INNSPUB

International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print), 2222-5234 (Online)
http://www.innspub.net
Vol. 15, No. 3, p. 130-136, 2019

RESEARCH PAPER OPEN ACCESS

Screening of drought tolerant wheat (*Triticum aestivum* L.) genotypes using stress tolerance indices and principle component analysis

Muzamil Hussain Memon[1*], Saima Mir Arain[2], Shah Nawaz Mari[1], Wazir Ali Metilo[3], Syed Razaq Amin Shah[4], Ghulam Sarwer Channa[5]

[1]*Department of Plant Breeding and Genetics, Sindh Agriculture University (SAU), Tandojam, Pakistan*

[2]*Plant Genetics Division, Nuclear Institute of Agriculture (NIA), Tandojam, Pakistan*

[3]*Department of Molecular Biology and Genetics, Shaheed Benazir Bhutto University, Shaheed Benazirabad, Pakistan*

[4]*Department of English, Sindh Agriculture University (SAU), Tandojam, Pakistan*

[5]*Department of Botany, Shah Abdul Latif University (SALU), Khairpur, Pakistan*

Key words: Water stress, Wheat, Selection indices, Principle component analysis.

http://dx.doi.org/10.12692/ijb/15.3.130-136 Article published on September 14, 2019

Abstract

As climate is changing and shortage of water resources takes place at alarming level wheat productivity is influenced at larger scale. Keeping this scenario in view, a field experiment was conducted at the experimental farm of Nuclear Institute of Agriculture (NIA), Tandojam, Pakistan, during Rabi season 2017-18. In this study, sixteen wheat genotypes were used to evaluate appropriate genotypes best suited to water stress based on stress selection indices. Statistically experiment was conducted in randomized complete block design (RCBD) with three replications. Seven stress tolerance indices i.e, Stress Tolerance Index (STI), Stress Susceptibility Index (SSI), Tolerance Index (TOL), Harmonic Mean Productivity (HMP), Geometric Mean Productivity (GMP), Mean Productivity (MP) and Yield Stability Index (YSI) were evaluated. Result showed that in first and second factors in principle component analysis (PCA) exhibited 99.7% of variability. Based on PCA analysis four genotypes (CIM-04-10, C_7-98-4, C_2-13-5c and C_5-13-5b) were categorized as tolerant (T), four genotypes (C_2-98-8, C_3-13-6b, V_2-10-3 and NIA-Sunhari) were classified as moderate-tolerant (MT), five genotypes (V_2-10-5, C_5-13-2b, V_2-10-15, Kiran-95 and C5-13-4a) were considered as moderate-sensitive (MS) and remaining three genotypes (CIM-04-18, V_3-10-9 and Chakwal) were identified as sensitive (S) genotypes against water stress conditions. Thus, the identified stress tolerant genotypes could be utilized for further breeding programs.

* **Corresponding Author:** Muzamil Hussain Memon ✉ muzamilhussain37@gmail.com

Introduction

Water scarcity is one of cardinal threats to agriculture and expected to increase in the coming decades in many regions of the world due to climate change (Slafer *et al.*, 2005). Life depends upon water availability. Its unavailability in appropriate amount and quality reduces crop yield. Although, wheat among cereals is drought tolerant crop but seasonal fluctuations in availability of water may severely affect grain yield (Fard and Sedaghat, 2013).Drought has harmful effects on various plant growth stages i.e; agro-morphology, physiology and anatomy. Hence, germination of seed is decreased and delayed, root and shoot length of crop is reduced and declined in production of biomass occurs (Ahmed *et al.*, 2015; Kabiri *et al.*, 2012; Janmohammadi *et al.*, 2008).

Wheat (*Triticum aestivum* L.) being the staple food crop among cereals (Kabir *et al.*, 2017),consumed by more than 35% of world population(FAO, 2015)is also major cereal crop of Pakistan, which adds 1.6% to GDP of the country (Pakistan Economic Survey, 2018-19). Its yield does not match with the increasing pace of human growth rate.

There is great need of time to enhance wheat yield to meet the pace of steady growth of human population particularly in developing countries where arable land is continuously declining but various environmental stresses including water shortage are constraints to its production (Khan and Mohammad, 2016).

