Pak. J. Agri. Sci., Vol. 49(3), 307-313; 2012
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
http://www.pakjas.com.pk

EVALUATION OF DROUGHT TOLERANCE AND YIELD CAPACITY OF BARLEY (*Hordeum vulgare*) GENOTYPES UNDER IRRIGATED AND WATER-STRESSED CONDITIONS

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Twelve barley genotypes developed through different selection methods were evaluated under drought and irrigated conditions. The results of a correlation matrix revealed highly significant associations between Grain Yield (Yp) and Mean Productivity (MP), Stress Tolerance Index (STI), Geometric Mean Productivity (GMP) and Yield Index (YI) under irrigated conditions while the Mean Productivity (MP), Yield Stability Index (YSI), Stress Tolerance Index (STI), Geometric Mean Productivity (GMP) and Yield Index (YI) had a high response under stressed condition. Based on a principal component analysis, Geometric Mean Productivity (GMP), Mean Productivity (MP) and Stress Tolerance Index (STI) were considered to be the best parameters for selection of drought-tolerant genotypes. The 2-row barley genotypes B-07023 and B-07021 performed better in yield response under drought conditions and were more stable under stress conditions. Furthermore, drought stress reduced the yield of some genotypes while others were tolerant to drought, suggesting genetic variability in this material for drought tolerance.
Keywords: Barley (*Hordeum vulgare* L.), correlation matrix, drought indices, principal component analysis, yield components

INTRODUCTION

In Pakistan, wheat is the staple food although its production cannot meet the growing demand. Wheat production in Pakistan amounted to 23,864,000 tons derived from 9,042 thousand ha but the demand was 25 million tons during 2009-2010 (MINFAL, 2010), resulting in a shortfall. The national production is insufficient to feed a population of 180 million people currently; the gap between supply and demand is increasing due to the rapid population growth rate. To balance the gap, another cereal crop is required as a staple food to decrease the pressure on the wheat crop. The cropping pattern in the wheat zone is wheat-rice, wheat-cotton for irrigated areas and wheat-peanut for rain-fed areas. Other abiotic factors leading to low yields in Pakistan are salinity, and erratic, extreme weather conditions. Kilic *et al*. (2010) reported that due to earliness and its ability to escape terminal drought-stress, barley would be a suitable crop in areas where irrigation is poorly available. Potentially, barley can give more stable yields than wheat in both saline and rain-fed areas. Anjum *et al*. (2006) indicated that wheat flour could be blended with 20% barley flour to make chapatti. Globally, barley is ranked as the fourth major cereal crop after maize, wheat and rice in the world (Kilic *et al*., 2010). Unfortunately, the cultivated area of barley in Pakistan is only 80,000 ha and its production about 78,000 tons (MINFAL, 2010). Low yields are partly caused by the unavailability of high-yielding stress-tolerant barley cultivars. Under rainfed conditions, barley frequently suffers from drought resulting in a significant loss of yield and decreased revenue: for example, the USDA estimated a crop loss of 21% due to drought and heat stress over a period of 55 years from 1948-2002 in Russia (USDA-NASS, 2004). Drought, the result of low precipitation or high temperature, is one of the main problems underlying the success of modern agriculture around the globe and is one of the most important environmental factors that affect the growth, development and production of plants, particularly cereals, although the stage of development exerts an influence (Martiniello and Teixeira da Silva, 2011; Hasanuzzaman *et al*., 2012; Hossain and Teixeira da Silva, 2012). Several research findings also indicated that not only high temperature and drought have an effect on spring crops, but also that low temperature is one of the major constraints of late sowing in sub-tropical climates (Hossain *et al*., 2012a,b). The development of stress-tolerant varieties is a judicial way of mitigating the adverse effects of abiotic stresses (Ruan and Teixeira da Silva, 2011). However, the adverse effect of drought and high temperature on a crop can be minimized by avoiding stress at the most sensitive stages of crop development such as reproductive and grain-filling periods, usually achieved by adjusting seeding date or by growing early-maturing varieties. However, as abiotic stresses are unpredictable, the best way to cope with them is to develop tolerant varieties that perform well under stress and under optimum environments (Hossain and Teixeira da Silva, 2012).

