95 (19)	3446.33 (17)	4158.33 (15)	1.02 (12)	0.33 (12)	0.83 (18)
5	2970.83 (1)	8254.29 (1)	0.576 (1)	5283.46 (19)	4329.06 (1)	4922.03 (1)	5612.56 (1)	0.98 (8)	0.36 (8)	1.28 (1)
6	2225.00 (10)	7187.50 (5)	0.348 (10)	4962.50 (15)	3375.04 (9)	3979.22 (9)	4706.25 (9)	1.07 (16)	0.30 (16)	0.95 (10)
7	2116.67 (15)	7839.58 (2)	0.370 (7)	5722.92 (20)	3318.87 (10)	4060.72 (7)	4978.13 (4)	1.13 (20)	0.27 (20)	0.91 (15)
8	2495.83 (7)	7114.58 (7)	0.399 (6)	4618.75 (12)	3686.43 (7)	4207.29 (5)	4805.21 (6)	0.99 (9)	0.36 (8)	1.07 (7)
9	2135.42 (14)	7293.75 (4)	0.356 (9)	5158.33 (18)	3285.86 (12)	3930.79 (10)	4714.58 (8)	1.08 (17)	0.30 (16)	0.92 (12)
10	2800.00 (4)	7031.25 (10)	0.441 (4)	4231.25 (7)	3999.05 (4)	4432.97 (4)	4915.63 (5)	0.92 (6)	0.40 (6)	1.20 (4)
11	2756.25 (5)	7512.50 (3)	0.481 (2)	4756.25 (13)	4005.17 (3)	4530.32 (2)	5134.38 (2)	0.97 (7)	0.37 (7)	1.19 (5)
12	2154.17 (12)	5564.58 (18)	0.262 (18)	3410.42 (4)	3068.74 (15)	3436.87 (18)	3859.38 (18)	0.90 (4)	0.41 (5)	0.92 (12)
13	2137.50 (13)	5158.33 (20)	0.240 (20)	3020.83 (2)	2992.94 (17)	3301.76 (20)	3647.92 (20)	0.85 (2)	0.44 (2)	0.92 (12)
14	2508.33 (6)	7004.17 (11)	0.403 (5)	4495.83 (11)	3689.58 (6)	4188.44 (6)	4756.25 (7)	0.99 (9)	0.36 (8)	1.09 (6)
15	1900.00 (19)	6866.67 (12)	0.289 (14)	4966.67 (16)	2947.27 (18)	3585.89 (14)	4383.33 (13)	1.11 (19)	0.28 (19)	0.81 (19)
16	2889.58 (2)	5743.84 (17)	0.364 (8)	2854.25 (1)	3784.58 (5)	4039.29 (8)	4316.71 (14)	0.75 (1)	0.52 (1)	1.23 (2)
17	1881.25 (20)	6108.33 (16)	0.254 (19)	4227.08 (6)	2863.34 (20)	3378.79 (19)	3994.79 (17)	1.06 (14)	0.31 (14)	0.80 (20)
18	2327.08 (8)	6683.33 (13)	0.342 (11)	4356.25 (9)	3417.57 (8)	3918.75 (11)	4505.21 (12)	0.99 (9)	0.36 (8)	1.00 (8)
19	2177.08 (11)	7085.42 (9)	0.335 (12)	4908.33 (14)	3312.80 (11)	3912.52 (12)	4631.25 (10)	1.06 (14)	0.31 (14)	0.93 (11)
20	2845.83 (3)	7186.47 (6)	0.457 (3)	4340.63 (8)	4013.79 (2)	4434.88 (3)	5016.15 (3)	0.88 (3)	0.42 (3)	1.23 (2)

The numbers in the parentheses are the genotype ranks for each index.

HM (r=0.57 and 0.96), GMP (r=0.78 and 0. 84) and MP (r=0.94 and 0.63) (Table 4). Positive significant correlation between GMP and MP and TOL in both drought and normal conditions shows that their effects are stronger than those of SSI and DI. These observed relationships are in consistence with numerous studies. Indices which had high correlation with grain yield in both stressed and non-stressed conditions have been selected as the best ones, because these were able to separate and identify genotypes with high grain yield in both conditions. With respect to the results of correlation coefficients of different indices and grain yield in two drought stress and normal irrigation conditions, genotypes which had higher values of these indices were more effective in identifying high high-yielding lines under drought stress as well as non-stress conditions. Many studies reported positive relationships between Ys and the most popular and widely used indices MP, GMP, STI, SSI, TOL (Farshadfar *et al.,* 2012; Naghavi *et al.,* 2013). Karimizadeh and Mohammadi (2011) were in opined that MP, GMP, STI, HARM and YI indices are preferred for practical usage. The observed relations were in consistence with those reported by Talebi *et al.,* (2009) and Mohammadi *et al.* (2010) in durum wheat.