Selection of different genotypes under environmental stress conditions is one of the main tasks of plant breeders to identify the stress-tolerant cultivars. Many selection indices based on mathematical calculations have been formulated to evaluate the response of genotypes under stress and non-stress conditions (Abdolshahi, 2013; Fard and Sedaghat, 2013; Clarke *et al.* 1984). Geometric mean productivity (GMP) and Stress tolerance index (STI)were introduced by Fernandez, (1992).Tolerance index (TOL) and mean productivity (MP) proposed by Rosielle and Hamblin, (1981), stress susceptibility index (SSI) developed by Fischer and Maurer, (1978), harmonic mean productivity (HMP) introduced by Fernandez, (1992) and yield stability index (YSI) suggested by Bouslama and Schapaugh, (1984) are most commonly employed indices under various stress and non-stress conditions. By using Principle component analysis (PCA) complex data is simplified.

Moreover, with the help of PCA analysis smaller number of variables are converted from number of correlated variables called principle components (El-Hashash *et al.*, 2018).

Different strategies can be employed to improve the efficiency of germplasm for higher yields and quality in dry environments. Identification of tolerant wheat cultivars to environmental stresses is aim of an optimum breeding strategy (Mohammadi *et al*; 2012).

In order to improve wheat yield under drought stress condition, there is prerequisite to recognize stress tolerance indices which may indicate potential wheat genotypes based on their yield under stress and non-stress conditions. Hence, this study was done with the objective to recognize suitable wheat cultivars for drought stress on the basis of selection indices.

Material and methods

Plant genetic material and experimental layout

Present study was conducted at the experimental field of Nuclear Institute of Agriculture (NIA), Tandojam during Rabi season 2017-18 with sixteen bread wheat genotypes viz., V_3-10-9, C_2-98-8, CIM-04-10, C_5-12-2b, C_5-13-4a, C_5-13-5b, CIM-04-18, V_2-10-3, C_3-13-5c, C_3-13-6b, V_2-10-15, C_7-98-4 and V_2-10-5 including three local checks namelyKiran-95, NIA-Sunhari and Chakwal-86. Statistically experiment was conducted as randomized complete block design (RCBD) with two irrigation treatments (T_1= Zero irrigation and T_2= Four irrigations) and three replications. Sowing was done in the month of November for both the treatments.

After harvesting the grain yield was calculated in Kg/plot. Seven stress tolerance indices were worked out by using following formulae.

Stress tolerance indices

Stress Tolerance Index = (STI) $= \frac{Yp \times Ys}{\bar{Y}p^2}$(Fernandez, 1992).

Tolerance = (TOL) = Yp –Ys (Rosielle and Hamblin, 1981).

Stress Susceptibility Index =

(SSI) $= (1 - (\frac{Ys}{Yp})) / (1 - \frac{\bar{Y}s}{\bar{Y}p})$(Fischer and Maurer, 1978).

Harmonic mean productivity =

(HMP) $= \frac{2\,Yp \times Ys}{Yp + Ys}$(Fernandez, 1992).

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

Mean Productivity = (MP) = (Ys + Yp) / 2 (Rosielle and Hamblin, 1981).

Yield Stability Index = (YSI) = $\frac{Ys}{Yp}$ (Bouslama and Schapaugh, 1984).

Where,

Y_S = Yield for each genotype under stress

Y_P = Yield for each genotype under non-stress

$\bar{Y}s$ = Mean yield for all the genotypes under stress

$\bar{Y}p$ = Mean yield for all the genotypes under non-stress

Statistical analysis

Correlation analysis were done by Statistics ver. 8.1 while principle component analysis (PCA) were performed by XLSTAT ver.2014.

Results and discussion

Ranking of stress tolerance Indices

Stress tolerance indices were evaluated based on grain yield /plot under water stress and non-stress environments (Table 1).

Table 1. Estimation of stress tolerance indices from the YP and YS for16 promising wheat genotypes.

