Water deficit stress tolerance assessment in barley cultivars using drought tolerance indices

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Abstract

Crop productivity is greatly affected by drought stress. Understanding the drought tolerance capability of the crop varieties available in a country is the foremost consideration for drought adaptation. The objective of this research work was to examine the drought tolerance potentiality of 5 cultivated barley varieties (BARI Barley5, BARI Barley6, BARI Barley7, BARI Barley8 and BARI Barley9) through calculating drought tolerance indices. A completely randomized design (CRD) with three replications was followed in the experiment, where crops were grown under control (80% of FC) and water deficit environment (50% of FC). Stress Tolerance (TOL), Mean Productivity (MP), Geometric Mean Productivity (GMP), Stress Susceptibility Index (SSI), Stress Tolerance Index (STI), Harmonic Mean (HAM), Yield Index (YI) and Yield Stability Index (YSI) were calculated based on grain yield under control and drought conditions. BARI Barley7 and BARI Barley8 were the most tolerant variety and BARI Barley9 considered as susceptible based on TOL and SSI. Drought tolerance indices like MP, HAM, GMP, TOL as well as STI were showed a high correlation with grain yield under both conditions and were recognized as appropriate indices to identify varieties with high grain yield and low sensitivity to drought stress.

Introduction

Barley (*Hordeum vulgare* L.) is the fourth most important cereal crop in the world after wheat, rice and maize. It was one of the first grains to be domesticated by early humans and is adapted to a broad range of agro- and profitable than any other major crops (Wang et al. 2018). It can grow low fertile soils ecological environments and lower temperatures better than does wheat. It can be used as a livestock feed, for malt and for preparing foods. It is a type of edible grain that can use in bread, cereal, soup, and beer. Barley grain contains 61.8% starch, 13.1% protein, 10.8% insoluble fibre, 7.55% moisture, 4.85% soluble fibre, 4.28% pentosan, 4.26% β -D glucan, 2.92% lipid, 1.89% ash and eight essential amino acids (Helam et al. 1999; Vasan et al. 2014).

The global production of barley is increasing. In the 2019/2020 crop year, it was amounted to 156.41 million metric tons (USDA 2020), whereas it was around 140.6 million metric tons in 2018/2019. The opposite scenario is found in Bangladesh. Barley production of Bangladesh fell gradually from 20 thousand tonnes in 1960 to 7 thousand tonnes in 2020 (Figure 1). Over the time barley cultivation area and production are decreasing day by day. It may be due to a lack of climate- adaptive especially drought - tolerant barley cultivar.

In Bangladesh, barley is usually grown as a single crop, under rain-fed conditions is about 22% of total cultivable land under barley cultivation (Khatun et al. 2018). This area locally called as “Khora” areas, which are characterized by low yields and severe water shortage conditions. So, this crop usually experiences water deficit and heat stress, especially during grain filling growth and development. Yield potential and its annual productivity is significantly lower than other aforementioned cereals (Saed-Moucheshi 2018) due to the water shortage that occurs in areas of its cultivation. To improve the

livelihoods of the farmers of barley growing areas in Bangladesh, it is demanded to introduce drought-tolerant high yielding barley variety which can adapt in water deficit environment.

Drought is one of the major environmental factors negatively affects the growth, physiology and metabolism of plants (Islam et al. 2011), which ultimately hampered the productivity of crop (Hassan et al. 2016). Agricultural production in many developing countries of the arid and semi-arid regions of the world and the productivity of 40 to 60% of the world's agricultural lands (Bray 1993) affected by drought stress.

