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IDENTIFICATION OF DROUGHT TOLERANT GENOTYPES OF BARLEY (*HORDEUM VULGARE* L.) THROUGH STRESS TOLERANCE INDICES

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ABSTRACT

Stress tolerance indices viz tolerance index (TOL), mean productivity (MP), stress susceptibility index (SSI), geometric mean productivity (GMP), stress tolerance index (STI), yield stability index (YSI), yield index (YI), etc., were used to evaluate genotypes with high yield and drought tolerance. The barley line B-09006 produced highest yield under irrigated conditions but could not perform well under drought stress conditions. The lines B-09008, B-09005, B-09003 and B-09023 gave comparable yield under irrigated conditions but highest yield under stress conditions. These have highest values of MP, GMP and STI so these lines have high stress tolerance and yield potential. The highest Y_s, MP, GMP, YI and STI were recorded in B-09008 line, followed by B-09003. Y_p had positive and significant correlation with MP, GMP and STI while Ys had significant and positive correlation with all stress indices except TOL and SSI. First principal component analysis (PCA) contributed 76.9% of the variation with Y_p, Y_s, MP, GMP, STI and YI. Thus the first component can be named as the yield potential and drought tolerance while second PCA explained 22.8% of the total variability. B-09008, B-09003, B09005 and B-09026 were more suitable and stable genotypes for irrigated and drought stress conditions.

Key words: barley, stress tolerance indices, principle component analysis.

INTRODUCTION

Barley is ranked as the fourth cereal crop after maize, wheat and rice in the world (Kilic *et al*., 2010) while it ranked sixth in Pakistan. Barley has been given least importance in Pakistan among the cereal crops because it is being cultivated only on marginal lands i.e. drought and saline conditions. Therefore, the area and production of barely is declining day by day. Currently, area and production of barley in Pakistan is only 75,000 ha and 70,000 tons (Anonymous, 2012) compared to 171600 ha and 174400 tons in 1995-96 (Anonymous, 2010), respectively. Loss of yield is the main concern of plant breeders and they emphasize on yield performance under moisture stress conditions (Nazari and Pakniyat, 2010). Stresses of heat, drought, cold, diseases and pests are major factors limiting the crop production and development (Mohammadi *et al*., 2010). The world mean surface temperature will increase by 1.8-4.0^{o}C by the end of 21st century and global precipitation systems will change significantly (IPCC, 2007), which will greatly impact both agriculture and water resources (Guo *et al*., 2010; Yang *et al*., 2011). Grain yield is affected by different environmental conditions (like moisture availability in soil) influencing the growth of the wheat plant and interaction of these conditions with genotypes (Karamanos *et al*., 2012). Drought resistance in crops is probably the most difficult trait to understand (Ashraf, 2010) due to lack of comprehensive information regarding the genetic mechanism of drought tolerance and grain yield under drought conditions (Farashdfar and Sutka, 2002). Drought tolerance indices which provide the measure of yield losses under drought conditions in contrast to normal conditions have been used to screen the drought tolerant genotypes (Mitra, 2001). Clarke *et al*., 1992; Fischer and Maurer, 1978; Winter *et al*., 1988 used different selection indices like Tolerance Index (TOL), Mean Productivity (MP), Stress Susceptibility Index (SSI), Geometric Mean Productivity (GMP), Stress Tolerance Index (STI), Yield Stability Index (YSI) and Yield Index (YI) to evaluate genotypes with high yield and drought tolerance. Some earlier researchers (Karami *et al*., 2005; Giancarla *et al*., 2010; Nazari and Pakniyat, 2010; Zare, 2012; Ajalli and Salehi, 2013) indicated the importance of STI, MP and GMP to identify high yielding barley advanced lines both under non-stressed and stress conditions. SSI was a useful parameter for wheat breeding in case of severe stress while in less severe stress MP, GMP, TOL and STI were suggested (Akcura *et al*., 2011). The objectives of present study were, a) to categorize drought tolerant barley varieties, b) to determine the proficiency of tolerance indices to classify barley varieties into sensitive and tolerant ones and c) to interpret the association among tolerance indices through biplot analysis.