Genotypes	Yp (kg/plot)	Ys (kg/plot)	GMP	R	MP	R	SSI	R	STI	R	TOL	R	YSI	R	HMP	R
V_3-10-9	0.71	0.24	0.412	(12)	0.475	(13)	1.005	(9)	0.289	(12)	0.47	(7)	0.33	(10)	0.358	(10)
C_2-98-8	0.83	0.21	0.417	(11)	0.520	(7)	1.134	(15)	0.296	(11)	0.62	(14)	0.253	(14)	0.335	(12)
CIM-04-10	0.99	0.33	0.577	(1)	0.660	(1)	1.012	(10)	0.555	(1)	0.66	(15)	0.333	(9)	0.495	(2)
C_5-13-2b	0.74	0.27	0.446	(9)	0.505	(9)	0.964	(6)	0.339	(9)	0.47	(8)	0.364	(6)	0.395	(9)
C_5-13-4a	0.65	0.33	0.463	(6)	0.490	(11)	0.747	(1)	0.364	(6)	0.32	(1)	0.507	(1)	0.437	(5)
C_5-13-5b	0.8	0.35	0.529	(3)	0.575	(2)	0.854	(3)	0.476	(3)	0.45	(5)	0.437	(3)	0.486	(3)
CIM-04-18	0.71	0.18	0.357	(14)	0.445	(14)	1.133	(14)	0.217	(14)	0.53	(10)	0.253	(15)	0.287	(15)
V_2-10-3	0.78	0.10	0.279	(16)	0.440	(15)	1.323	(16)	0.132	(16)	0.68	(16)	0.128	(16)	0.177	(16)
C_2-13-5c	0.79	0.27	0.462	(8)	0.530	(6)	0.999	(8)	0.362	(7)	0.52	(9)	0.341	(8)	0.402	(8)
C_3-13-6b	0.81	0.23	0.431	(10)	0.520	(8)	1.087	(12)	0.316	(10)	0.58	(13)	0.283	(12)	0.358	(11)
V_2-10-15	0.71	0.30	0.463	(7)	0.505	(10)	0.876	(4)	0.362	(8)	0.41	(3)	0.422	(4)	0.421	(7)
C_7-98-4	0.84	0.29	0.493	(4)	0.565	(4)	0.994	(7)	0.414	(4)	0.55	(11)	0.345	(7)	0.431	(6)
V_2-10-5	0.77	0.31	0.488	(5)	0.540	(5)	0.907	(5)	0.405	(5)	0.46	(6)	0.402	(5)	0.442	(4)
Kiran-95	0.76	0.38	0.537	(2)	0.570	(3)	0.759	(2)	0.491	(2)	0.38	(2)	0.500	(2)	0.506	(1)
NIA-Sunhari	0.77	0.21	0.402	(13)	0.490	(12)	1.104	(13)	0.275	(13)	0.56	(12)	0.272	(13)	0.330	(13)
Chakwal-86	0.61	0.19	0.340	(15)	0.400	(16)	1.045	(11)	0.197	(15)	0.42	(4)	0.311	(11)	0.289	(14)

As per the results obtained from STI, GMP and MP genotypes CIM-04-10, Kiran-95 and C_5-13-5b were considered as drought tolerant (T) genotypes, whereas genotypes V_2-10-3, Chakwal-86 and CIM-04-18 were proved as the moderate tolerant (MT)cultivars. The higher TOL and SSI values represents greater stress sensitivity, hence the lesser value is desirable for these indices (Ghasemi and Farshadfar, 2015). Genotypes found with lower values of TOL and SSI were C_5-13-4a and Kiran-95 hence considered as the drought tolerant (T), while, genotype V_2-10-3 possessed higher value and considered as moderate tolerant (MT) genotype. Likewise, as per YSI and HMP indices genotypes V_2-10-3 and CIM-04-18 showed greater reduction in yield under drought conditions, hence these genotypes were considered as drought sensitive(S) genotypes.

Table 2. Association among the tolerance and susceptibility indices evaluated under present investigation.