In the context of these problems, a study was carried out to evaluate indices for selecting the genotype that are higher yielding and more stable under rain-fed conditions. This study also aimed to provide breeders with information to develop drought-tolerant lines in a breeding program. This follows the logic used by Golabadi *et al*. (2006), Talebi *et al.* (2009) and Khodarahmpour *et al*. (2011) who used different selection indices (viz., Tolerance Index (TI), Mean Productivity (MP), Stress Susceptibility Index (SSI), Geometric Mean Productivity (GMP), Stress Tolerance Index (STI), Yield Stability Index (YSI), Yield Index (YI)) to evaluate drought tolerance. This would also be helpful to evaluate the association between yield and yield components under drought and normal irrigation conditions.

MATERIALS AND METHODS

Research was carried out at an experimental station of the Wheat Research Institute, Faisalabad (longitude 73° and 74°East, latitude 30° and 31.5° North, at an elevation of 605 feet above sea level) during 2009-10. The weather conditions during the crop season are presented in Figure 1.

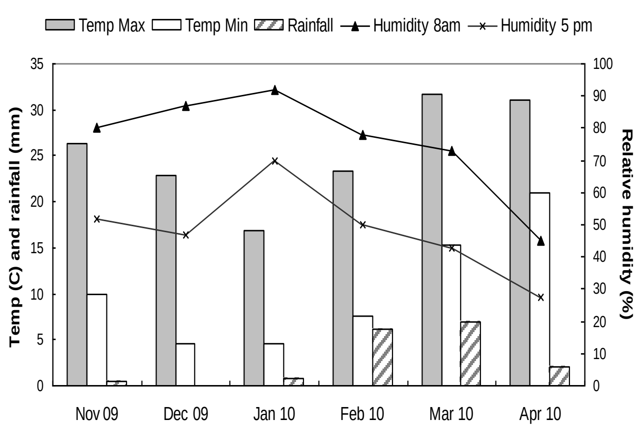

Figure 1. Minimum, maximum temperature, rainfall and average relative humidity during the growing season of barley crop at the Wheat Research Institute, Faisalabad in 2009-10.

Two plots having normal irrigation and no irrigation (i.e. stress) were maintained at the same location. In 1st treatment, three irrigations were applied in normal plot and in 2nd treatment, no irrigation was applied. During the crop season from 09th November to 10th April, the data of total rainfall along with humidity were collected (Fig. 1). The experiment was conducted in a randomized complete block design with three replications using 11 advanced lines and one check Haider-93 (Table 1). Plot size was 6 m^2 (1.2 × 5 m) having 4 rows with a row-to-row distance of 30 cm. The seed rate was 12 g for each row and sowing was done by the *rabi* drill. A full dose of fertilizers was applied at the time of sowing at a rate of 50 kg nitrogen ha^{-1} and 50 kg phosphorus ha^{-1}.

Table 1. List of barley genotypes used in this study

V.CODE	Pedigree	Characters
B-07002	MOROC	2 Rows
B-07006	GLORI-BAR/COME//LIGNEE/3/S.P-B/4/SLLO	6 Rows
B-07012	CIRUELO	6 Rows
B-07021	TRIUMPH-BAR/TYRA	2 Rows
B-07022	GOB 12DH/CANELA/3/ARUPO/K 8755//MORA	2 Rows
B-07023	GOB/ALELI//CANELA/3/MSEL	2 Rows
B-08018	PETUNIA 2/3/GLORIA-BAR/COME//ESPERANZA/4/CABUYA	6 Rows
B-08019	CHENGDU 105/4/EGYOT 4/TERAN 78//P.STO/3/QUINA/5/ABETO//GLORIA-BAR/COME/3/SEN/4/MJA	6 Rows
B-08021	BBSC/CONGONA//BLLU/3/CIRU	6 Rows
B-08023	PETUNIA2/3/TOCTE/TOCTE//BERROS/4/PENCO/CHEVRON-BAR	6 Rows
B-08027	TOCTE/3/MJA/BRB2//QUINA/4/CIRU	6 Rows
CHECK	HAIDER-93	6 Rows