MATERIALS AND METHODS

This study was carried out in the research area of the Wheat Research Institute, Faisalabad (31º 39`; 73º 04`; 183.35 meters a.s.l) during 2011-12 under irrigated and drought stress conditions. Fifteen advanced lines and one commercial variety Haider 93 of barley was sown in a randomized complete block design with three replications on November 5, 2011. Irrigation was restricted throughout the growing period for one set of experiment to create drought stress conditions while other was irrigated thrice. Each entry was sown in a plot size of 1.8m x 5.0m (9.0 m^2) keeping row to row distance of 30 cm and at seed rate of 85 kg ha^{-1}. Full dose of fertilizer @ 80-60 NP kg ha^{-1} in the form of diammonium phosphate (DAP) and urea was applied at the time of sowing. Weeds were controlled manually. Minimum and maximum temperature varied 4.1 – 19.8ºC and 19.5 – 33.4ºC, respectively, and only 46.8 mm rainfall was received during crop season (Table 1).

After maturity, each plot was harvested and threshed separately in both sets of experiment and grain yield (kg ha^{-1}) was calculated in irrigated (Y_p) as well as drought stress (Y_s) conditions. Stress tolerance indices were calculated according to the equations given in Table 2.

Data collected were subjected to statistical analysis of variance (Steel *et al*., 1997) with the help of statistical software MSTATC. Correlation coefficients among yield of irrigated (Y_p) and drought stress (Y_s), and stress indices were estimated according to the statistical techniques (Kown and Torrie, 1964). All data were subjected to analysis using a computer software program Minitab v.16 including principal component and cluster analysis.

RESULTS AND DISCUSSION

Analysis of variance showed that yield under both irrigated and drought stress conditions and all stress tolerance indices were significantly different for all barley genotypes under study (Table 3).

The advanced line B-09006 produced highest grain yield under irrigated conditions but could not perform well under water stress conditions (Table 4). It seemed that it was not a stable line to perform well in both conditions. The advanced lines B-09028, B-09008, B-09005 and B-09046 produced 3876, 3803, 3724 and 3667 kg ha^{-1} yield under irrigated conditions, respectively, while lowest yield (2817 kg ha^{-1}) was produced by B-05011. In case of drought stress conditions, B-09008 produced maximum grain yield (2403 kg/ha^{-1}) followed by B-09003, B-09023, B-09025 and B-09005. The genotype B-09035, Haider 93, B-09006 and B-09028 showed maximum values of TOL and SSI, which indicates that these lines are more sensitive to drought conditions. A large value of TOL and SSI characterize quite more sensitivity to stress as reported by Bruckner and Frohberg, (1987) and Solomon and Labuschagne, (2003) thus, the genotypes having a smaller value of TOL and SSI are more stable. While selection based on these two indices favours genotypes with low yield potential under irrigated conditions and high yield under drought stress conditions. It is clear from Table 4 that B-05011 line had the lowest TOL and SSI, which has lowest yield production in irrigated conditions compared to other genotypes. It is evident from stress tolerance indices (TOL and SSI) that this line was more tolerant genotype due to low values of TOL and SSI. It seems that TOL had prospered in selecting genotypes with high yield under stress, but had failed to identify genotypes with proper yield under both environments. Obviously, this index only pointed out the genotypes with the lowest yield in irrigated conditions. The greatest value of YSI index was recorded for the genotype B-05011 and lowest for B-09035. It is exhibited from Table 4 that these lines had the lowest and greatest TOL and SSI values, respectively. Therefore, based on YSI, TOL and SSI indices, B-05011 and B-09035 lines could be considered relatively drought tolerant and sensitive, respectively. TOL, SSI and YSI were found to be more useful indices in discriminating drought tolerant/ susceptible genotypes. SSI has been commonly used by earlier researchers (Akcura *et al*., 2011; Clarke *et al*., 1992; Fischer and Maurer, 1978; Winter *et al*., 1988). SSI does not discriminate between potentially drought tolerant varieties and those that had low overall yield potential. To reduce the effect of yield reduction from stressed to normal conditions, Yadav and Bhatnagar (2001) suggested the use of SSI in combination with yield under stress. These two factors were used earlier by Gavuzzi *et al*. (1993) to identify varieties with superior drought adaptation. In the case of this combination, B-09008 was the best genotype under drought stress conditions whereas the B-05011 had the lowest yield in irrigated conditions and showed less yield reduction under drought stress conditions so showed the lowest value of SSI. Ramirez and Kelly (1998) reported the same findings that selection based on a combination of both GMP and SSI may deliver a more desired criterion for improving drought resistance. By considering these two indices (GMP, SSI), B-09008 was the best genotype. As far as stress tolerance indices are concerned, the advanced lines viz B-09008, B-09005, B-09003 and B-09023 have highest values of MP, GMP and STI (Table 4) so these lines have high stress tolerance and yield potential. The highest Y_s, MP, GMP, YI and STI values were recorded in B-09008 line, followed by B-09003. Maximum Y_p produced by B-09006 line that had significant difference with B-09008 line. While the least MP, GMP, YI and STI values were noted for variety

