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Evaluation of Drought Tolerance Indices for Selection of Barley (*Hordeum vulgare* L.) Cultivars under Different Levels of Irrigation

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A B S T R A C T

The field experiment were conducted at Research Farm of CCS Haryana Agricultural University, Hisar, India (29°10'N latitude, 75º46'E longitude and 215.2 M altitude) during *Rabi* season of 2010-11 and 2011-12. The experiment was laid out in split plot design with four levels of irrigations (I_o– no irrigation, I_1-one irrigation at 45 DAS, I_2-two irrigations at 45 and 85 DAS and I_3- three irrigations at 45, 85 and 105 DAS) in main plot and three genotypes (V_1- RD 2552, V_2 - BH 902 and V_3- DWRUB 52) in sub plots with three replications. On the basis of two years pooled data revealed that soil moisture stress causes low grain as well as straw yield, by inducing low 1000-grain weight and number of tillers m^{-2}. The grain yield improvement in barley with three irrigation levels was 70.5 percent over no irrigation. Test weight, effective tillers, grain and straw yield were significantly affected by irrigation levels. Among highest grain yield was recorded under DWRUB 52 and BH 902 during 2010-11 and 2011-12, respectively. The study of correlation coefficients revealed that based on TOL and SSI, RD 2552 was found as most drought sensitive genotype. MP, STI, GMP, SSI and HARM had the most significant correlation with grain yield.

Introduction

Barley (*Hordeum vulgare* L.) is the world's fourth most important cereal crop, which is hardy and used for producing malt for brewing industries, as human food and as animal feed. Barley being a fast growing crop with high biomass in early stages can be cultivated as a dual purpose cereal, which can permit forage production in early stage in addition to the grain yield later on (Singh *et al.*, 2016). Barley is having a remarkable area of 49 percent under rainfed situation, resulting in failure or poor stand and yield. But the adaptation of barley is better than wheat and other crops in water stress conditions. Furthermore due to climate change the uncertainty in rainfall pattern is also emerging a great challenge to sustain the yield level of barley. For this reason, the prediction of amount and distribution of rainfall in each year is very difficult. In regard with this problem a study was conducted to assess drought indices and crop parameters so that selection genotypes that are more stable in dry and semi dry regions. Khokhar *et al.*, (2012) suggested that for selecting better genotypes under stressed condition mainly four indices *i.e.* Geometric Mean Productivity (GMP), Mean Productivity (MP) and Stress Tolerance Index (STI) should be used and compared with performance under irrigated condition.

In addition, Jafari *et al.,* (2009) reported that GMP, MP and STI showed the highest correlation with grain yield under both optimal and stress conditions. Therefore, the present investigation was planned to determine drought tolerant and high-yielding genotypes under different levels of irrigation.

Materials and Methods

The field experiments were conducted at Research Farm of CCS Haryana Agricultural University, Hisar, India (29°10'N latitude, 75°46'E longitude and 215.2 M altitude) during *Rabi* season of 2010-11 and 2011-12. The soil of the field was sandy loam in texture, slightly alkaline in pH (7.9), low in organic carbon, poor in available nitrogen and medium in available phosphorus and available potassium. The experiment was laid out in split plot design with four levels of irrigations (I_o– no irrigation, I_1-one irrigation at 45 DAS, I_2-two irrigations at 45 and 85 DAS and I_3-three irrigations at 45, 85 and 105 DAS) in main plot and three genotypes (V_1-RD 2552, V_2- BH 902 and V_3- DWRUB 52) in sub plots with three replications.