***Crop parameters*:** Agronomic traits (viz. 50% days to heading, days to maturity and plant height) were recorded at the appropriate phonological stages. All drought tolerance indices were calculated after threshing by using the following formulae:

Stress Tolerance Index $STI = Ypi \times Ysi / Yp^2$ (Fernández, 1992)

Mean Productivity $MP = YPi + YSi / 2$ (Rosielle and Hamblin, 1981)

Geometric Mean Productivity $GMP = \sqrt{Ypi \times Ysi}$ (Fernández, 1992)

Stress Tolerance $TOL = (Ypi - Ysi)$ (Rosielle and Hamblin, 1981)

Stress Susceptibility Index $SSI = [1 - (Ysi) / (Ypi)] / SI$;
$SI = 1 - (Ys / Yp)$ (Fischer and Maurer, 1978)

Yield Stability Index $YSI = Ysi / Ypi$ (Bouslama and Schapaugh, 1984)

Yield index $(YI) = Ysi/Ys$ (Gavuzzi *et al.*, 1997; Lin *et al*., 1986)

In these equations, YPi and Ysi indicate the yield of a given genotype under normal and stressed conditions while Yp and Ys are the average yield of all genotypes under normal and stressed conditions, respectively. All data were subject to analyses using a computer software program MSTAT-C, including analysis of variance, mean comparison of traits and correlation matrix. Principal component analysis (PCA) was used to classify and screen genotypes, also with MSTAT-C.

RESULTS

All indices were highly significantly different for genotypes except for plant height and days to maturity under irrigated condition but differences were highly significant for all parameters under drought conditions (Table 2) indicating the genetic variability.

Correlation analysis between drought indices and yield components showed that grain yield under irrigated and stress condition was positively correlated with MP, YSI, STI, GMP and YI, (Table 3). Furthermore, correlation analysis between the various stress tolerant indices used in this study provided interesting observations. Grain yield was highly significantly correlated with grain yields under normal (Yp) and stressed (Ys) conditions (Table 5). A negative correlation was observed between SSI and Ys under stress (Table 5). MP was highly positively significantly correlated with Ys and Yp (Table 5). Another important drought parameter is stress tolerance (TOL), which was not significantly associated with Ys, unlike Ys, which was highly positively significantly correlated with YSI (Table 5). Fernandez (1992) originally introduced STI and used it to identify tolerant genotypes in wheat that gave high yield under both stressed and normal conditions. STI was highly positively significantly correlated with Yp and Ys (Table 5); there was a similar association between GMP and Yp, Ys and MP; moreover, a strong association was observed between YI and Yp and Ys. The first two PCAs accounted for about 99.49% of total variation, (Table 6). The first PCA, which accounted for 76.217% of variation among all variables, was positively correlated with GMP, Ys, YI, MP, STI, YP and YSI (Table 7). Thus, the first principal component indicates the main yield potential in drought stress. The second PCA accounted for 23.3% of all variation and was highly positively correlated with TOL and SSI (Table 7). It is thus a stress-tolerant dimension that is capable of separating stress-tolerant from non-stress tolerant genotypes.

Table 2. Analysis of variance for barley under normal and stress conditions

	DF	MEAN SQUARE					
IRRIGATED		**GY**	**SL**	**SL/S**	**DH**	**DM**	**PH**
REPLICATION	2	698.78	0.285	3.014	1.861	0.694	9.468
GENOTYPES	11	137022.38**	2.340**	658.197**	9.543**	0.899NS	64.209NS
ERROR	22	2517.99	0.246	1.44	0.467	1.210	30.366
DROUGHT	DF						
REPLICATION	2	4117.75	0.46	0.054	3.694	0.250	8.694
GENOTYPES	11	74266.364**	3.143*	395.929**	33.846**	1.583**	55.475**
ERROR	22	1109.295	0.201	1.865	0.391	0.492	9.331