Haider-93. Fernandez (1992) also used these indices (MP, GMP, YI and STI) for screening drought tolerant and high yielding genotypes in the both conditions These indices were able to discriminate varieties belong to A-group, including varieties with high yield in both conditions, from the others (B, C or D groups). In these cases, varieties with a high MP, GMP, YI and STI would belong to A-group. Furthermore, these indices are related to yield under drought stress if it is not too severe and the difference between Y_s and Y_p is not too large. A higher MP, GMP, YI and STI value is indicating more tolerance to drought stress. These results are corroborated with the findings of Fernandez (1992); Gavuzzi *et al*. (1997); Bouslama and Schapaugh (1984) and Hossain *et al*. (1990). Therefore, based on these indices values, B-09008 belonged to A-group and was superior line, followed by B-09003. Haider-93 belonged to D-group and was considered as the sensitive line in respect of drought tolerance.

Selection based on a combination of indices may provide a useful measure for improving drought resistance of barley, but studies of correlation are useful to find out the degree of overall association only between any two measured characteristics. Thus a better approach such as biplot analysis is needed to identify the superior varieties for both drought stress and irrigated environments. Varieties subjected to biplot analysis were compared for measuring association between all the traits at once. It is depicted from the principal component analysis that first two components (PCA1 & PCA2) comprised of about 99.8 percent of the total variation (Table 5).

Principal component analysis (PCA) revealed that first PCA elucidated 76.9% of the variation with positive values of Yp, Ys, MP, GMP, STI, YI and YSI (Table 5). Thus the first component can be termed as the yield potential and drought tolerance. Considering the high and positive value of this component, genotypes that have high values of these indices will be high yielding in drought stress and irrigated conditions (Fig. 1). The second PCA explained 22.8% of the total variability, therefore the second component can be named as stress tolerant dimension and it separates the stress tolerant genotypes from non stress tolerant. In this respect, selection of genotypes that have high PCA1 and PCA2 are suitable for both irrigated and drought stress 2conditions. These results are in agreement with the finding of Kaya *et al*. (2006). Therefore, B-09008, B-09003, B-09005 and B-09026 genotypes with higher PCA1 and PAC2 are more suitable genotype for stress and irrigated conditions (Fig. 1). Genotype Haider-91, B-05011, B-09035 and B-05013 with low PCA1 and PAC2 were the poorest genotypes under both drought stress and irrigated conditions (Fig. 1). Therefore, they can be identified as highly drought susceptible with low yield stability. These findings are similar with the findings of Zare (2012) and Ajalli and Salehi (2013). Genotypes that have high PCA1 and low PCA2 are suitable for irrigated environments. So the genotypes B-09023, B-09025 and B-09027 with higher PC1 and lower PC2 are superior genotypes under irrigated conditions.

Cluster analysis has been used for description of genetic diversity and grouping based on similar characteristics (Souri *et al*., 2005). Cluster analysis based on Y_p, Y_s and other drought stress indices were performed (Fig. 2).

Table 1. Temperature and rainfall during crop season 2011-12.

