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Full Length Research Paper

Assessment of drought tolerance in segregating populations in durum wheat

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Wheat improvement for drought tolerance requires reliable assessment of drought tolerance variability among segregating populations. One hundred and fifty-one F_3 and F_4 families of durum wheat derived from a cross between Oste-Gata (as drought tolerance) and Massara-1 (as susceptible) genotypes were evaluated both under moisture stress (E_1) and non-stress (E_2) field environments using a randomized complete block design for each environment and growing season (2003-04, 2004-05) . Entries of E_1 were subjected to moisture stress at grain filling period. Five drought tolerance indices comprising: stress tolerance index (STI), stress tolerance (TOL), stress susceptibility index (SSI), mean productivity (MP), and geometric mean productivity (GMP) were used. The indices were adjusted based on grain yield under drought (Ys) and normal (Yp) conditions. Analysis of variance for each individual year showed that there was a significant genetic variation among families for all criteria with the exception of SSI. The combined analysis of variance over seasons indicated the genetic diversity of lines, significant variation of seasons and differential response of genotypes over seasons for all indices with the exception of SSI. The significant and positive correlations of Yp and (MP, GMP and STI) and Ys and (MP, GMP and STI) under both the seasons as well as significant negative correlation of SSI and TOL in E_1 revealed that selection could be conducted for high MP, GMP and STI under both environments and low SSI and TOL under E_1 conditions. The calculated correlation coefficients revealed that STI, MP, and GMP are the superior criteria for selection of high yielding genotypes both under E_1 and E_2. Cluster analysis of families using Ys, Yp and five other indices categorized genotypes into five groups each of which having 37, 56, 13, 34 and 11 genotypes in year 2003-04 growing season, respectively. Based on 2004-05 growing season data, six groups each of which having 25, 9, 25, 45, 10 and 37 genotypes were obtained, respectively. Cluster analysis distinguished groups contains superior lines for both E_1 and E_2, superior lines for only E_1 conditions and superior lines for E_2 conditions, considering their yield performance (Yp and Ys). Results of calculated gain from indirect selection indicated that selection from moisture stress environment would improve yield in moisture stress environment better than selection from non -moisture stress environment. The comparison of the number of families in common within the top 25% families at E_1 in year 2004-05 and those selected using various indices indicated that drought tolerant indices could perform comparable with yield performance (Yp and Ys).

Key words: Durum wheat, Moisture stress, Drought tolerance index, grain yield.

INTRODUCTION

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

Breeding for resistance to drought is complicated by the lack of fast, reproducible screening techniques and the inability to routinely create defined and repeatable water stress conditions where large populations can be evaluated efficiently (Ramirez and Kelly, 1998). 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

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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).These indices are either based on drought resistance or susceptibility of genotypes (Fernandez, 1992). Drought resistance is defined by Hall (1993) as the relative yield of a genotype compared to other genotypes subjected to the same drought stress. Drought susceptibility of a genotype is often measured as a function of the reduction in yield under drought stress (Blum, 1988) whilst the values are confounded with differential yield potential of genotypes (Ramirez and Kelly, 1998).

Rosielle and Hamblin (1981) defined stress tolerance (TOL) as the differences in yield between the stress (Ys) and non- stress (Yp) environments and mean productivity (MP) as the average yield of Ys and Yp. Fischer and Maurer (1978) proposed a stress susceptibility index (SSI) of the cultivar. Fernandez (1992) defined a new advanced index (STI= stress tolerance index), which can be used to identify genotypes that produce high yield under both stress and non-stress conditions. Other yield based estimates of drought resistance are geometric mean (GM), mean productivity (MP) and TOL. The geometric mean is often used by breeders interested in relative performance since drought stress can vary in severity in field environment over years (Ramirez and Kelly, 1998).

The optimal selection criterion should distinguish genotypes express uniform superiority in both stress and non-stress environments from the genotypes that are favorable only in one environment (E_1 or E_2) . Among the stress tolerance indicators, a larger value of TOL and SSI represent relatively more sensitivity to stress, thus a smaller value of TOL and SSI are favored. Selection based on these two criteria favors genotypes with low yield potentional under non-stress conditions and high yield under stress conditions. On the other hand, selection based on STI and GMP will be resulted in genotypes with higher stress tolerance and yield potential will be selected (Fernandez, 1992).

Clarke et al. (1992) used SSI for evaluation of drought tolerance in wheat genotypes and found a year-to-year variation in SSI for genotypes and their ranking pattern. In spring wheat cultivars, Guttieri et al. (2001) using SSI criterion suggested that SSI more than 1 indicating above-average susceptibility and SSI less than 1 indicated below-average susceptibility to drought stress. Ramirez and Kelly (1998) reported that GM and SSI as the mathematical derivations of the same yield data, selection based on a combination of both indices may provide a more desirable criterion for improving drought resistance in common bean. In wheat, SSI and grain yield were used as stability parameters and identified drought resistant genotypes (Bansal and Sinha, 1991).