The crop was sown on 18th November during both the years (2010-11 and 2011-12) using the seed rate of 100 kg/ha at a row to row spacing of 23 cm. To control weeds one hand weeding was done at 30 DAS in all the treatments but in no irrigation treatment (I_0) one more hand hoeing was done at 50 DAS to control weeds and check evaporation from soil. Other management practices were adopted as per recommendations given by CCS Haryana Agricultural University, Hisar for barley crop. Data on number of effective tillers, number of grains/ear head, 1000 grain weight, grain yield and straw yield were recorded by using standard procedure. The crop was harvested on 4th April in 2010-11 and 11th April in 2011-12. During crop season the highest (33.2°C) and lowest (11.2°C) weekly mean maximum temperature was recorded in 13th and 1st standard weeks, respectively in 2010-11 and highest (35.6°C) and lowest (17.0°C) weekly mean maximum temperature was recorded in 14th and 2nd standard weeks, respectively in 2011-12. Whereas, weekly mean minimum temperature, the highest (15.5°C) and lowest (3.1°C) were recorded during 46th and 50th standard week, respectively during 2010-11 and during 2011-12, the highest minimum temperature (19.0°C) and lowest (1.2°C) were recorded during 14th and 52nd standard week, respectively. During the crop season of 2010-11, the rainfall of 43.6, 24.2, 8.2, 6.7, 3.6, 4.6 and 10.3 mm was received in 52nd, 7th, 8th, 9th, 10th and 14th standard weeks, respectively. While during 2011-12 only 14.4 mm rainfall was received in the 3rd standard week.

The brightest week during the crop season of 2010-11 was 11th week with 9.5 hrs per day, whereas, 1st week was the least bright with 1.2 hrs per day. During 2011-12, 9th week was brightest week with 9.0 hrs per day, whereas, 1st week was the least bright with 1.8 hrs per day. Evaporative demand was highest in 14th standard week with 4.5 mm per day, whereas the lowest open pan evaporation was recorded in 2nd standard week with 0.7 mm per day during 2010-11 and during 2011-12, the highest evaporative demand was recorded in 14th standard week with 5.9 mm per day, whereas, the lowest open pan evaporation was recorded in 1st standard week with 0.8 mm per day. Eight selection indices mean productivity (MP), stress tolerance index (STI), geometric mean productivity (GMP), tolerance index (TOL), stress susceptibility index (SSI), harmonic mean (HARM), yield index (YI) and yield stability index (YSI) were estimated for each genotype based on grain yield under stress (Ys) and non-stress (Yp) conditions. Quantitative drought resistance indices were calculated using the following formulas:

$MP = \frac{Yp+Ys}{2}$ (Rosielle and Hambline, 1981)

$STI = \frac{Yp \times YS}{\bar{Y}p^2}$ (Fernandez, 1992)

$GMP = \sqrt{Yp \times Ys}$ (Fernandez, 1992)

TOL = *Yp-Ys* (Rosielle and Hambline, 1981)

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

$HARM = \frac{2(Yp \times Ys)}{Yp+Ys}$ (Kristin *et al.*, 1997)

$YI = \frac{Ys}{\bar{Y}s}$ (Lin *et al.*, 1986; Gavuzzi *et al.*, 1997)

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

$Reduction\ (\%) = \left(\frac{Yp - Ys}{Yp}\right) \times 100$ (Choukan *et al.*, 2006)

Where, Yp is the yield under non-stress condition; Ys the yield under stress; and $\overline{Yp}$ and $\overline{Ys}$ is the mean yields of all genotypes under non-stress and stress condition, respectively and $1 - \left(\frac{\overline{Ys}}{\overline{Yp}}\right)$ is the stress intensity (SI).