Month	Mean Temperature (ºC)		Rainfall (mm)
	Minimum	Maximum	
November, 2011	13.6	29.2	T
December, 2011	4.8	23.1	-
January, 2012	4.1	19.5	3.2
February, 2012	5.6	21.0	6.3
March, 2012	12.9	28.1	1.8
April, 2012	19.8	33.4	35.4
Mean/Total	**10.1**	**25.7**	**46.8**

Association between Y_p, Y_s and other indices of drought tolerance were calculated to determine the most desirable drought tolerance criteria (Table 6). Y_p had positive and significant correlation with MP, GMP, STI and YI while negative and significant correlation with YSI. Positive and significant correlations were found between Y_s and MP, GMP, STI, YI and YSI but yield under stress conditions (Y_s) showed a negative and significant correlation with TOL and SSI. The significant and positive association of Y_p with MP, GMP, and STI showed that these indices were more operative in classifying high yielding cultivars under different moisture conditions. The stress susceptibility index (SSI) had significant and negative correlation with Y_s while positive and non-significant correlation with Y_p. Thus, a small value of SSI is desirable and selection for this parameter would also tend to favor low yielding genotypes. SSI has been widely used by some earlier

Table 2. Stress tolerance indices used for the evaluation of barley genotypes to drought tolerance.

S. No.	Stress tolerance indices	Equation[1]	Reference
1	Stress susceptibility index	$SSI = 1–(Y_s/Y_p)/SI$	Fisher and Maurer (1978)
2	Stress intensity	$SI = 1–(\hat{Y}_s/\hat{Y}_p)$	
3	Mean productivity	$MP = (Y_s + Y_p) / 2$	Rosielle and Hambline (1981)
4	Stress tolerance	$TOL = Y_p – Y_s$	
5	Geometric mean productivity	$GMP = (Y_p{}^*Y_s)½$	Fernandez (1992)
6	Stress tolerance index	$STI = (Y_p{}^*Y_s)/(\hat{Y}_p)^2$	
7	Yield index	$YI = Y_s / \hat{Y}_s$	Gavuzzi *et al.* (1997)
8	Yield stability Index	$YSI = Y_s /Y_p$	Bouslama and Schapaugh (1984)

[1] Y_s and Y_p, are grain yield of each genotype under stress and non-stress conditions, respectively. While $\hat{Y}_s$ and $\hat{Y}_p$ are the mean grain yield of all genotypes in stress and non-stress conditions, respectively.

Table 3. Analysis of variance of Y_p, Y_s and stress tolerance indices of 16 barley genotypes (Mean squares).

SOV	df	Y_p	Y_s	TOL	MP	SSI	GMP	STI	YI	YSI
Rep	2	156320	353121	954573	16092	0.230	82159	0.013	0.103	0.053
Genotype	15	251986**	534189**	611638**	240188**	0.195**	393321**	0.052**	0.156**	0.045**
Error	30	97399	129456	200991	63181	0.056	78190	0.013	0.038	0.013

** = Significant at 0.01 probability level.

Table 4. Mean values of Y_p, Y_s and stress tolerance indices of 16 barley genotypes

S. No.	Genotype	Y_p	Y_s	TOL	MP	SSI[1]	GMP	STI	YI	YSI
1	B-05011	2817[e]	1845[bcd]	972[e]	2331[de]	0.70[d]	2264[d]	0.41[d]	1.00[bcd]	0.67[a]
2	B-05013	3540[cd]	1742[d]	1798[cd]	2641[bcd]	1.06[bc]	2480[cd]	0.49[cd]	0.94[d]	0.49[bc]
3	B-09003	3646[abcd]	2235[ab]	1411[de]	2940[ab]	0.80[cd]	2845[ab]	0.64[ab]	1.21[ab]	0.61[ab]
4	B-09005	3724[abcd]	2094[abcd]	1630[cde]	2909[abc]	0.91[bcd]	2791[abc]	0.62[abc]	1.13[abcd]	0.56[abc]
5	B-09006	4080[a]	1750[d]	2330[ab]	2915[abc]	1.18[b]	2661[bc]	0.56[bc]	0.95[d]	0.43[c]
6	B-09008	3803[abc]	2403[a]	1400[de]	3103[a]	0.76[cd]	3016[a]	0.72[a]	1.30[a]	0.64[ab]
7	B-09023	3524[bcd]	2219[abc]	1306[de]	2872[abc]	0.78[cd]	2792[abc]	0.63[abc]	1.20[abc]	0.62[ab]
8	B-09025	3499[bcd]	2137[abcd]	1362[de]	2818[abc]	0.79[cd]	2702[abc]	0.58[abc]	1.16[abcd]	0.62[ab]
9	B-09026	3642[abcd]	2062[abcd]	1580[cde]	2852[abc]	0.90[bcd]	2728[abc]	0.60[abc]	1.11[abccd]	0.57[abc]
10	B-09027	3319[cde]	2036[abcd]	1283[de]	2678[bc]	0.77[cd]	2568[bcd]	0.53[bcd]	1.10[abcd]	0.63[ab]
11	B-09028	3876[ab]	1780[d]	2096[abc]	2828 [abc]	1.13[b]	2624[bc]	0.55[bc]	0.96[d]	0.46[c]
12	B-09031	3662[abcd]	1853[bcd]	1810[bcd]	2757[bc]	1.03[bc]	2602[bc]	0.54[bcd]	1.00[bcd]	0.51[bc]
13	B-09033	3369[bcd]	1845[bcd]	1524[cde]	2607[cd]	0.93[bcd]	2492 [cd]	0.50[cd]	1.00[bcd]	0.55[abc]
14	B-09035	3525[bcd]	895[e]	2630[a]	2200[e]	1.56[a]	1758[e]	0.25[e]	0.48[e]	0.25[d]
15	B-09046	3667[abcd]	1813[cd]	1853[bcd]	2740[bc]	1.05[bc]	2576[cd]	0.53[bcd]	0.98[cd]	0.50[bc]
16	Haider-93	3222[de]	891[e]	2331[ab]	2057[e]	1.50[a]	1681[e]	0.23[e]	0.48[e]	0.28[d]
	LSD(0.05)	520.4	407.7	677.0	322.4	0.313	328.3	0.14	0.221	0.15