Although, there are several reports on the association of the indices with drought tolerance of cultivar, reports employing segregating populations are rare. Selection of segregating populations under environmental stress conditions is one of the main tasks of plant breeders for exploiting the genetic variations to improve the stress-tolerant cultivars (Clarke, 1984). This study was conducted to assess the selection criteria for identifying drought tolerant F_3 and F_4 families and high-yielding genotypes in drought stress and non-stress field conditions.

MATERIALS AND METHODS

F_3 and F_4 populations originated from a cross between a susceptible (Massara- 1) and tolerant (Oste-Gata) durum wheat lines were used in this study. Parents were chosen based on a two-year field experiment conducted at four sites located in central and western regions of Iran (Arzani, 2002). The experiment was conducted at Research Farm of Isfahan University of Technology, located at Lavark, Iran (40 km south west of Isfahan, 32° 32 N and 51° 23 E, 1630m asl) during two growing seasons of 2003-2004. The soil type at this location is silty clay loam, typic Haplargids of the arid tropic, with ph=7.3-7.8. Mean annual precipitation and mean annual temperature were 140 mm and 15° C.

One hundred and fifty-one F_3 and F_4 lines were evaluated using a randomized complete block design with two replications under each of irrigated and drought stress (at grain filling period) field conditions. Each plot contained 3 rows 20 cm apart and 3m in length. Fertilizers were applied prior to sowing at a rate of 50 kg N ha^{-1} and 30 kg P ha^{-1} , and additional side dressing of 50 kg N ha^{-1} was applied at the early square stage(floral buds). Initiation of differential irrigation was started at %50 heading stage and continued through crop maturity. Moisture deficit plots were irrigated only once after initiation of stress. Grain yield of F3 and F4 families were determined under both moisture non-stress and moisture stress experiments and used as Yp and Ys, respectively.

The analysis of variances was performed for each individual experiment, year and their combinations to assess the genotypic and environment effects using SAS computer program. The CORR procedure of SAS was used to estimate correlations among traits. The correlation coefficients and the scatter plots were used in finding out the degree of overall linear association between any two attributes. Cluster analysis of the 151 lines was conducted for each studied year using cluster methods Ward and Between-groups linkage (hierarchical cluster analysis, SPSS 10 for windows). The multivariate display as a biplot was used to investigate the relationships between more than two variables. This analysis plots two-way table consisting of genotypes and the stress-tolerant attributes and illustrates the relationship between the genotypes and stress tolerance attributes in the same graph. This graph provides a useful tool for data analysis and allows the visual appraisal of the structure of a large two-way data matrix. To display the genotype by trait two way data in biplot, a principal component analysis is necessary. This analysis is concerned with explaining the variance-covariance structure through a few linear combinations of the original variables. Although *p* components (number of traits) are required to reproduce the total system variability, often much of this variability can be accounted for by a small number, *k*, of the principal components. If so, there is (almost) as much information in the *k* components as there is in the original *p* variables. The *k* principal components

Table 1. Analysis of variance fof Yp, Ys, and drought tolerance indices in durum wheat F_3 and F_4 lines.

Year	Source of variation	df				Mean Square			
			Yp	Ys	MP	GMP	TOL	SSI	STI
2003-04	Replication	1	0.379***	0.64***	0.46***	0.501***	0.794*	0.69	0.002
	Genotype	150	0.015***	0.26***	0.016***	0.017***	0.219*	0.45	0.058***
	Error	150	0.006	0.013	0.006	0.007	0.16	0.38	0.026
	C.V.		2.84	4.4	2.92	3.1	15	36	18
2004-05									
	Replication	1	108651**	70548*	88575**	82804**	4097	0.001	0.005
	Genotype	150	51233**	30837**	33059**	32751**	31904*	0.163	0.113**
	Error	150	19363	13030	10588	10709	22433	0.139	0.034
	C.V.		15.1	18.9	14.5	15	29.2	32.4	24.4

***, ** and * Significant at the 0.1, 1 and 5% levels of probability, respectively
STI= stress tolerance index, TOL= stress tolerance, SSI= stress susceptibility index, MP= mean productivity, GMP= geometric mean productivity, Ys= grain yield under drought conditions and Yp= grain yield under normal conditions.

can then replace the initial *p* variables, and the original data set, consisting of *n* measurements on *p* variables, is reduced to one consisting of *n* measurements on *k* principal components. An analysis of principal components often reveals relationships that were not previously suspected and thereby allows interpretations that would not ordinarily result (Johanson and Wichern, 1996). The biplot display of principal component analysis was used to identify stress-tolerant and high-yielding genotypes and to study the interrelationship between the stress-tolerant attributes. Thus, some of families from subgroups in the cluster analysis were selected and subjected to biplot.
Stress tolerance attributes were calculated by the following formula:

$SSI = [1 - (Ys)/(Yp)] / SI$. SI is the stress intensity and calculated as: $SI = [1 - (\overline{Ys})/(\overline{Yp})]$

$$STI = [(Yp) \times (Ys) / (\overline{Yp})^2]$$

$$GM = \sqrt{(Ys \times Yp)} \quad TOL = (Yp - Ys) \quad MP = (Yp + Ys)/2$$

where Ys and Yp are the yields of genotypes evaluated under stress and non-stress conditions and $\overline{Ys}$ and $\overline{Yp}$ are the mean yields over all genotypes evaluated under stress and non-stress conditions.