It is a very difficult challenges for plant breeders to achieve genetically higher yield under water-limited conditions, as compared to the progress in grain yield in favorable environments (Richards et al. 2002). Therefore, different methods are suggested to provide a way for finding the best genotypes that have the more adaptive capability in a drought environment. Many researchers used drought tolerance indices as screening techniques for selecting drought-tolerant genotypes which provide a measure of drought based on loss of yield under drought conditions in comparison to normal conditions (Mitra 2001). Fernandez (1992) opined that these indices are either based on drought tolerance capability or susceptibility of cultivars. Drought resistance is the relative yield of genotype compared to other genotypes subjected to the same drought condition reported by Hall (1993). Blum (1988) found that drought susceptibility of a genotype is often measured as a function of the reduction in yield under drought stress. Stress tolerance (TOL) as the differences in yield between the stress and non-stress environments, mean productivity (MP) as the average yield under stress and non- stress environments (Rosielle and Hamblin, 1981) and Geometric mean (GM) estimates the drought tolerance based on yield under drought condition. The Geometric mean is often used by breeders interested in relative performance since drought stress can vary in severity in a field environment (Ramirez and Kelly 1998). Fischer and Maurer (1978) proposed a stress susceptibility index (SSI) of the cultivar. Stress tolerance index (STI) which can be used to identify cultivars that produce high yield under both stress and non-stress conditions (Fernandez 1992). The aim of the experiment to find out the best selection criteria for identifying drought-tolerant barley variety to grow in the drought-prone areas of Bangladesh. Moreover, different stress indices were appraised to distinguish the best indices applicable for finding favorable variety by using advanced statistical techniques.

Materials And Methods

Experimental site

The pot experiment was laid out in a semi-controlled environment (inside screenhouse) at the Department of Agronomy, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur, Bangladesh during November 2019 to March, 2020. The experimental site is in the centre of Madhupur Tract (AEZ 28), 24.09° N latitude and 90.26° E longitude at 8.4 m above the sea level. Each pot (30 cm length and 24 cm diameter) was filled with 11 kg soil. The chemical and physical properties of the experimental soil are presented in Table 1. . The recommended fertilizers were applied with 0.99, 0.55 and

0.50 g urea, triple super phosphate and muriate of potash corresponding to 180-100-85 kg urea, triple super phosphate and muriate of potash per hectare, respectively. (BARC 2018). The air temperature and relative humidity of the experimentation period are presented in Figure 2.

Experimental materials

Five barley cultivars (BARI Barley5, BARI Barley6, BARI Barley7, BARI Barley8 and BARI Barley9) were used in this study. The seeds of barley varieties were collected from Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh and were sown on November 20, 2019, and crops were grown following the standard cultivation techniques (Mandal et al. 2011).

Experimental factors

The experiment consisted of two factors: barley cultivars and drought stress. Ten seeds of each cultivar were sown in each pot. Slight irrigation was applied for seed germination. After germination, 80% of field capacity (FC) and 50% of FC were maintained throughout the growing season in control pots and drought-stressed pots, respectively. The moisture level of soil in each pot was monitored by using a portable digital moisture meter (POGO Soil Sensor II, Stevens, USA) and the required amount of water was applied. .

Experimental design

In this study Complete randomized design (CRD) was followed with 3 replications.

Data collection and statistical analysis

At the physiological maturity stage, crop was harvested and data on grain yield were recorded at 14% seed moisture level. Drought tolerance indices were calculated by the following formula (Table 2). The recorded data were analyzed using the statistical package program CropStat 7.2 and MS office Excel version 10 program.

Results

The analysis of variance (ANOVA) was implemented for measured data and it showed that no significant differences among genotypes in respect to grain yield under non-stress condition (Table 3). Significant differences ($p < 0.01$) were observed among varieties under drought stress conditions.

Mean comparisons result showed that the highest grain yield was obtained from BARI Barley7 with 3.89 g plant⁻¹ and the lowest yield was recorded from BARI Barley9 with 2.77 g plant⁻¹ (Table 4). Under stress condition, BARI Barley7 with 2.98 g plant⁻¹ and BARI Barley9 with 1.76 g plant⁻¹, respectively had the highest and the lowest grain yields. But there were no significant differences among BARI Barley5, BARI Barley6 and BARI Barley8.

Five barley genotypes were ranking based on drought tolerance indices. There was found a positive and significant correlation ($r^2 = 0.59$) between grain yield under control (Y_p) and drought stress (Y_s) treatments. Calculation of tolerance indices showed that the lowest stress tolerance (TOL) value and Stress Susceptibility Index (SSI) value were recorded in BARI Barley7 and BARI Barley8. On the other hand, the highest stress tolerance (TOL) value and Stress Susceptibility Index (SSI) value were found in BARI Barley5 and BARI Barley6 (Table 5).