GY: Grain yield, SL: Spike length, SL/S: Spike length per spike, DH: Days to 50% heading, DM: Days to maturity and PH: Plant height

Table 3. Simple correlation coefficients between drought indices and GY, SL, SL/S, DH, DM, PH, of barley genotypes under normal and stress conditions

	SSI	MP	TOL	YSI	STI	GMP	YI
GYDR	-0.838**	0.925**	0.085NS	0.843**	0.871**	0.976**	0.994**
GY IR	-0.345*	0.960**	0.644**	0.344*	0.889**	0.896**	0.772**
SL DR	-0.375*	0.369*	0.051NS	0.361**	0.249NS	0.397**	0.416*
SL IR	-0.262 NS	0.292NS	0.077NS	0.253NS	0.201NS	0.306NS	0.288NS
SL/S DR	0.593**	-0.768**	-0.188NS	-0.588**	-0.711**	-0.793**	-0.805**
SL/S IR	0.510**	-0.723**	-0.254NS	-0.506**	-0.668**	-0.734**	-0.732**
DH DR	0.492**	-0.496**	-0.033NS	-0.477**	-0.467**	-0.534**	-0.594**
DH IR	0.596**	-0.263NS	0.243NS	-0.603**	-0.233NS	-0.351*	-0.440*
DM DR	0.553**	-0.445**	0.090NS	-0.546**	-0.473**	-0.482**	-0.498**
DM 1R	0.374*	-0.306NS	0.151NS	-0.401*	-0.268NS	-0.345*	-0.391*
PH DR	0.193NS	0.219NS	0.443**	-0.206NS	0.159NS	0.144NS	0.072NS
PH IR	-0.166NS	-0.116NS	0.206NS	0.156NS	-0.151NS	-0.062NS	-0.012NS

**: Significant at 5% levels of probability; **: highly Significant at 1% levels of probability*
DR: drought condition, IR: irrigated condition
GY: Grain yield, SL: Spike length, SL/S: Spike length per spike, DH: Days to 50% heading, DM: Days to maturity and PH: Plant height

Table 4. Drought indices of 12 barley genotypes under normal and stress conditions

Genotypes	Yp	Ys	SSI	MP	TOL	YSI	STI	GMP	YI
B-07002	941.00	463.67	0.819	702.33	477.33	0.495	0.0015	660.19	1.31
B-07006	1075.00	370.67	1.059	722.83	704.33	0.345	0.0017	630.43	1.05
B-07012	789.67	226.00	1.155	507.83	563.67	0.287	0.0012	421.96	0.638
B-07021	1235.33	562.67	0.881	899.00	672.67	0.457	0.0021	832.98	1.595
B-07022	1066.33	456.33	0.926	761.33	610.00	0.428	0.0018	697.57	1.29
B-07023	1256.67	605.00	0.871	930.83	651.67	0.482	0.0022	871.06	1.71
B-08018	624.33	121.67	1.296	373.00	502.67	0.199	0.0009	273.29	0.34
B-08019	567.67	255.33	0.891	411.50	312.33	0.450	0.0010	379.99	0.72
B-08021	849.33	201.33	1.237	525.33	648.00	0.237	0.0012	413.45	0.57
B-08023	965.33	221.67	1.248	593.50	743.67	0.228	0.0014	459.76	0.62
B-08027	831.00	278.00	1.077	554.50	553.00	0.335	0.0013	480.55	0.79
CHECK	897.00	481.67	0.748	689.33	415.00	0.539	0.0016	656.84	1.37

Yp: grain yield under normal condition, Ys: grain yield under stress condition, SSI: Stress Susceptibility Index, MP: Mean Productivity, TOL: Tolerance Index, YSI: Yield Stability Index, STI: Stress Tolerance Index, GMP: Geometric Mean Productivity, YI: Yield Index