Finally, Yp, Ys, STI, TOL, SSI, MP and GMP were used to select drought tolerant lines. The effect of selection for moisture-stress yield potential under non-moisture or moisture-stress conditions was simulated by selecting the top 25% of the cultivars from the non-moisture stress conditions and from the moisture-stress environment in one year of the data set and then comparing their yield in the moisture-stress environment of the other year of the data set. The selected 25% of the highest Yp, Ys, STI, GMP and the lowest TOL in year 2003-04 was then assessed in the moisture-stress environment of year 2004-05. The duplicate(s) of the selected line(s) from both the non-moisture and moisture-stress conditions and indices was discarded from the sets of selected cultivars. Mean comparisons of the selected cultivars were conducted using Fisher's LSD.

Non-moisture stress and moisture stress selection for improving yield in drought environments can be compared within the theoretical frame work of gain from indirect selection, i.e., what is the yield gain in a drought environment from selection in irrigated or non-irrigated trial conducted in a different year? This question can be answered by evaluating the ratio of yield gain in a non-irrigated environment in year 2 from selection in a non-irrigated environment in year 1 to yield gain in a non-irrigated environment in year 2 from selection in an irrigated environment in year 1 (Falconer, 1989; Sneller and Dombek, 1997) :

$$i\ r_{N1.N2}\ h_N\ \ _{N2} / i\ r_{I1.N2}\ h_I\ \ _{N2} = r_{N1.N2}\ h_N\ r_{I1.N2}$$

where $r_{II.N2}$ and $r_{N1.N2}$ were the genetic correlation of irrigated and non-irrigated yield for year 2003-04, respectively, with non-irrigated yield in year 2, h_N and h_I were the square roots of grain yield heritability under non-irrigated and irrigated environments, respectively, $_{N2}$ was the genetic standard deviation of seed yield in a non-irrigated environment in year 2, and *i* was the standardized selection differential.

RESULTS AND DISCUSSION

The results of analysis of variance showed highly significant differences for all the indices with the exception of SSI, which in turn indicating the population segregated for genes conditioning yield potential and drought resistance (Table 1). Combined analysis of variance over environments (years) indicated variability among the genotypes, significant influence of growing season and different response of genotypes over environments for all the criteria with the exception of SSI (data not shown). Therefore, separate analysis of clustering, correlation and biplot were performed for each year. Guttieri et al. (2001) found that stress intensity and yield under irrigated (control), a moderate moisture-deficit treatment and sever

Table 2. Correlation coefficients between Yp, Ys and drought tolerance indices during two years.

	Yp	Ys	MP	GMP	TOL	SSI	STI
Yp	1	.57**	.88**	.81**	.46**	.14**	.79**
Ys	.71**	1	.89**	.94**	-.47**	-.71**	.94**
MP	.93**	.92**	1	.99**	-.03	-.71**	.98**
GMP	.89**	.95**	.99**	1	-.14*	-.44	.99**
TOL	.49**	-.27**	.07	-.01	1	.92**	-.16*
SSI	.12	-.59**	-.24**	-.31**	.9**	1	-.44**
STI	.88**	.93**	.99**	.99**	.05	-.31**	1

** and * Significant at the 1% and 5% levels of probability, respectively.
† Data on below of diameter are related to 2003-04 year and data on above of diameter are related to 2004-05 year.
STI= stress tolerance index, TOL= stress tolerance, SSI= stress susceptibility index, MP= mean productivity, GMP= geometric mean productivity, Ys= grain yield under drought conditions and Yp= grain yield under normal conditions.