Results and Discussion

Drought tolerance indices

DWRUB 52 and RD 2552 cultivars had the highest grain yield in non-stress and stress conditions, respectively (Table 4). The average grain yield under non-stress condition was 49.4 q/ha while in stress condition it was 29.8 q/ha, with a decrease of 60.3 %. Stress intensity (SI) has been given in stress susceptibility index (SSI) formula that it can be at most 1. All the genotypes were found with SSI values lower than unit, so can be identified as lower drought susceptibility and high yield stability genotypes (Table 2). But according to SSI values, DWRUB 52 and RD 2552 genotypes recorded with lowest (0.59) and highest (0.62) values, respectively, which were considered as genotypes with lowest and highest drought susceptibility, respectively in stress and non-stress conditions. Zare (2012) also reported similar results for wheat genotypes. The lowest (37.80) and highest (38.62) TOL was observed for BH 902 and DWRUB 52 cultivar, respectively (Table 4). Similar results were also reported by Nazari and Pakniyat (2010), who reported that among stress tolerance indicators, a larger TOL value represents the sensitive genotypes under drought condition. Based on STI, DWRUB 52 cultivar followed by RD 2552 with the highest values were considered to be tolerant genotypes, whereas the BH 902 with the lowest STI was intolerant (Table 4). These results indicated that the genotypes with high STI usually have high difference in yield in two different conditions.

In general, similar ranks for the genotypes were observed by GMP and MP indices as well as STI, which suggested that these three indices were equal for selecting genotypes (Table 3). Based on data (Table 3), genotype DWRUB 52 had the highest MP (40.16) and GMP (38.62) values showing more stability of this genotype in drought condition, while BH 902 with lowest MP (38.91) and GMP (37.80) values was undesirable for less irrigated or rainfall areas. These results are in conformity with Ajalli and Salehi (2012), who evaluated drought stress indices in barley.

Mohammadi *et al.*, (2010) showed yield stability index (YSI) to be a more useful index to discriminate drought-resistant from drought-susceptible genotypes. Based on YSI values, the highest and lowest YSI index belong to BH 902 and DWRUB 52 cultivars, respectively (Table 3). YI can be used as a selection criterion, although it only ranks cultivars on the basis of Ys (grain yield in stressed plot). RD 2552 cultivar had the highest YI and Ys (Tables 3 and 4). To determine the most desirable drought tolerance criteria, the correlation coefficient between Yp, Ys and other indices of drought tolerance were calculated (Table 5). Correlation coefficient of Ys and Yp with TOL (-0.78 and 0.97, respectively), SSI (-0.86 and 0.93, respectively), YI (0.99 and -0.59, respectively) and YSI (0.85 and -0.93, respectively) showed that MP, STI, GMP and HARM indices were better predictor of Yp and Ys than TOL, SSI, YI and YSI. These results agree with the finding of Khokhar *et al.,* (2012) and Yazdchi (2008) in barley crop.

TOL index was significantly correlated with grain yield in non-stress condition and had negative correlation with grain yield under stress condition, having in mind that small value of TOL is desirable. These results agree with the results of Shirani Rad and Abbasian (2011) in winter rapeseed cultivars that TOL was strongly correlated with yield under non-stress condition and had negative and non-significant correlation with yield under stress condition. Selection for this parameter would tend to favor low yielding genotypes. TOL and SSI indices had significantly positive correlation with each other (r = 0.99).

YSI had significantly negative correlation with SSI and TOL (r = -0.99 and r = -0.99, respectively). Thus a big value of this index is desirable. HARM index was significantly positively correlated with MP and GMP indices.

HARM can be considered to reflects a little better performance under stress than MP and GMP due to more correlation of HARM with grain yield in stressed condition (r = 0.53). But MP can be considered to reflects a little better performance under unstressed condition than HARM due to more correlation of MP with grain yield in unstressed condition (r = 0.93). STI was perfectly correlated with MP, GMP and HARM. Similar results were also reported by Bonea and Urechean (2011). The greater the TOL value, the larger the yield reduction under stress condition and the higher the drought sensitivity. Therefore, based on TOL and SSI, RD 2552 was found as most drought sensitive genotype. MP, STI, GMP, SSI and HARM had the most significant correlation with grain yield.

Yield attributes

The data given in table 1 revealed that on pooled mean basis the number of effective tillers differed significantly by different levels of irrigation during both the years and each increment in irrigation number improved the effective tillers.

