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Study of variability of bread wheat lines based on drought resistance indices

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Abstract. Current research was conducted to evaluate drought tolerance potential in wheat lines based on Augmented Design with four checks (Bahar, Cross Alborz, Sardari and DN-11 cultivars). Drought tolerance and susceptibility indices for yield and its principal components were calculated in two irrigation and drought stress conditions. Result of correlation coefficients analysis revealed that there was a positive and significant correlation between yield in stress and non-stress environments (0.403). Indices GMP, HAM, MP, YI and YSI showed higher correlation with Ys and were known as suitable indices for survey of drought resistance and achieve high yield in both environments. The triplot diagram based on STI showed that genotypes No. 11, 34, 22, 13, 24, 25, 16, 17, 15 and 8 had high yield and situate in the region according to Fernandez's model that were high yield in the stress and non-stress conditions. The first two components explained about 99.53% of the total variations. In this study, 61.70% of total variability determined by the first component that had high and positive correlation with GMP, MP, DRI, HAM, STI, YSI, YI and yield in both stress and non-stress conditions. So the first component can be nominated as yield potential and drought tolerance component. Second component determined 37.82% of total variability and showed negative correlation with YI, YSI, DRI and Ys and positive correlation with SSI, TOL, MP, GMP, STI, HAM and Yp. This component can be nominated as stress susceptibility component. Relationship between indices showed the indices GMP and STI are high correlated with Yp. Based on biplot analysis, genotypes that are located in the midsection and near the center showed almost same yield in both conditions. The MP, YI, DRI and YSI Indices were highly correlated with Ys. Then based on these indicators genotypes can be selected via high yield in stress conditions. The SSI and TOL Indices showed high correlation with other indices. So genotypes that are near these indices seem to be susceptible to stress conditions.

Keywords: Genotype, drought resistance indices, drought tolerance, bread wheat lines.

Abbreviations: Yp: yield of a genotype in non-stress environment, Ys: yield of a genotype in drought stressed environment, $\overline{Y}p$: mean yield in non-stress environment, $\overline{Y}s$: mean yield in drought stress environment

Introduction

Agriculture as a most important sector in the production of food in Iran is also a big consumer of energy in this country (Farahmandpour et al. 2008). Wheat (*Triticum aestivum* L.) is the most widely grown crop in the world with its unique protein characteristics that serves as an important source of food and energy (Cooke & Law 1998).

Wheat is mainly grown in rainfed areas of the world. In developing countries, about 37% of the total areas are located in semi-arid region (Anon 2000). This crop is the most important agriculture product in the Iran that is cultivated in about four million hectares of rain fed lands (Tavakoli et al. 2005). What is able to cultivate in widely regions of areas by 350 mm to 550 mm and precipitation monthly average temperature from 6 to 15 ºC with the altitude over 1200 meters. This plant has a vital role in nourishment of people all over the world. It is necessary to increase wheat production to remove nourishment needs of the increasing population (Aycicek & Yildirim 2006).

In arid and semiarid regions with Mediterranean climate, wheat crops usually face drought stress during the grain filling period. Drought stress at grain filling period decreases grain yield, dramatically (Ehdaie & Waines 1996).

Water stress at different growth stages causes various morpho-physiological changes in the plants to acclimatize under such conditions. For example, water stress at seedling stage might lead to higher dry root weights, longer roots, coleoptiles and higher root/shoot ratios which could be exploited as selection criteria for stress tolerance in crop plants at very early stage of growth (Takele 2000, Dhanda et al 2004, Kashiwagi et al 2004). Water stress is a problem in 45% of the world's geographical area and is a major limitation to the productivity of agricultural systems and food production worldwide (Boyer 1982).

For the plant breeding program drought is defined as insufficient moisture supply which causes a reduction in plant production (Blum 2011).

Drought resistance is defined by Hall (1993) as the relative yield of a genotype compared to other genotypes studied to the same drought stress. Yield is reduced mostly when drought stress occurs during the heading or flowering and soft dough stages. Drought stress during maturity stage caused about 10% decrease in yield, while moderate stress during the early vegetative period has essentially no effect on yield (Bauder 2001). Resistance is generally a function of the plant basic anatomy, development and metabolism. Some resistance mechanisms such as those of stomata are also variable depending on plant responses and environment effects (Blum 2011).