Y_p : Grain yield under normal conditions, Y_s : Grain yield under stress conditions, TOL : Stress tolerance, MP : Mean productivity, SSI : Stress susceptibility index, GMP : Geometric mean productivity, STI : Stress tolerance index, YI : Yield index, YSI : Yield stability index
[1]Fisher and Maurar (19778) defined stress susceptibility index (SSI), which was used to classify the studied genotypes into three groups i.e. tolerant (SSI≤0.5), moderately tolerant (0.5<SSI≤1) and sensitive (SSI>1).

researchers to identify sensitive and tolerant varieties (Akcura *et al*., 2011; Clarke *et al*., 1992; Golabadi *et al*., 2006) There was a positive and significant correlation between TOL and SSI while both have negative correlation with all other indices. STI was positively and significantly associated with yield under stress and normal conditions and also with other drought tolerance indices studied except TOL and SSI. Fernandez (1992) also used STI to identify tolerant genotypes in wheat that gave high yield under stress and normal conditions. A negative and non-significant correlation was shown between yield under irrigated condition and YSI.

It is concluded from the present findings that SSI and TOL were not useful indices because both has significant and negative correlation with yield under drought stress conditions. MP, STI, GMP were considered to be the important indices for selecting high yielding genotypes of barley both under irrigated and drought stress conditions. It is depicted from principal component analysis that B-09008, B-09003, B09005 and B-09026 were more suitable and stable genotypes for irrigated and drought stress conditions.

Table 5. Principal component analysis for Y_p, Y_s and stress tolerance indices of 16 barley genotypes.

Traits	PC 1	PC 2	PC 3	PC 4
Y_p	0.093	0.676	0.314	-0.193
Y_s	0.380	-0.005	-0.152	-0.224
TOL	-0.295	0.438	0.343	0.086
MP	0.332	0.341	0.047	-0.266
SSI	-0.349	0.272	-0.468	0.064
GMP	0.363	0.200	-0.014	0.875
STI	0.361	0.211	-0.500	0.003
YI	0.380	-0.006	-0.121	-0.251
YSI	0.348	-0.276	0.524	0.044
Eigenvalue	6.928	2.053	0.015	0.003
Variance (%)	76.9	22.8	0.002	0.000
Cumulative variance (%)	76.9	99.8	100.0	100.0

Table 6. Correlations between Y_p, Y_s, and stress tolerance indices.

	Y_p	Y_s	TOL	MP	SSI	GMP	STI	YI
Y_s	0.238							
TOL	0.420	-0.782**						
MP	0.690**	0.868**	-0.368					
SSI	0.154	-0.919**	0.957**	-0.606*				
GMP	0.512*	0.954**	-0.563*	0.973**	-0.765**			
STI	0.529*	0.948**	-0.547*	0.978**	-0.747**	0.996**		
YI	0.238	1.000**	-0.782**	0.868**	-0.919**	0.954**	0.948**	
YSI	-0.154	0.919**	-0.957**	0.606*	-1.000**	0.765**	0.747**	0.919**

*, ** = Significant at 0.05 and 0.01 probability level, respectively.