Table 5. Correlation coefficients between drought indices

	Yp	Ys	SSI	MP	TOL	YSI	STI	GMP	YI
YP	1.000								
YS	0.808**	1.000							
SSI	-0.374NS	-0.835**	1.000						
MP	0.965**	0.934**	-0.598*	1.000					
TOL	0.683NS	0.121NS	0.406NS	0.467NS	1.000				
YSI	0.392NS	0.848**	-0.999**	0.615*	-0.392NS	1.000			
STI	0.965**	0.920**	-0.573*	0.994**	0.484NS	0.591*	1.000		
GMP	0.910**	0.979**	-0.717**	0.987**	0.318NS	0.733**	0.977**	1.000	
YI	0.807**	1.00**	-0.836**	0.934**	0.119NS	0.849**	0.920**	0.979**	1.000

**= Significant at 5% level of probability; **=highly Significant at 1% level of probability*

Yp: grain yield under normal condition, Ys: grain yield under stress condition, SSI: Stress Susceptibility Index, MP: Mean Productivity, TOL: Tolerance Index, YSI: Yield Stability Index, STI: Stress Tolerance Index, GMP: Geometric Mean Productivity, YI: Yield Index

Table 6. Latent roots, percentage variance and cumulative variance values of principal components analysis (PCA)

PCA #	Latent roots	Percentage variance	Cumulative variance
PCA 1	6.860	76.217	76.217
PCA 2	2.095	23.281	99.499
PCA 3	0.034	0.382	99.881
PCA 4	0.010	0.106	99.987
PCA 5	0.001	0.007	99.994
PCA 6	0.001	0.006	100.000

PCA = Principal components analysis

Table 7. Effect of principal component analysis on drought indices

DROUGHT INDICES	PCA 1	PCA 2	PCA 3	PCA 4	PCA 5	PCA 6
Yp	0.335	0.332	-0.115	0.183	0.110	-0.143
Ys	0.378	-0.085	0.291	0.224	0.121	-0.187
SSI	-0.294	0.435	0.534	0.054	0.578	0.310
MP	0.371	0.163	0.060	0.211	0.121	-0.171
TOL	0.095	0.665	-0.555	0.030	0.032	-0.007
YSI	0.299	-0.426	-0.397	-0.116	0.68	0.297
STI	0.367	0.179	0.225	-0.882	-0.042	-0.058
GMP	0.380	0.053	0.109	0.162	-0.399	0.809
YI	0.378	-0.087	0.292	0.225	0.006	-0.269

PCA = Principal components analysis; Yp: grain yield under normal condition, Ys: grain yield under stress condition, SSI: Stress Susceptibility Index, MP: Mean Productivity, TOL: Tolerance Index, YSI: Yield Stability Index, STI: Stress Tolerance Index, GMP: Geometric Mean Productivity, YI: Yield Index