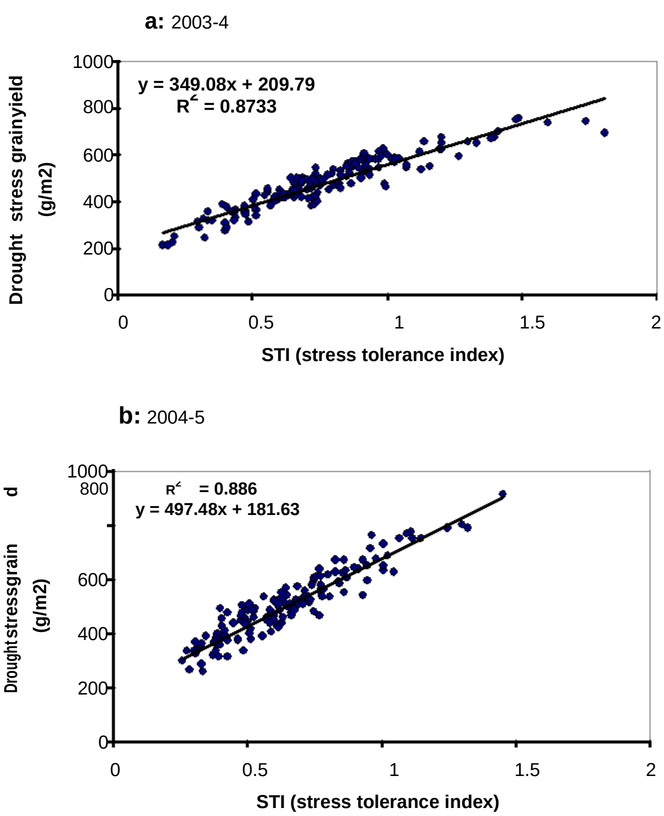

Figure 1. The relationship between drought stress grain yield (g/m2) and stress tolerance index (STI) calculated for each year.

moisture deficit treatment significantly varied in 16 spring wheat cultivars combined over 2 year.

To determine the most desirable drought tolerance criteria, the correlation coefficient between Yp, Ys and other quantitative indices of drought tolerance were calculated (Table 2). The results indicated that there were positive and significant correlations among Yp and (MP, GMP and STI) and Ys and (MP, GMP and STI) in both years and they hence were better predictors of Yp and Ys than TOL and SSI. The observed relationship between Yp and (MP and STI) and Ys and (MP and STI) are in consistent with those reported by Fernandez (1992) in mungbean and Farshadfar (2002) in maize. Ramirez and Kelly (1998) observed positive and significant correlation of some yield components with geometric mean yield (GMP) in common bean. Nasir ud-Din et al. showed significant and positive correlation between Ys and TOL, and Ys and Mp as well as between Yp and MP, while TOL was negatively correlated with Yp and MP. In the present study, the correlation coefficient for stress tolerance (TOL) vs. grain yield under moisture stress (Ys) was r=-0.27 and r=-0.47 in two years, respectively. Thus selection for tolerance should decrease yield in the moisture stress environment, and increase grain yield under non-moisture stress in both years, as indicated by r=0.49 and r=0.46 in two years. Therefore selection for stress tolerance should give a positive yield response under moisture- stress environment. Thus, selection for tolerance will be worthwhile only when the target environment is non-drought stressed. The correlation coefficient for mean productivity vs. yields in moisture and non-moisture stress environments are 0.92 and 0.93 in year 2003-04 and 0.89 and 0.88 in year 2004-05. Thus, selection for MP should give positive responses in both environments. No significant correlations were observed between TOL and GMP (r=0.01) and TOL and STI (r=-0.05) in year 2003-04 and between TOL and MP (r=-0.03) in year 2004-05 suggesting that each index may be a potential indicator of different biological responses to drought. The lack of a correlation between TOL and GMP and between TOL and STI would indicate that the combination of high GMP and STI with a low to moderate TOL is biologically attainable in wheat, thereby combining different traits that associate with each index.

Fernandez (1992) proposed STI index which discriminates genotypes with high yield and stress tolerance potentials. In this study, a general linear model regression of grain yield under drought stress on STI revealed a positive correlation between these criteria with a similar