Loss of yield is the main concern of plant breeders and they hence emphasize on yield performance under moisture stress conditions but variation in yield potential could arise from factors related to adaptation rather than to drought tolerance per se. Thus, drought indices which provide a measure of drought based on loss of yield under drought-conditions in comparison to normal conditions have been used for screening drought-tolerant genotypes (Mitra 2001).

The tolerance (TOL) (Clarke et al 1992), mean productivity (MP) (Mc Caig & Clarke 1982), harmonic mean (HAM) (Fernandez 1992), yield index (YI) (Gavuzzi et al. 1997), stress susceptibility index (SSI) (Fischer & Maurer 1978), yield stability index (YSI) (Bouslama & Schapaugh 1984), drought response index (DRI) (Bidiger et al. 1987), geometric mean productivity (GMP) and stress tolerance index (STI) (Fernandez 1992) have been employed under various conditions.

The relative yield performance of genotypes in drought-stressed and favorable environments seems to be a common starting point in the identification of desirable genotypes for unpredictable rainfed conditions (Mohammadi et al. 2010). Drought susceptibility of a genotype is often measured as a function of the reduction in yield under drought stress (Blum 1988) while the values are confounded with differential yield potential of genotypes (Ramirez & Kelly 1998). Analysis of plant traits with significant effects on drought tolerance and high yield potential under stress conditions seem to be necessary (Richards 2004). The relative yield performance of genotypes in drought stress conditions and more favorable environments seems to be a common starting point in the identification of traits related to drought tolerance and the selection of genotypes for applying in breeding for water deficient environments (Clarke et al. 1992). Comparisons between average grain yields in previous studies showed only 25% of lines are high yield lines in stress and non-stress conditions. Indices such as TOL, STI, MP and GMP are criteria in the drought environment revealed that all the average of grain yield were nearly identical (Golabadi et al. 2006).

Therefore, the main objectives of this investigation were (i) assessment of the selection criteria for identifying drought tolerant genotypes and high-yielding genotypes in drought stress and non-stress field conditions, (ii) selection of wheat lines based on drought resistance indices and (iii) study the relationships among recorded traits using biplot and triplot analysis techniques.

Materials and methods

The research was carried out in Eslam Abad-e Gharb Agricultural and Natural Resource Research Station Field (47°26'N. 34°8'E. 1346 m elevation) at the 2009 and 2010 growing seasons. 200 wheat genotypes selected from 810 different wheat lines entry of the CIMMYT in Mexico based on some traits such as day to heading (DTH), day to maturity (DTM), 1000-kernel weight (TKW) and grain yield (GY) were evaluated and compared yield based on Augmented Design with ten blocks and four checks (Bahar, Cross Alborz, Sardari and DN-11 cultivars in each block) in two irrigated and rainfed (at filling grain period by interception irrigation) conditions. Plot size was 7.2 m^2 (six rows, 6 m long, 0.2 m row spacing and 0.5 m between the plots). After plough for a good seed preparation, fertilizer rate was 50 kg N ha^{-1} and 50 kg P_2O_5 ha^{-1} applied at planting. Annealing was provided by means of furrow irrigation before sowing. The lines were sown on clay loam soil and plant density was 400 m^2 seeds.

In order to consider susceptibility or resistance ratio of genotypes to water stress and evaluated main criteria for segregate genotypes, some indices were used as below:

(1.) Stress Tolerance Index (STI) (Fernandez 1992)

$$STI = \left[\frac{Y_p}{\overline{Y}_p}\right] \times \left[\frac{Y_s}{\overline{Y}_s}\right] \times \left[\frac{\overline{Y}_s}{\overline{Y}_p}\right] = \frac{Y_p \times Y_s}{(\overline{Y}_p)^2}$$

(2.) Stress susceptibility index (SSI) (Fischer & Maurer 1978)

$$SSI = \frac{1 - \left(Y_s / Y_p \right)}{SI}$$

Where SI is stress intensity and calculated as:

$$SI = 1 - \left(\frac{\overline{Y}_s}{\overline{Y}_p} \right)$$

(3.) Tolerance (TOL) (Clarke et al. 1992)

$$TOL = Y_p - Y_s$$

(4.) Mean productivity (MP) (Hossain 1990)

$$MP = \frac{Y_p + Y_s}{2}$$

(5.) Geometric Mean Productivity (GMP) (Fernandez 1992)

$$GMP = \sqrt{Y_s \cdot Y_p}$$

(6.) Harmonic Mean (HAM) (Fernandez 1992)

$$HAM = \frac{2(Y_p \times Y_s)}{Y_p + Y_s}$$

(7.) Yield Index (YI) (Gavuzzi et al. 1997)

$$YI = \frac{Y_s}{\overline{Y}_s}$$

(8.) Yield Stability Index (YSI) (Bouslama & Schapaugh 1984)

$$YSI = \frac{Y_s}{Y_p}$$

(9.) Drought Response Index (DRI)