Mean Productivity, Geometric Mean Productivity, Stress Tolerance Index, Harmonic Mean, Yield Index and Yield Stability Index values were higher in genotype BARI Barley7 and BARI Barley8. On contrary, the lowest Mean Productivity, Geometric Mean Productivity, Stress Tolerance Index, Harmonic Mean, Yield Index and Yield Stability Index were obtained in BARI Barley5 and BARI Barley9 (Table 5).

The positive and significant correlations with Y_p were observed among MP, HAM, GMP, TOL and STI (Table 6) and there was a negative and significant correlation with YSI. A significant and positive correlation was also observed among Y_s and YI, STI, GMP, HAM, STI, MP and YSI. The highest correlation ($r^2 = 0.93$) was observed between Y_s and YI. The correlations of TOL ($r^2 = 0.44$) and SSI ($r^2 = 0.50$) with Y_s was positive but non-significant. There was a positive and significant correlation between TOL and SSI ($r^2 = 0.84$) but a negative and significant correlation ($r^2 = -0.89$) was observed between TOL and YSI. There were also, positive and significant correlations among MP, GMP, STI, HAM and YI ($p < 0.01$). The highest correlation ($r^2 = 0.96$) was observed between MP and GMP. It was observed positive and significant correlation among GMP, HAM, STI and YI but the highest correlation ($r^2 = 0.95$) was found between GMP and HAM. There was a negative and significant correlation ($r^2 = -0.84$) was found between SSI and YSI. A positive and significant correlation was observed among STI, HAM and YI. The positive and significant correlation ($r^2 = 0.75$) was found between HAM and YI. The same relationship was also observed among between YI and YSI ($r^2 = 0.70$).

Considering the all drought-tolerance indices ranking of barley varieties studied showed that BARI Barley7 and BARI Barley8 had the best position and BARI Barley9 was in the worst position in mean ranking (Table 5).

Discussion

ANOVA table shows a significant difference among the varieties under stress condition. This high diversity among the varieties under a stressful environment helps us to select drought-tolerant barley variety.

BARI Barley7 gave the highest yield ($2.98 \text{ g plant}^{-1}$) under stress condition indicated that this genotype is relatively drought tolerant in relation to yield compared to other genotypes studied. On the other hand, BARI Barley9 is the susceptible to drought in relation to yield capability.

The positive and significant correlation between grain yield under control (Y_p) and drought stress indicated that tolerant varieties showed their best performance under stress condition in relation to yield.

BARI Barley7 and BARI Barley8 possess lower TOL and SSI value, indicating that these two varieties had lower yield reduction due to drought stress and these indicated that these were the most tolerant varieties based on TOL and SSI, which their low quantity is indication tolerance genotypes. On the other hand, higher, TOL and SSI value were found in BARI Barley6 and BARI Barley5 indicating that higher yield reduction was occurred in these two varieties and categorized as susceptible.

BARI Barley7 and BARI Barley8 were the tolerant varieties based on of Mean Productivity (MP), Geometric Mean Productivity (GMP), Stress Tolerance Index (STI), Harmonic Mean (HAM), Yield Index (YI) and Yield Stability Index (YSI). Based on the results, BARI Barley5 and BARI Barley9 were the most sensitive varieties.

Considering the mean ranking among the varieties BARI Barley7 and BARI Barley8 were the tolerant and BARI Barley9 was considered as susceptible to drought stress.

The experimental results indicated that the most appropriate index to select drought-tolerant variety is an index that has a high correlation with grain yield under both controls (non-stress) and stress conditions. So, HAM, YI, STI, MP and GMP were identified as appropriate indices to select drought tolerance varieties. Karimizadeh and Mohammadi (2011) reported that among drought-tolerance indices, harmonic mean (HM), GMP, CTD and modified STI index (K2STI) can be used as the most suitable indicators for screening drought-tolerant cultivars. Similar results were reported by Sanjari-Pireivatlou and Yazdansepar (2008).