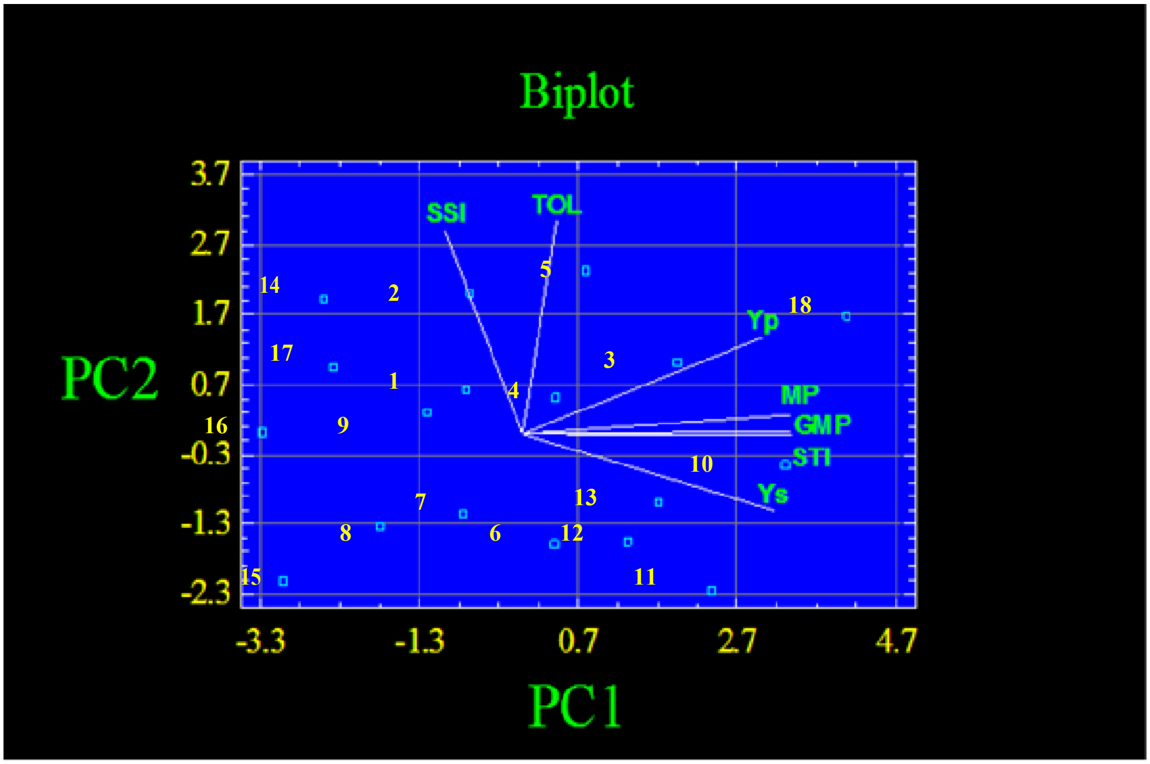

Figure 2. The genotype by trait biplots of 2003-04. The traits are spelled out in lowercase letters, and each genotype is represented by numbers. STI= stress tolerance index, TOL= stress tolerance, SSI= stress susceptibility index, MP= mean productivity, GMP= geometric mean productivity, Ys= grain yield under drought conditions and Yp= grain yield under normal conditions.

coefficient of determination in each studied year (R^2=0.88) (Figure 1). Limitations of using the SSI and TOL indices have already been described in wheat (Clarke et al., 1992) and in common bean (Ramirez and Kelly, 1998). SSI does not differentiate between potentially drought-tolerant genotypes and those that possessed low overall yield potential. Although low TOL has been used as a basis for selecting cultivars with resistance to water stress, the likelihood of selecting low yielding cultivars with a small yield differential can be anticipated (Ramirez and Kelly, 1998).

Selection based on a combination of indices may provide a more useful criterion for improving drought resistance of wheat but study of correlation coefficients are useful in finding out the degree of overall linear association between any two attributes. Thus a better approach than a correlation analysis such as biplot is needed to identify the superior genotypes for both stress and non-stress environments. Therefore, some genotypes were selected randomly from subgroups in the cluster analysis and subjected to biplot analysis for assessing the relationships between all of attributes at once and their comparisons in each year (Figure 2 and Figure 3) . It was surprisingly observed a similar outcome for each of two studied years. Principal component analysis (PCA) revealed that the first PCAs explained 70.8% and 66.8% of the variation with Yp, Ys, MP, GMP and STI in 2003-04 and 2004-05, respectively. Thus, the first dimension can be named as the yield potential and drought tolerance. Considering the high and positive value of this PCA on biplot, selected genotypes will be high yielding under stress and non-stress environments. The second PCA explained 28.3% and 28% of the total variability and had positive correlation with TOL and SSI in 2003-04 and 2004-05 respectively. Therefore the second component can be named as a stress-tolerant dimension and it separates the stress-tolerant genotypes from non-stresstolerant ones. Thus, selection of genotypes that have high PCA1 and low PCA2 are suitable for both stress and non-stress environments. Therefore, genotypes belong-ing to subgroups number 10, 11, 13 and 18 in 2003-04 and 13, 14, 15 and 16 in 2004- 05 are the superior genotypes for E_1 and E_2 conditions with high PC1 and low PC2. Subgroups number 3, 4 and 5 in 2003-04 and 6, 7 and 8 in 2004-05 with high PC2 are more suitable for E_2 than E_1 and subgroups numbers 6 and 7 in 2003-04 and 9, 17 and 1 in 2004- 05 are more desirable for E_1 than E_2. Farshadfar and sutka (2003) obtained similar results