This index correct the seed yield under stress conditions over diversity in the day to flowering and yield under non-stress conditions (Bidinger et al. 1987).

$$DRI_i = \frac{(Y_{act.i} - Y_{est.i})}{S.E.of.Y_{est}}$$

Where Y_{act} is the actual grain yield under the water stress treatment for each genotype, Y_{est} is the estimated grain yield for each genotype under the water stress treatment, and S.E. of Y_{est} is the standard error of estimated grain yield of all genotypes. Estimated grain yield of a specific genotype i, $Y_{est.i}$, was derived from a multiple regression analysis as follow:

$$Y_{est.i} = a + bY_{p.i} + cFL_i$$

Where $Y_{p.i}$ is the potential grain yield of genotype i, as measured under the normal treatment, and FL_i is the DTF of genotype i under the normal treatment, and a, b and c are regression parameters estimated by least square methods.

Statistical Analysis. Data was analyzed using SPSS (vers. 16) and Minitab (vers. 15) software in order to drawing triplot and biplot diagrams.

Results

Results showed that drought resistance quantitative indices were significantly correlated with yield (in both stress and non-stress conditions). Correlation coefficient between Ys and Yp was positive and significant (0.403). The results indicated (Table 1) that there were positive and significant correlations among Ys with MP (0.835), GMP (0.843), STI (0.838), YI (1), YSI (0.542), HAM (0.850) and DRI (0.913). Then these indices are favorable for genotypes selection in stress condi-

Table 1. Correlation coefficient for Ys and Yp with drought resistance indices in bread wheat genotypes.

	Ys	Yp	SSI	TOL	MP	GMP	STI	YI	YSI	HAM
Yp	0.403**									
SSI	-0.542**	0.538**								
TOL	-0.537**	0.556**	0.988**							
MP	0.835**	0.840**	0.002	0.017						
GMP	0.843**	0.831**	-0.010	0.00	0.999**					
STI	0.838**	0.818**	-0.018	-0.007	0.988**	0.989**				
YI	1.000**	0.402**	-0.542**	-0.537**	0.834**	0.843**	0.837**			
YSI	0.542**	-0.538**	-1.000**	-0.988**	-0.003	0.010	0.017	0.542**		
HAM	0.850**	0.820**	-0.022	-0.016	0.977**	0.999**	0.989**	0.850**	0.022	
DRI	0.913**	0.000	-0.826**	-0.829**	0.541**	0.555**	0.555**	0.913**	0.825**	0.568**

* P< 0.05 ; ** P<0.01

Table 2. Value and specials vectors for drought resistance indices in bread wheat genotypes.

Component	Total	Variance (%)	Cumulative Variance (%)	Vector Special SSI	TOL	MP	GMP	STI	YI	YSI	HAM	DRI	Ys	Yp
1	6.787	61.703	61.703	-0.392	-0.383	0.917	0.923	0.919	0.984	0.392	0.928	0.831	0.985	0.554
2	4.161	37.828	99.531	0.916	0.921	0.397	0.384	0.317	-0.172	-0.916	0.371	-0.551	-0.172	0.830
3	0.028	0.256	99.788											
4	0.018	0.165	99.953											
5	0.003	0.028	99.981											
6	0.002	0.015	99.996											
7	0.00	0.002	99.998											
8	0.00	0.002	100.00											
9	0.00	0.00	100.00											
10	0.00	0.00	100.00											
11	0.00	0.00	100.00											

tions. Nevertheless relationships between Ys-SSI (-0.542) and Ys-TOL (-0.537) showed negative correlations.

The Yp showed positive and significant correlations with SSI (0.538), TOL (0.556), MP (0.840), GMP (0.841), STI (0.818), YI (0.402) and HAM (0.820) that explanatory main this indices seem to be suitable for selection genotypes in non-stress condition, but showed negative correlation and significant with YSI (-0.538).