Many researchers opined that drought tolerance indices based on yield are more useful tools to select stress-tolerant cultivars. STI was more useful in order to select favorable cultivars under stress and non-stress conditions reported by Moghadam and Hadi-Zadeh (2002). Based on GMP and STI indices, cultivars with high yield in both stress and non-stress environments can be selected reported by Khalili et al. (2004). On the other hand, susceptibility indices such as SSI, TOL, and PEV and also tolerant indices such as STI appeared to be very useful for extracting suitable genotypes (Saed-Moucheshi et al. 2013). Similar analysis has been used for introducing tolerant and susceptible genotypes by (Fernandez 1992) in mung bean, Farshadfar and Sutka (2003) in maize, Golabadi et al. (2006) and Talebi et al. (2009) in durum wheat, and Jamaati-e-Somarin and Zabihi-e-Mahmoodabad (2012) in lentil. Based on yield potential under control (non-stress) and stress conditions Fernandez (1992) grouped the genotypes into 4: i) varieties with high production under both conditions (Group A), ii) genotypes with high production only under non- stress conditions (Group B), iii) varieties with high production only under stress conditions (Group C) and iv) genotypes with weak production under both conditions (Group D). Sio-Se Mardeh et al. (2006) evaluate drought tolerance indices in wheat genotypes under different environmental conditions and concluded that under mild drought stress conditions MP, GMP and STI were more effective to recognize genotypes. Golabadi et al. (2006) reported significant and positive correlations of Yp and (MP, GMP and STI) and Ys and (MP, GMP and STI) under both conditions as well as significant negative correlation of SSI and TOL under moisture stress environment, revealed that selection could be conducted

for high MP, GMP and STI under both environments and low SSI and TOL under moisture stress environments.

Conclusion

From the results, it may be concluded that BARI Barley7 and BARI Barley8 were the relatively tolerant and BARI Barley9 considered as susceptible varieties based on TOL and SSI. Drought tolerance indices like MP, HAM, GMP, TOL and STI had a high correlation with grain yield under stress and non-stress conditions and were recognized as appropriate indices to identify genotypes with high grain yield and low sensitivity to drought stress condition.

Declarations

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Author Contributions

M. A. Habib as an MS student planned the research and carried out the experiment. M. A. Mannan contributed to data analysis and wrote the manuscript. M. A. Karim, M. E. Miah and H. P. Singh contributed to manuscript proofreading. All authors read and approved the manuscript.

Ethics

There are no any ethical issues that may arise after the publication of this manuscript.

Conflict of Interest: There is no conflict of interest of the research work.

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Tables

Table 1. Chemical and physical properties of the soil

PWP (%)	FC (%)	SP (%)	EC (dS m ⁻¹)	Texture	Clay (%)	Silt (%)	Sand (%)
8.05	30.1	50.9	0.40	Sandy clay loam	30.78	28.00	40.51
CONTINUOUS TABLE 1							
Exchangeable Cu (mg kg ⁻¹)	Extractable Mn (mg kg ⁻¹)	Extractable Zn (mg kg ⁻¹)	Extractable Fe (mg kg ⁻¹)	Exchangeable K (meq 100g ⁻¹)	Available P (mg 100 g ⁻¹)	OC (%)	pH
2.50	8.3	1.5	2.8	0.790	0.08	0.61	6.93

PWP, FC and SP : Permanent wilting point, Field capacity, soil moisture at saturation, EC: electrical conductivity of saturated paste, OC: organic carbon

Table 2. Drought tolerance indices

Index	Formula	Reference
Stress Tolerance	$TOL=Y_p-Y_s$	Rosielle and Hamblin (1981)
Mean Productivity	$MP=(Y_p+Y_s)/2$	Rosielle and Hamblin (1981) (1981) (1981) (1981)
Geometric Mean Productivity	$GMP=(Y_p*Y_s)^{0.5}$	Fernandez (1992)
Stress Susceptibility Index	$SSI=[(1-(Y_s/Y_p))/SI]$	Fischer and Maurer (1978)
Stress Index (SI)	$SI=1-(\tilde{Y}_s/\tilde{Y}_p)$	
Stress Tolerance Index	$STI=(Y_p*Y_s)/(\tilde{Y}_p)^2$	Fernandez (1992)
Harmonic Mean	$HAM=[2*(Y_p*Y_s)]/(Y_p+Y_s)$	Kristin et al. (1997)
Yield Index	$YI=Y_s/\tilde{Y}_s$	Lin et al. (1982)
Yield Stability Index	$YSI=Y_s/Y_p$	Bousslama and Schapaugh (1984)

Y_p and Y_s : Grain yield of each genotype under control (non-stress) and drought stress conditions, respectively.