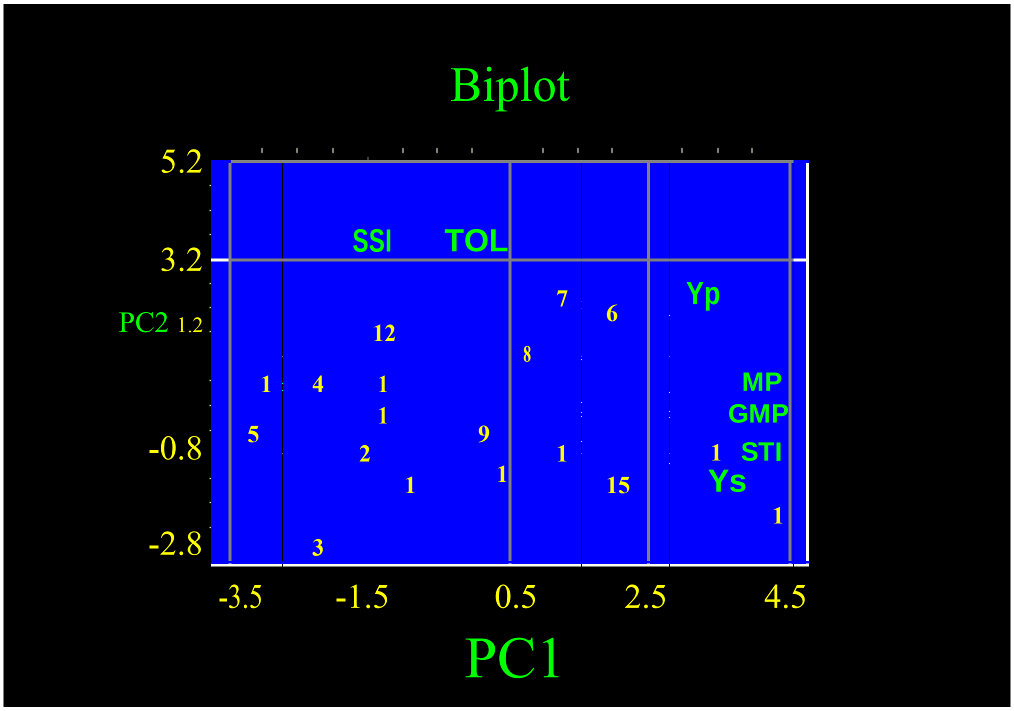

Figure 3. The genotype by trait biplots of 2004-05. The traits are spelled out in lowercase letters, and each genotype is represented by numbers. STI= stress tolerance index, TOL= stress tolerance, SSI= stress susceptibility index, MP= mean productivity, GMP= geometric mean productivity, Ys= grain yield under drought conditions and Yp= grain yield under normal conditions.

in multivariate analysis of drought tolerance in substitution lines. They suggested that PCA1 and PCA2 explained 66 and 34% of the variation. These two PCA were related to yield potential and stress tolerant.

The correlation coefficient among any two indices is approximately by the cosine of the angle between their vectors. Thus, r = cos 180˚= -1, cos 0˚=1, and cos 90˚=0 (Yan and Rajcan, 2002) . The most prominent relations revealed by these biplot are: (i) a strong negative association between SSI and TOL with Ys, as indicated by the large obtuse angles between their vectors, (ii) a near zero correlation between SSI and Yp and also TOL with GMP and MP, as indicated by the near perpendicular vectors and (iii) a positive association between Yp and Ys with MP, GMP, and STI, as indicated by the acute angles. The results obtained from biplot graph confirmed correlation analysis.

Thomas et al. (1996) observed that some of 25 accessions of meadow fescue from seven countries that investigated in four experiments could be distinguished based on biplot display. Kaya et al. (2002) were able to reveal that genotypes with larger PCA1 and lower PCA2 scores gave high yields (stable genotypes), and genotypes with lower PCA1 and larger PCA2 scores had low yields (unstable genotypes). Yan and Rajcan (2002) showed that applying GT (genotype-trait) biplot to the multiple trait data illustrated that GT biplots graphically displayed the interrelationship among seed yield, oil content, protein content, plant height and days to maturity, among other traits and facilitated visual cultivar comparisons and selection in soybean.

Cluster analysis of F_3 and F_4 families based on Yp, Ys, TOL, MP, GMP, SSI and STI, categorized genotypes into five groups each of which having 37, 56, 13, 34 and 11 genotypes, in 2003-04, respectively (Table 3) . This analysis divided families into six groups each of which having 25, 9, 25, 45, 10 and 37 genotypes in 2004-05, respectively (Table 3) . In 2003- 04, third group had the highest amount of Yp, Ys, GMP, MP, and STI, and it was hence known as one of the most desirable cluster for both E_1 and E_2. Two groups of 2 and 5 had smaller value for SSI and TOL while their Yp and Ys were lower than group number 3. These two groups had low yield potentional under non-stress conditions. Group number 2 had high yield under stress conditions and ranked as the second best group. Therefore the genotypes of this group are suitable only for stress conditions. Selection in group number 5 favors genotypes with low SSI, TOL, Yp and Ys that not appropriate for none of E_1 and E_2, but can be used in breeding program aiming at low SSI and TOL. In forth group, families had high yield potentials under E_2 and low yield potential under E_1, thus they only suited for

Table 3. Analysis of variation and mean values of groups in cluster analysis during two years.