	Ys	Yp	GMP	MP	SSI	STI	TOL	YSI
Ys	1							
Yp	0.206$^{n/s}$	1						
GMP	0.515*	0.939**	1					
MP	0.816**	0.733**	0.912**	1				
SSI	0.199$^{n/s}$	-0.915**	-0.726**	-0.401$^{n/s}$	1			
STI	0.548*	0.927**	0.994**	0.928**	-0.700**	1		
TOL	0.703**	-0.549*	-0.241$^{n/s}$	0.164$^{n/s}$	0.834**	-0.205$^{n/s}$	1	
YSI	-0.194$^{n/s}$	0.916**	0.728**	0.406$^{n/s}$	-0.999**	0.703**	-0.831**	1
HMP	0.330$^{n/s}$	0.986**	0.978**	0.812**	-0.848**	0.966**	-0.434$^{n/s}$	0.850**

Note. n/s= non-significant, * and ** significant at the 5% and 1% levels of probability, respectively.

Correlation analysis between stress tolerance indices

Correlation analysis between grain yield under stress (Ys) and grain yield under non-stress (Yp) conditions were non-significant. Drikvand *et al.* (2012) also found non-significant correlation between Ys and Yp. Stress tolerant indices (Table 2) indicated that Ys was significant (P>1) and positively correlated with MP and TOL indices while, significant (P>5) and positive association was observed with GMP and STI. However, correlation results regarding yield under non-stress condition (Yp) and among stress conditions (Ys) showed positive and significantly (P>1) associated with GMP, MP, STI, YSI and HMP. Our results are in accordance with the results of Asl *et al.* (2011); Mollasadeghi (2010); Sio-se mardeh *et al.*, (2006).

Table 3. Results of principle component analysis for Yp, Ys and and drought tolerance indices of16 promising wheat genotypes.

Traits	Component 1	Component 2
Ys	0.285	0.958
Yp	0.996	-0.081
GMP	0.965	0.254
MP	0.786	0.617
SSI	-0.879	0.472
STI	0.955	0.290
TOL	-0.480	0.877
YSI	0.881	-0.468
HM	0.996	0.051
Eigenvalue	6.307	2.666
Variability %	70.080	29.623
Cumulative %	70.080	99.704

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.

TOL had positive and significant association with SSI at 1% of probability level. Rosielle and Hamblin (1981) found positive correlation between these two traits in most of the experiments they conducted. Fard and Sedaghat (2013) also found positive and significant association of TOL with SSI. GMP was positive and significantly (P>1) associated with MP, STI, YSI and HMP. Our these findings matches with the findings of Sourifarjam *et al.* (2013)who worked on these indices for selecting desirable genotypes under stress condition. MP was positive and significantly correlated with STI and HMP and negatively correlated with SSI. SSI was significant but negatively correlated with STI, YSI and HMP and was positive and significantly correlated with TOL. STI and YSI were positive and signicantly associated with HMP. TOL was negative and significantly correlated with YSI and HMP.