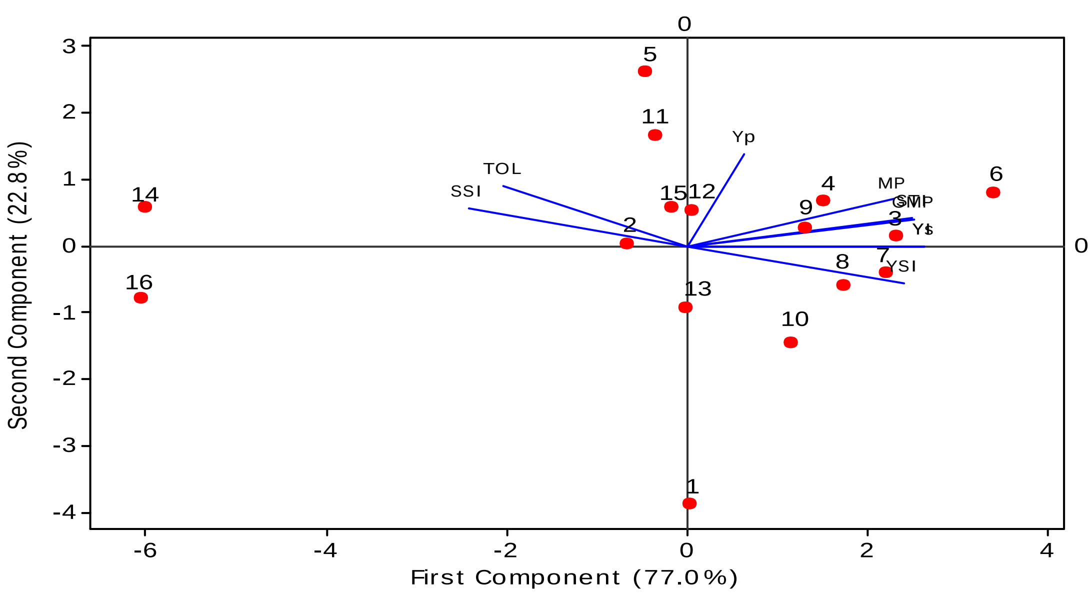

Figure 1. Biplot of stress indices between PC1 and PC2

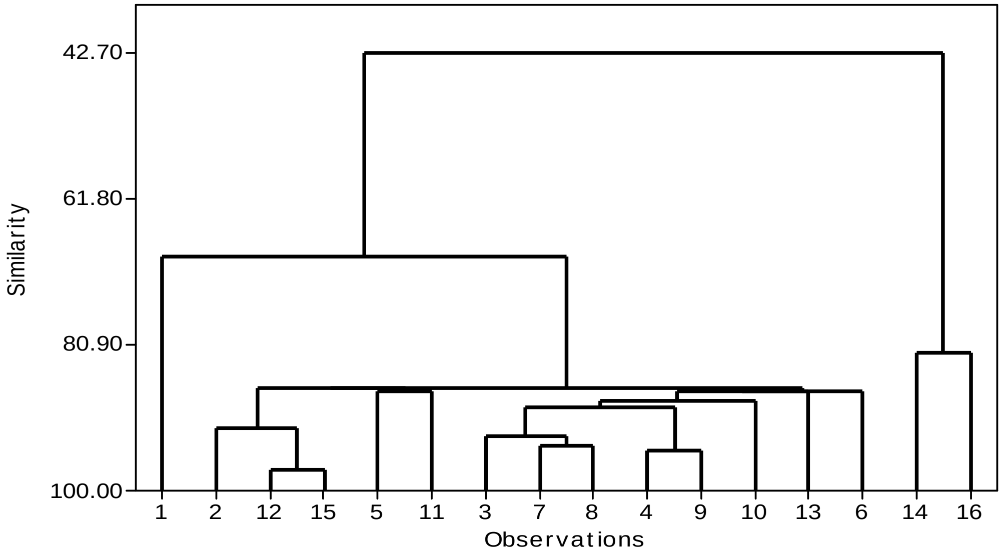

Figure 2: Dendrogram of cluster analysis of Barley advanced lines based on stress tolerance indices

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