The maximum tillers/m^2 (403) were recorded with three irrigations, which were significantly higher than no and one irrigation whereas, the difference between two and three irrigations was found non-significant. Effective tillers were increased by 15.9, 24.4 and 26.3 percent with one, two and three irrigations, respectively as compared to no irrigation. This increase in number of tillers per m^2 might be due to availability of water at critical stages with more uptake of nutrients (Sarwar *et al.,* 2010; Gill *et al.,* 2013 and Baloch *et al.,* 2014).

Among genotypes, the maximum number of effective tillers was recorded in DWRUB 52 (412) which was significantly higher than BH 902 (360) and RD 2552 (345). The results indicated that inherent tillering potential per unit area of DWRUB 52 was relatively higher than that of BH 902 and RD 2552. The two row barley had higher spikes number per unit area compared to six row types (Sharma and Verma, 2010). Genotypic variation in tillers production was also reported by Hossain (2001) and Kakar *et al.,* (2007).

Table.1 Effect of irrigation levels on yield and yield attributes of barley genotypes

Treatments	Grain yield (q/ha)			Straw yield (q/ha)			Effective tillers/m^2			Grains/ear head			1000-grains weight (g)		
	2010-11	**2011-12**	**Pooled**	**2010-11**	**2011-12**	**Pooled**	**2010-11**	**2011-12**	**Pooled**	**2010-11**	**2011-12**	**Pooled**	**2010-11**	**2011-12**	**Pooled**
Irrigation levels															
I_0 – No Irrigation	39.1	20.5	29.8	36.2	20.2	28.2	327	312	319	37.1	36.0	36.5	40.6	42.7	41.7
I_1 -One Irrigation	48.1	44.1	46.1	64.3	64.0	64.1	360	379	370	39.0	36.4	37.7	42.5	43.7	43.1
I_2 - Two Irrigations	49.9	48.8	49.4	65.8	70.2	68.0	379	415	397	40.5	40.9	40.7	44.2	44.7	44.4
I_3 – Three Irrigations	51.8	49.7	50.8	66.6	69.6	68.1	387	418	403	41.7	39.8	40.7	44.1	44.7	44.4
SE(m)	0.62	0.69	0.36	1.25	0.63	0.89	10.13	7.94	5.11	0.87	2.05	1.07	0.66	0.39	0.41
CD at 5%	**2.12**	**2.39**	**1.24**	**4.32**	**2.17**	**3.06**	**34.9**	**27.4**	**17.63**	**2.99**	**N.S**	**N.S**	**2.26**	**1.36**	**1.42**
Varieties															
V_1 – RD 2552	46.3	41.3	43.8	63.6	57.3	60.5	331	359	345	43.9	45.3	44.6	37.9	42.7	40.3
V_2 – BH 902	45.0	42.0	43.5	59.0	56.9	57.9	364	355	360	47.8	42.6	45.2	41.7	43.7	42.7
V_3 –DWRUB 52	50.5	39.0	44.8	52.1	53.8	52.9	395	429	412	27.0	26.9	27.0	49.0	45.4	47.2
SE(m)	1.45	0.65	0.76	1.43	0.95	0.90	4.48	7.55	4.92	0.50	2.04	1.06	0.42	0.34	0.30
CD at 5%	**4.35**	**1.95**	**N.S**	**4.29**	**2.84**	**2.69**	**13.4**	**22.6**	**14.7**	**1.5**	**6.11**	**3.18**	**1.26**	**1.03**	**0.90**

Table.2 Interaction effect of irrigation levels and genotypes on grain yield of barley (pooled data of 2010-11 and 2011-12)

Irrigation levels	Varieties			
	V_1 – RD 2552	**V_2 – BH 902**	**V_3 –DWRUB 52**	**Mean**
I_0 – No Irrigation	30.41	29.73	29.25	**29.79**
I_1 -One Irrigation	46.31	44.94	47.12	**46.12**
I_2 - Two Irrigations	48.94	48.08	51.07	**49.36**
I_3 – Three Irrigations	49.55	51.25	51.59	**50.79**
Mean	**43.80**	**43.50**	**44.76**	
CD for Irrigation levels (A)	1.24			
CD for genotypes (B)	NS			
Factor B at same level of A	**NS**			
Factor A at same level of B	**NS**			