$\tilde{Y}_p$ and $\tilde{Y}_s$: Mean grain yield of all genotypes under control and drought stress conditions, respectively

Table 3 Analysis of variance of grain yield under control and drought conditions and different drought tolerance indices of six varieties of barley (MEAN SQUARES)

Source of variation	DF	Y_p	Y_s	TOL	MP	GMP
Variety	4	0.49NS	0.64*	0.21NS	0.53*	0.58*
Error	10	0.41	0.18	0.72	0.12	0.13
Total	14	0.43	0.31	0.57	0.24	0.26

THE CONTINUATION OF TABLE 3

Source of variation	DF	SSI	STI	HAM	YI	YSI
Variety	4	0.38*	0.15*	1.29*	0.15*	0.12*
Error	10	0.27	0.31	0.37	0.64	0.39
Total	14	0.20	0.65	0.63	0.89	0.31

NS and *:Non-significant and significant at 5% probability levels, respectively.

Table 4. Grain yield under control (Yp) and drought (Ys) conditions and different drought tolerance indices of barley

Variety	Yp (g plant ⁻¹)	Ys (g plant ⁻¹)	TOL	MP	GMP
BARI Barley5	3.25a-d	1.98b	1.26	2.62b	2.46bc
BARI Barley6	3.53ab	2.09b	1.43	2.81ab	2.70b
BARI Barley7	3.89a	2.98a	0.91	3.44a	3.38a
BARI Barley8	3.38a-c	2.26b	0.77	2.82ab	2.63bc
BARI Barley9	2.77a-d	1.76b	1.01	2.27b	2.20c
LSD (0.05)	1.16	0.77	NS	0.63	0.66

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Variety	SSI	STI	HAM	YI	YSI
BARI Barley5	0.89	0.54b	2.34b	0.94b	0.65a-c
BARI Barley6	0.75	0.64b	2.56b	1.00ab	0.61a-e
BARI Barley7	0.61	1.03a	3.68a	1.42a	0.78a
BARI Barley8	0.70	0.68b	2.57b	0.98ab	0.67ab
BARI Barley9	0.85	0.44b	1.90b	0.83b	0.65a-d
LSD (0.05)	NS	0.32	1.11	0.46	0.35

Table 5: Ranking of 5 barley varieties in response to different drought tolerance indices

Variety	TOL	MP	GMP	SSI	STI	HAM	YI	YSI	Average Ranking
BARI Barley5	4	4	4	4	4	4	4	3	4
BARI Barley6	5	3	2	3	3	3	2	5	3
BARI Barley7	2	1	1	1	1	1	1	1	1
BARI Barley8	1	2	3	2	2	2	3	2	2
BARI Barley9	3	5	5	5	5	5	5	4	5

Table 6. Correlation coefficient among grain yield under control and drought condition and different drought tolerant indices in 5 variety of barley

	Yp	Ys	TOL	MP	GMP	SSI	STI	HAM	YI	YSI
Yp	1.00									
Ys	0.59*	1.00								
TOL	0.66**	0.44NS	1.00							
MP	0.84**	0.76**	0.19NS	1.00						
GMP	0.69**	0.87**	-0.02NS	0.96**	1.00					
SSI	0.48NS	0.50NS	0.84**	0.04NS	-0.16NS	1.00				
STI	0.54*	0.89**	-0.13NS	0.87**	0.87**	0.17NS	1.00			
HAM	0.71**	0.83**	0.07NS	0.95**	0.95**	0.00NS	0.89**	1.00		
YI	0.18NS	0.93**	-0.39NS	0.65**	0.75**	0.43NS	0.87**	0.75**	1.00	
YSI	-0.51*	0.67**	-0.89**	0.04NS	0.25NS	-0.84**	0.37NS	0.20NS	0.70**	1.00

NS= non-significant,* and **= 5 and 1% level of significance, respectively.

Figures

Fig. 1. Production of barley in Bangladesh, 1960 -2020.
Data source: <http://apps.fas.usda.gov/psdonline/app/index.html>

Figure 1

See image above for figure legend.

Figure 2

See image above for figure legend.