Year	Traits	Mean Square	C.V.	Means					
				Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
2003-04									
	Yp	457800**	9.2	579.3^{d†}	625.1^{c}	851.8^{a}	754.4^{b}	395.1^{e}	-
	Ys	358984**	11.9	379.6^{d}	533.6^{b}	687.1^{a}	482.3^{c}	302.9^{e}	-
	MP	358693**	9.1	479.5^{d}	579.3^{c}	769.4^{a}	618.3^{b}	349^{e}	-
	GMP	359489**	9.4	465^{c}	576.8^{b}	761.3^{a}	598.9^{b}	343.2^{d}	-
	TOL	198793**	25	199.6^{b}	91.5^{c}	164.7^{b}	272.1^{a}	92.2^{c}	-
	SSI	5.42	27	1.35^{a}	.56^{c}	.69^{bc}	1.39^{a}	.87^{b}	-
	STI	2.65	18.8	.53^{c}	.82^{b}	1.42^{a}	.88^{b}	.31^{d}	-
2004-05									
	Yp	370501**	7.2	781.4^{c}	976.8^{a}	938.6^{a}	652.6^{d}	799.4^{c}	853.1^{b}
	Ys	381683**	10.8	604.3^{b}	787.6^{a}	592.1^{b}	412.6^{d}	320.9^{e}	476.1^{c}
	MP	314243**	6.5	692.8^{c}	882.2^{a}	765.3^{b}	532.6^{e}	560.2^{e}	664.6^{d}
	GMP	339509**	6.9	684.5^{c}	867.2^{a}	737.5^{b}	512.7^{e}	499.6^{e}	632.2^{d}
	TOL	247395**	25.1	177.1^{d}	189.2$^{c d}$	346.6^{b}	239.9^{c}	478.5^{a}	377.1^{b}
	SSI	2.14**	22	.6^{d}	.52^{d}	.99^{c}	.94^{c}	1.58^{a}	1.18^{b}
	STI	1.45**	13.6	.75^{c}	1.21^{a}	.88^{b}	.43^{e}	.39^{e}	.63^{d}

STI= stress tolerance index, TOL= stress tolerance, SSI= stress susceptibility index, MP= mean productivity, GMP= geometric mean productivity, Ys= grain yield under drought conditions and Yp= grain yield under normal conditions.

E_2. In 2004-05, second and third groups had the highest amount of Yp, Ys, MP, GMP and STI respectively. These two groups were suited for both E_1 and E_2. Thus second group also had the lowest TOL and SSI, and the genotypes of this group have more stress tolerance and adaptation to high moisture conditions. Families in groups' number one and six were suitable only for stress and non-stress environments, respectively. This was due to high Ys and low TOL and SSI values of these groups. In sixth group, only parameter Yp was high, and it may hence conclude that there was not any drought tolerance mechanism in these families. The other groups (4,5) were not suitable for any environment and they have the least amount of the studied criteria. Comparing genotypes of different groups in two years, about 40 percentage of group number 1 (high yield only under E_1), groups number 2 and 3 (high yield under E_1 and E_2) and group number 6 (high yield only under E_2) in 2004-05 derived from families with high yield only under stress environment of 2003-04. But genotypes having high yield only under non- stress environment, included about 20% of these groups in 2004-05 where the majority of which belong to group number 6 (high yield only under E_2) . In general, moisture- stress environment was well suited for selecting superior genotypes for drought tolerance while normal environment of irrigated conditions was relatively suited for selecting well genotypes which adapted to non-stress environments in this population. The genotypes that grouped in cluster analysis were similar to genotypes that recognized from biplot analysis for every environment.

Mean grain yield under stress conditions was 480.7 g/m^{-2} in 2003-04 which showed a reduction of 26% with comparison of the non-stress conditions (control). In 2004- 05, the reduction of grain yield under stress was about 36%. Therefore, although mean grain yield in both water-stress and non-stress environments were higher in 2004-05, but the percentage of yield loss was higher in 2004-05 than 2003-04. A positive correlation was found between drought- stress grain yield and non-stress grain yield within each year and grain yield averaged on two years (Figure 4). The relationship between grain yield under drought stress and non-stress conditions in 2003-4 was closer (R^2= 0.5) than 2004-05 (R^2=0.3) and R^2 for grain yield averaged on two years and 2004-05 year were nearly equal (R^2= 0.32, R^2=0.37). These results indicated that the amount of grain yield in 2004-05 is close to average of two years which was due to increase in the degree of homozygosity with each subsequent generation (F_4), and the declines of environmental effects. Therefore, selection for responsiveness to increa-sed moisture should be carried out initially under opti-mum conditions during the earlier generation with higher heterozygosity (F_2) and then could be applied at low moi-