Table.3 Drought tolerance indices for barley genotypes

Genotypes	MP			GMP			YI			YSI			HARM		
	2010-11	2011-12	Pooled	2010-11	2011-12	Pooled	2010-11	2011-12	Pooled	2010-11	2011-12	Pooled	2010-11	2011-12	Pooled
V_1 – RD 2552	43.53	35.82	39.68	43.12	33.34	38.56	0.76	0.47	0.62	0.78	0.46	0.62	42.72	31.04	37.48
V_2 – BH 902	42.18	35.64	38.91	42.11	31.78	37.80	0.80	0.40	0.60	0.90	0.38	0.62	42.04	28.35	36.73
V_3 –DWRUB 52	47.89	32.44	40.16	46.95	29.49	38.62	0.79	0.39	0.59	0.70	0.42	0.57	46.05	26.83	37.14

Table.4 Drought tolerance indices for barley genotypes

Genotypes	STI			TOL			SSI			Reduction (%)			Ys (Grain yield of stressed plot)			Yp Grain yield of unstressed plot)		
	2010-11	2011-12	Pooled	2010-11	2011-12	Pooled	2010-11	2011-12	Pooled	2010-11	2011-12	Pooled	2010-11	2011-12	Pooled	2010-11	2011-12	Pooled
RD 2552	43.53	35.82	39.68	43.12	33.34	38.56	0.76	0.47	0.62	0.78	0.46	0.62	38.06	22.76	30.41	49.00	48.88	48.94
BH 902	42.18	35.64	38.91	42.11	31.78	37.80	0.80	0.40	0.60	0.90	0.38	0.62	39.87	19.59	29.73	44.49	51.68	48.08
DWRUB 52	47.89	32.44	40.16	46.95	29.49	38.62	0.79	0.39	0.59	0.70	0.42	0.57	39.43	19.08	29.25	56.35	45.81	51.08

Table.5 Correlation coefficients among drought indices and yield

Indices	MP	STI	GMP	TOL	SSI	HARM	YI	YSI	Reduction percentage	Grain yield of stressed plot (Ys)	Grain yield of unstressed plot (Yp)
MP	1										
STI	0.96	1									
GMP	0.95	0.99	1								
TOL	0.82	0.64	0.49	1							
SSI	0.74	0.54	0.49	0.99	1						
HARM	0.65	0.83	0.86	0.11	-0.02	1					
YI	-0.25	0	0.06	-0.76	-0.84	0.56	1				
YSI	-0.74	-0.54	-0.49	-0.99	-0.99	0.02	0.84	1			
RD%	0.74	0.54	0.49	0.99	0.99	-0.02	-0.84	-1	1		
Grain yield of stressed plot (Ys)	-0.29	-0.03	0.03	-0.78	-0.86	0.53	0.99	0.85	-0.86	1	
Grain yield of unstressed plot (Yp)	0.93	0.8	0.77	0.97	0.93	0.34	-0.59	-0.93	0.93	-0.62	1

The numbers of grains per earhead were not influenced significantly by irrigation treatments on pooled mean basis. However, two and three irrigations increased the grains per earhead by 11.5 percent as compared to no irrigation. The numbers of grains per earhead were influenced significantly by genotypes. The maximum grains per earhead were found in BH 902 (45.2) which were at par with RD 2552 (44.6), but 67.4 percent higher than DWRUB 52 (27.0), that might have associated with genetic makeup of their parent materials (Gill *et al.*, 2013).