These results indicate that GMP, HAM, MP, YI and STI indices showed higher correlation with yield in both conditions. Usually these indices are suitable for survey of drought resistance and achieve high yield in both environments. So according to these indices, genotypes No. 204, 190, 5, 184 and 195 were selected.

In this experience in order to assay susceptibility or tolerance of bread wheat lines, STI, SSI, TOL, MP, GMP, HAM, YI, YSI and DRI indices were used. For this purpose triplot diagram was draw. Triplot diagram showed relationship between Ys, Yp and one of resistance indices. In this diagram, based on STI (Fig. 2) showed that genotypes No. 11, 34, 22, 13, 24, 25, 16, 17, 15 and 8 have high yield in the stress and non-stress conditions and showed relatively drought tolerance.

In triplot diagram MP, Ys and Yp (data not shown) indicate there is that genotypes No. 28, 24, 11, 43, 42, 25, 22, 23 and 17 were located in "A" group. Furthermore triplot diagram based on GMP, Ys and Yp (The data was not shown) the genotypes No. 12, 25, 43, 42, 24, 27, 28, 81 and 8 were located in the "A" region and showed high yield in both conditions.

Through the triplot diagram only relation between three variables can be studied and in order to studying the relationship among more than three variables, applying of multivariate methods i.e. biplot is necessary. The biplot diagram is drown based on two components extracted from principal component analysis (PCA) in this research, the first two components in total, explained more than 99.53% of the variation among the data (Table 2).

In this study, 61.70% of total variations of data were determined by the first component. This component had high and positive correlation with GMP, MP, DRI, HAM, STI, YSI and YI in both stress and non-stress yield.

The second component explained 37.82% of total data variability. This component showed negative correlation with YI, YSI, DRI and Ys and positive correlation with SSI, TOL, MP, GMP, STI, HAM and Yp.

The relationship among the indices is shown in Figure 1. Indices GMP and STI had high correlation with Yp. The genotypes that are located near these indices had high yield and high drought tolerance in normal condition (region 1). The MP, YI, DRI and YSI indices showed high correlation with Ys. Region 2 is able to selection of genotypes with high yield

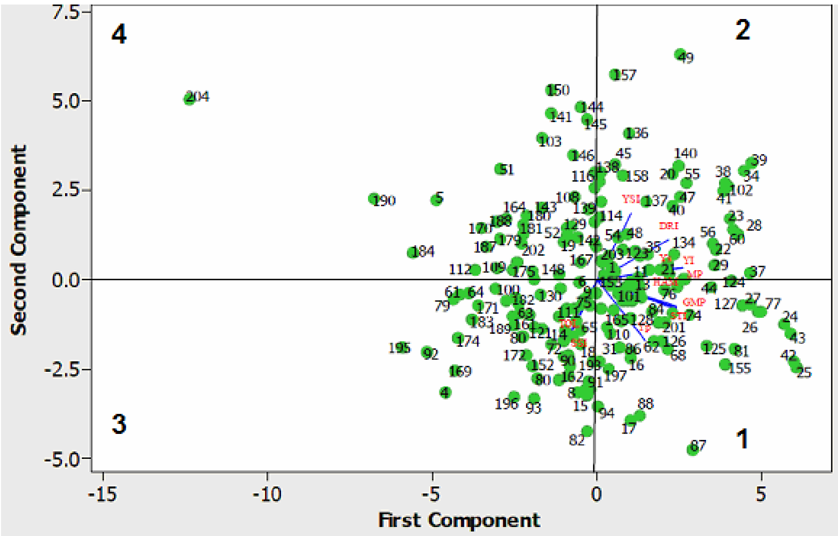

Figure 1. Biplot for nine drought resistance indices in genotypes of beard wheat based on first two components.