In drought stress condition, YSI had a positive and significant correlation with grain yield(r=0.597). While, it had a negative and significant correlation with grain yield in normal condition (r= - 0.532). So, it cannot be a proper index for selecting the genotypes which have a high yield in normal irrigation and drought stress conditions. (Sio-Se Mardeh, 2006). Genotype GW 2017-878(2889.58 kg ha^{-1}) had high yield in stress condition, but it didn't have a high yield in normal condition. The genotypes with high YSI are expected to have high yield under stressed and low yield under non-stressed conditions (Mohammadi *et al.,* 2010).

Principal components analysis

In further evaluation of relations between genotypes and drought tolerance indices, principal components analysis was performed. Table 5 shows latent roots and special vector of under-study genotypes for the first two components, the most variations between data expressed by two components (99.00%). The first vector showed 61% of variations and showed that indices GMP, STI, HARM, MP, YI, Ys and Yp in the formation of this component has the highest positive coefficient, since high values of these indices were optimal and considering the positive relation of the first component with these indices, if we selected the top level, the genotypes were selected which had high and stable yield in different environments (drought stress, non-stress). So, this component was identified as drought

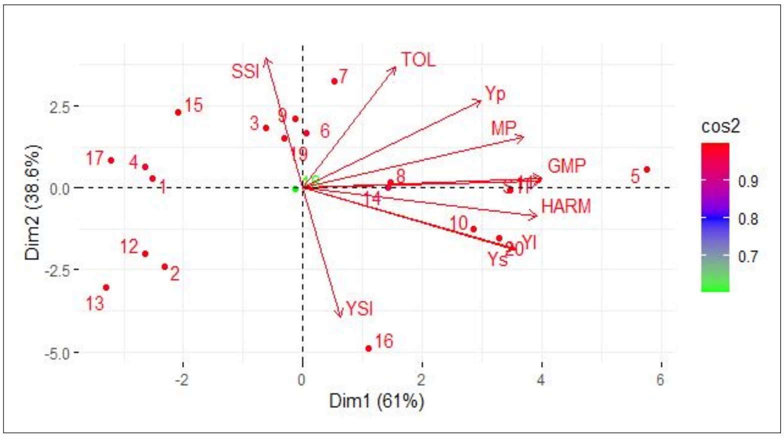

Fig 2: Biplot of durum wheat genotypes and drought tolerant indices based on first and second components.

Table 4: Spearman rank correlation coefficients of Yp, Ys and drought tolerance indices for the twenty durum wheat genotypes.

Parameter	Ys	Yp	STI	TOL	HARM	GMP	MP	SSI	YSI	YI
Ys	1.000									
Yp	0.345	1.000								
STI	0.849**	0.771**	1.000							
TOL	-0.086	0.905**	0.434	1.000						
HARM	0.962**	0.579**	0.956**	0.179	1.000					
GMP	0.848**	0.786**	0.992**	0.451*	0.959**	1.000				
MP	0.635**	0.944**	0.932**	0.715**	0.814**	0.945**	1.000			
SSI	-0.590**	0.536*	-0.096	0.836**	-0.353	-0.079	0.234	1.000		
YSI	0.597**	-0.532*	0.100	-0.835**	0.360	0.087	-0.229	-0.998**	1.000	
YI	0.999**	0.356	0.857**	-0.074	0.966**	0.855**	0.644**	-0.582**	0.588**	1.000

* and ** Significantly at p < 0.05 and < 0.01, respectively.

Table 5: Principal components analysis for yield in stress and normal condition and drought tolerance indices.

Drought tolerance indices	Component	
	PC_1	PC_2
YS	0.357	0.237
YP	0.300	-0.339
STI	0.401	-0.028
TO	0.157	-0.467
HARM	0.394	0.108
GM	0.403	-0.036
MP	0.373	-0.196
SSI	-0.061	-0.501
YSI	0.064	0.501
YI	0.360	0.232
Cumulative (%)	0.61	0.38

tolerant component (Farshadfar *et al.,* 2001). The second component had 38% of these variations (Fig 2). This component has high and positive correlation with YSI, Ys and YI. Tahmidul *et al.* (2023) and Sheeba and Mohan (2025) obtained similar results in first principal component analysis of drought tolerance in wheat and rice crop.

CONCLUSION

In the present investigation, significant differences among the grain yield under stress, non-stress condition and stress indices were observed suggesting presence of genetic variation among genotypes for drought. Based on indices and association results STI, HARM, GMP and MP indices were the best predictors of yield under water-stressed and non-stress environments. Based on indices selection, principal component analysis GW 1339, GW 2017-864 and HI 8737were the high-yielding and drought tolerant genotypes among the 20 lines evaluated. These lines could be a good source of germplasm for deriving drought tolerant lines. Principle component analysis showed that most variance among data is justified by first two components with 99% of the total changes.

Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript. Informed consent. All animal procedures for experiments were approved by the Committee of Experimental Animal care and handling techniques were approved by the University of Animal Care Committee.

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