DISCUSSION

The results in Table 4 show that yield selected in normal conditions can increase yield both for non stress and stress conditions. Narouie Rad *et al*. (2009) also reported same results in lentil crop. On the basis of this index (YP), line B-07023 gave high grain yield under both normal and rain-fed conditions, followed by line B-07021. Sio-Se Mardeh *et al*. (2006), Bansal and Sinha (1991) and Clarke *et al.* (1992) used SSI to evaluate drought tolerance genotype in wheat and found variation in SSI for genotypes which they could rank. Golabadi *et al*. (2006) and Khayatnezhad *et al*. (2010) reported that lowest SSI values were associated with greater stress tolerance. SSI has been regularly used to identify sensitive and tolerant genotypes in cereal crops. In this study, genotype B-07023 with an SSI value of 0.871 showed a low index among all genotypes and performed better in both environments. Thus, SSI is favorable for selection of drought tolerance genotype. Similar results were reported by Golabadi *et al.* (2006) and Talebi *et al.* (2009), who reported that SSI was a useful index for selection of better genotypes under drought conditions. Cengiz and Ilhan (1998) reported that MP had a positive and significant relation with grain yield under drought conditions. When selection was based on MP, again B-07023 and B-07021 (Table 4) were the best performing genotypes under a stress environment. The negative association between TOL and Ys (Table 5) suggests that selection based on TOL will result in reduced yield under stress conditions. Ramírez and Kelly (1998), Zangi (2005), Mardeh *et al*. (2006) and Khayatnezhad *et al.* (2010) also indicated that a larger TOL value showed more sensitivity to stress in wheat crop; thus, a smaller value is favored. Mohammadi *et al*. (2010) showed YSI to be a more useful index to discriminate drought-resistant from drought-susceptible genotypes; therefore, breeders should select this parameter for selection of stress-tolerant genotypes. Based on YSI values, B-07023 (0.482) and B-070214 (0.457) were the best barley genotypes under stress (Table 4) while genotype B-08O18 had a low YSI under both conditions and was most susceptible for drought. A high STI value indicates higher stress tolerance and high yield potential (Zangi, 2005; Khodarahmpour *et al*., 2011). Based on STI, barley genotype B-07023 with an STI value of 0.0022, followed by B-07021 with a value of 0.0021, showed a good response for yield under rain-fed conditions. GMP is another index which is often used by breeders to evaluate high-yielding genotypes under stressed and normal conditions (Ramírez and Kelly, 1998). Our results are supported by those of Narouie Rad *et al.* (2009) who reported that if a significant correlation between MP and GMP exists, then GMP can reflect performance under stress a little better than MP. The highest values of GMP, recorded for genotypes B-07023 (871.05) and B-07021 (832.97) (Table 4), show that both these genotypes performed better for high yield under drought conditions. YI can be used as a selection criterion (Khodarahmpour *et al*., 2011) although it only ranks cultivars on the basis of Ys. Nouri *et al.* (2011) reported PCA to be a better approach than correlation analysis to identify better genotypes under normal and stressed conditions in cereal crops. Farshadfar and Sutka (2002) and Khodarahmpour *et al*. (2011) stated that genotypes with high PCA1 and low PCA2 values are suitable for both stressed and non-stressed environments. Genotype B-07023 had the highest positive value in PCA-1 and the lowest value of PCA-2 followed by genotype B-07021 (Table 8); thus, they were selected as drought-tolerant genotypes. Kaya *et al.* (2002), Mardeh *et al*. (2006), Golabadi *et al*. (2006) and Khodarahmpour (2011) reported that a lower PCA1 and a larger PCA2 value represent susceptible genotypes. Based on this association, lines B-08018 and B-08021 were most susceptible to drought as they had low PCA1 and larger PCA2 values. Based on PCA and highest values of YS, MP, GMP, and STI vs. PCA, genotypes B-07023 and B-0702 performed best under both environments (Yp and Ys). Based

Table 8. Effect of Principal components analysis (PCA) on barley genotypes

Genotypes	PCA 1	PCA 2	PCA 3	PCA 4	PCA 5	PCA 6
B-07002	1048	740	-124	547	-2	190
B-07006	1075	945	-294	557	23	160
B-07012	752	724	-261	389	27	96
B-07021	1341	1001	-206	698	4	235
B-07022	1153	883	-206	591	7	193
B-07023	1389	997	-178	724	-0.97	249
B-08018	545	608	-262	280	37	43
B-08019	614	462	-98	320	3	107
B-08021	774	804	-322	399	39	82
B-08023	873	918	-33	449	47	86
B-08027	825	737	-235	427	20	120
HAIDER 93	1028	680	-80	538	-7	193

PCA = Principal components analysis

on the correlation matrix and PCA analysis, the drought indices GMP, MP, YI and STI could be effectively used to evaluate drought-tolerant genotypes. Mohammadi *et al*. (2010) preferred four indices (MP, GMP and STI GMP and STI) for evaluating drought-tolerant wheat genotypes.

***Conclusion*:** Highly significant variation in genotypes was observed for all characters in both stressed and unstressed conditions. This indicates that the magnitude of differences in genotypes was sufficient to select them against drought. MP, STI, GMP and YI were highly correlated with grain yield under both conditions, suggesting that these indices were the most suitable to screen drought-tolerant genotypes.
This study also revealed that under stressed condition, the yield of some genotypes was significantly reduced while other genotypes showed tolerance against drought, confirming the genetic variability in this germplasm. Therefore, breeders should select better genotypes based on mainly four indices (GMP, MP, STI and YI) under stressed conditions and compare results with performance under irrigated conditions by using different methods of selection.

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