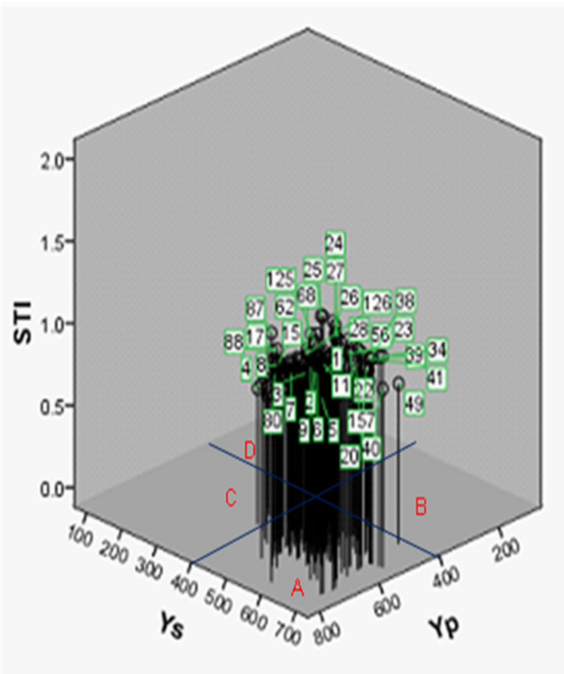

Figure 2. Selection of drought tolerance genotypes using STI index.

stability, high DRI and high yield in stress condition. The SSI and TOL indices showed high correlation to others (region 4), so the genotypes that are located near of these indices would be susceptibility stress. Finally genotypes that are placed in region 3, are not particular based on these indices and genotypes that are located in the center of biplot, are medium particular according to mentioned.

Discussion

Statistical analysis of data showed that drought tolerance quantitative indices were significantly correlated with yield.

Sanjari Pireivatlou & Yazdansepas (2008) also reported Ys of genotypes under pre and post-anthesis drought stress conditions showed positive and highly significant correlations with MP, GMP and STI, and a significantly negative correlation with SSI. Nouri et al. (2011) reported that Ys had significant positive correlation with MP, GMP, YI, YSI, and STI which is consistent with the results of the current experiment.

Sanjari Pireivatlou & Yazdansepas (2008) reported that grain yield of genotypes under non-stress condition indicated positive and highly significant correlations with TOL, MP, GMP and STI under pre and post-anthesis drought stress conditions.

Nouri *et al.* (2011) reported Yp with MP, GMP, TOL, SSI, and STI had positive and significant correlations that corresponding to current experiment. Golabadi et al. (2006) reported there are significant and positive correlations between Yp with MP, GMP, STI, and Ys with MP, GMP, and STI.

Golabadi et al. (2006), Sio-Se Mardeh et al. (2006) and Talebi et al. (2009) suggested that selection for drought tolerance in wheat could be conducted for high MP, GMP and STI under stressed and non-stressed environments.

In this experience in order to assay susceptibility or tolerance of bread wheat lines, STI, SSI, TOL, MP, GMP, HAM, YI, YSI and DRI indices were applied. The indices that are able to distinguish genotypes in region A from other, are desirable and the genotypes that are located in this region have high yield in both conditions (Fernandez 1992). The STI, MP and GMP indices potentially have this ability.

Through the triplot diagram only relation between three variables can be studied and in order to studying the relationship among more than three variables, applying of multivariate methods i.e. biplot is necessary. The biplot diagram is drown based on two components extracted from principal component analysis (PCA) in this research, the first two components in total, explained more than 99.53% of the variation among the data.

In current study, 61.70% of total variations of data were determined by the first component. This component had high and positive correlation with GMP, MP, DRI, HAM, STI, YSI and YI in both stress and non-stress yield. So the first component can be nominated as yield potential and drought tolerance component. The genotypes with high values GMP, MP, STI, HAM indices and low values TOL and SSI indices are desirable. As they produce high yield in stress condition.

The second component explained 37.82% of total data variability. This component showed negative correlation with YI, YSI, DRI and Ys and positive correlation with SSI, TOL, MP, GMP, STI, HAM and Yp. Regarding to negative and significant correlation among second component with SSI and TOL, whatever first component has top value, genotypes with low yield in non-stress condition will be selected. Thus this component can be nominated as stress susceptibility component as it can segregate genotypes with low yield in stress condition. Ahmadizade et al. (2011) showed that based on principal component analysis, the first two components explained 99.8% variability of data.

Ozkan et al. (1999) indicated that the genotypes with lower susceptibility index, showed tolerance to drought and these genotypes indicated lower differences for grain yield in both stress and non-stress conditions. These researchers expressed that have not necessity to select genotypes tolerance based on this index high yield, but these genotypes have drought tolerance mechanism, that cause low yield difference between non-stress condition and stress condition.

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