The 1000 grain weight differed significantly among various irrigation treatments as well as among different genotypes during both the years of study (Table 1). A significant improvement in grain weight was recorded with increase in number of irrigations except among two and three irrigation levels. On pooled mean basis, the increase in grain weight with two and three irrigations was 6.53 percent over no irrigation (41.7 g). Higher 1000 grains weight with two irrigations might be due to the more translocation of photosynthates toward grains due to availability of more amount of water in root zone as compared to one and no irrigation treatments. On other hand plant having less supply of water in no irrigation treatment had produced lighter grains which might be due to the less availability of nutrients from soil solution (Sarwar *et al.,* 2010). Similar results were reported by Wajid *et al.,* (2002), who observed significant effect of irrigation on grains weight. Among genotypes, boldest grains (47.2 g) were recorded in DWRUB 52 and minimum 1000 grain weight (40.3g) was recorded in RD 2552. Sharma and Verma (2010) also reported that two row varieties had significantly higher 1000- grain weight than six row type. This trait helps in yield compensation of the two row type compared to the six row barley.

Yields

Grain yield was significantly influenced by irrigation treatments (Table 2). Among irrigation levels, maximum grain yield (50.8 q/ha) was recorded in three irrigations, which was 70.5, 10.2 and 2.8 percent higher than no, one and two irrigation, respectively. The improvement in grain yield with increase irrigation levels might be due to sufficient soil moisture available in the root zone which increased photosynthetic efficiency of plant and resulted in increased number of effective tillers/m^2, number of grains/earhead and 1000 grain weight and finally reflected in grain yield. These results corroborate with the findings of Sawar *et al.,* (2010), who reported that wheat yield increased with increasing irrigation levels. Among the genotypes, maximum grain yield (44.8 q/ha) was recorded in DWRUB 52 though the differences were non-significant on pooled mean basis. The highest grain yield was recorded in DWRUB 52 (50.5q/ha) and BH 902 (92.0q/ha) during 2010-11 and 2011-12, respectively. The higher grain yield was recorded during 2010-11 may be due to more rainfall during the crop season as compared. The might be due to higher number of effective tillers per m^2 and test weight. The higher tillering capacity and higher 1000- grain weight of two row type helps in yield compensation for less number of grains per spike compared to the six row barley (Sharma and Verma, 2010).

The interaction among genotypes and irrigation levels showed non-significant differences with higher grain yield (30.41 q/ha) recorded in RD 2552 under zero irrigated condition followed by BH 902 (Table 2). Whereas, DWRUB 52 had given highest grain yield under irrigated conditions on pooled mean basis. Ngwako and Mashiqa (2013) also reported that irrigation treatments significantly increased grain yield over no irrigation in all the cultivars. Irrigation enhance grain yield by improving the growth of the crop and thus enabling it to intercept more photosynthetic radiation over non irrigated plants. Drought stress reduced the yield of some genotype while other were tolerant to drought, suggesting genetic variability in the genotypes for drought tolerance (Zare, 2012). The straw yield was improved significantly by each increment in irrigation level (Table 1).

The response of two and three levels of irrigation on straw yield was non-significant. The increase in straw yield under two and three irrigation levels was 141.1 and 6.08 percent over no irrigation and one irrigation, respectively. Gill *et al.*, (2013) and Abdelkhalek *et al.*, (2015) also reported that straw yield increased significantly with increase in level of irrigation. Among the genotypes, maximum straw yield (60.5 q/ha) was recorded in RD 2552 which was significantly higher than other genotypes. Sharma and Pannu (2008) at Hisar reported that the grain yield, straw yield, harvest index, effective tillers /plant, number of grains/spike and test weight were higher in two irrigations over no irrigation.

Results concluded that soil moisture stress causes reduction in grain as well as straw yield, by inducing low 1000-grain weight and number of tillers m^{-2}. The grain yield improvement in barley with three irrigation levels was 70.5 percent over no irrigation. Higher grain yield was recorded in DWRUB 52 and BH 902 during 2010-11 and 2011-12, respectively. The study of correlation coefficients revealed that based on TOL and SSI, RD 2552 was found as most drought sensitive genotype. MP, STI, GMP, SSI and HARM had the most significant correlation with grain yield.

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