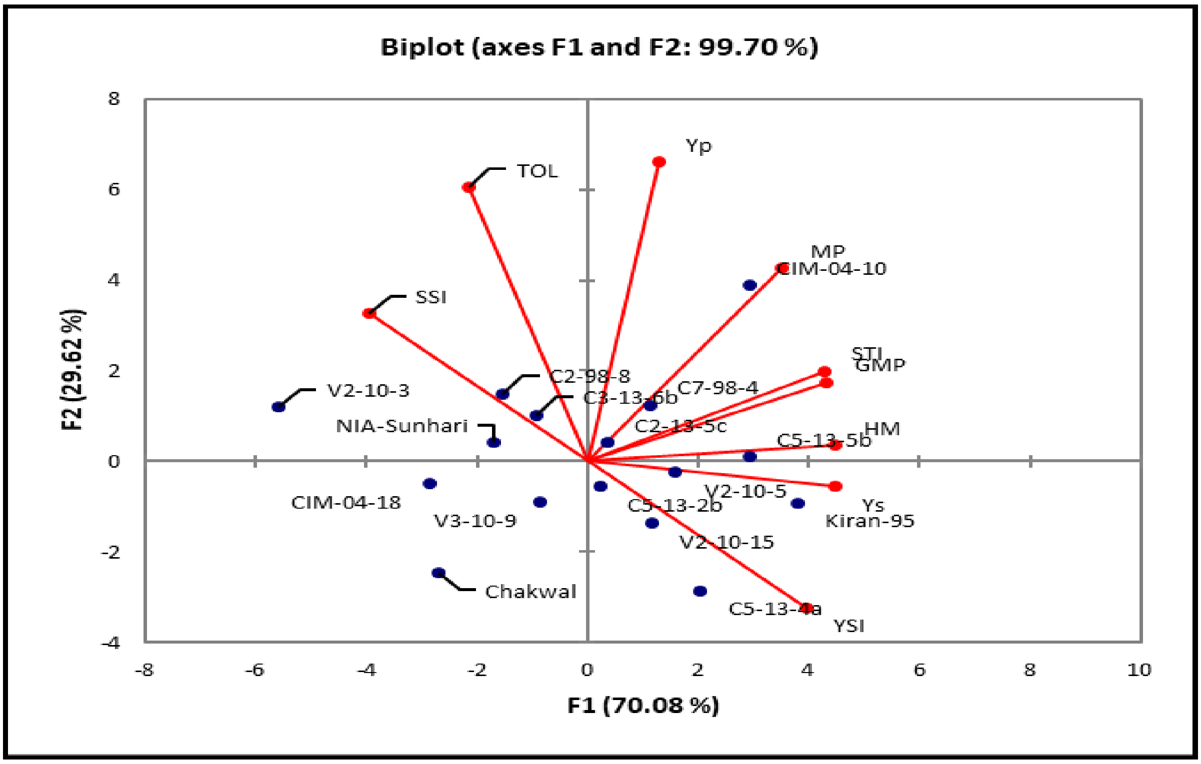

Fig. 1. Bi-plot based on first and second components for 16 promising wheat genotypes and stress indices.

Principle components and biplot analysis

Principle component analysis was carried out to know the association between genotypes and stress indices. The results regarding this (Table 3) exhibited that first and second factors in principle component analysis explained 99.7 percent variation. Using principle components, biplot for genotypes and stress tolerance indices were performed (Fig. 1.). As per the findings of PCA, genotypes were categorized into four groups i.e. tolerant (Group A), moderate-tolerant (Group B), moderate-sensitive (Group C) and sensitive genotypes (Group D). Group A includes four genotypes *viz.* CIM-04-10, C_7-98-4, C_2-13-5c and C_5-13-5b and was considered as drought tolerant group. Four genotypes viz., C_2-98-8, C_3-13-6b, V_2-10-3 and NIA-Sunhari were placed in Group B, which was known as moderate-sensitive group. While genotypes included in Group C were five *viz.*, V_2-10-5, C_5-13-2b, V_2-10-15, Kiran-95 and C5-13-4a that were considered as moderate-sensitive genotypes. Group D consists four genotypes *viz.*, CIM-04-18, V_3-10-9 and Chakwal and this group was considered as sensitive group. According to bi-plot analysis the first component displayed high positive coefficients for indicators MP, GMP, HM, STI, YSI, Ys and Yp. With respect to desirability of high levels of these indicators this may be used as a component of stability and tolerance to water stress. The first component explained 70.08% variation for grain yield. Whereas, the second component showed 29.62% of variation of data having positive coefficient for indicators *viz.*, SSI and TOL, this component was considered as stress sensitivity component. These observations confirms with the results of Puri *et al.* (2015); Asl *et al.* (2011); Mohammmadi *et al.* (2011).

Conclusion

It may be concluded from the present work that water stress significantly reduced the yield in wheat genotypes. Moreover, MP, GMP, STI had similar ability to differentiate genotypes for water stress sensitiveness and tolerance. On the basis of PCA analysis four genotypes (CIM-04-10, C_7-98-4, C_2-13-5c and C_5-13-5b) were categorized as tolerant (T). Four genotypes (C_2-98-8, C_3-13-6b, V_2-10-3 and NIA-Sunhari) were classified as moderate-tolerant (MT). Five genotypes (V_2-10-5, C_5-13-2b, V_2-10-15, Kiran-95 and C5-13-4a) were considered as moderate-sensitive (MS) and remaining three genotypes (CIM-04-18, V_3-10-9 and Chakwal) were identified as sensitive (S) genotypes against drought stress conditions.

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