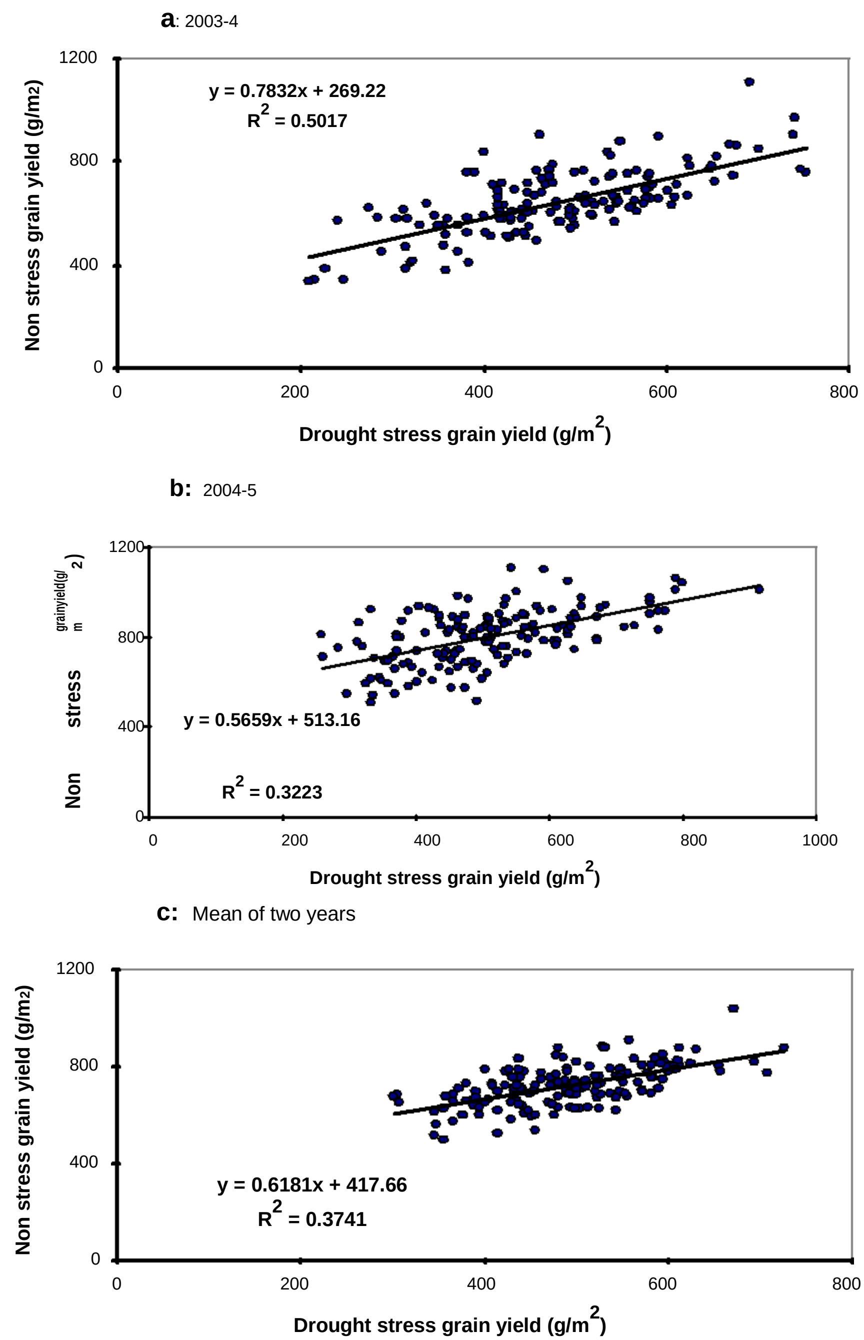

Figure 4. The relationship between grain yield produced under non stress and drought stress environments in different years (a, b) and mean of two years (c).

sture conditions in subsequent generations (F_3, F_4) (Kirigwi et al., 2004). Rizza et al. (2004) used linear regression between relative yield under irrigation and relative yield under rainfed conditions and observed four main types of genotypic response in barley. These four quadrant includes the genotypes with high and stable yield, the genotypes with good adaptability to water stress but lower yield potential, the genotypes with constant low yield and the genotypes with high yield potential and low adaptability to water stress. The same results obtained in the study of Houshmand et al. (2005) and they could recognize genotypes that performed superior under both salinity stress and nonstress conditions.

Table 4. Principal component loadings for the traits measured on some families of durum wheat F_3 and F_4 lines.

Traits	2004-04		2004-05	
	Component 1	Component 2	Component 1	Component 2
Yp	0.41	0. 3	0.37	0.4
Ys	0.43	-0.24	0.44	-0.23
MP	0.46	0.06	0.46	0.12
GMP	0.46	-0.01	0.46	0.02
TOL	0.06	0.66	0.01	0.65
SSI	-0.14	0.64	-0.19	0.59
STI	0.45	-0.01	0.46	-0.01
Eigenvalue	4.95	1.98	4.67	1.69
Percent of variation	70.82	28.34	66.79	28.05
Cumulative percentage	70.82	99.17	66.79	94.84

STI= stress tolerance index, TOL= stress tolerance, SSI= stress susceptibility index, MP= mean productivity, GMP= geometric mean productivity, Ys= grain yield under drought conditions and Yp= grain yield under normal conditions.

The result of gain from indirect selection using r N1.N2=0.33, r I1.N2=0.12, hI =0.47 and hN=0.45 showed that the yield gain in a drought environment from selec-tion conducted under moisture-stress environments will be 2.6 times greater than that of under non-stress environment. In general, moisture-stress conditions were more suited for selecting superior drought-tolerant geno-types. The selection advantage of the moisture-stress environments is due to the higher genetic correlation of non- irrigated yields obtained in different years compared with genetic correlation of irrigated yield with non-irrigated yield in different years. Low moisture selection environ-ment was expected to favor expression of adaptive traits associating with the soil moisture. Cecarelli (1989) belie-ved that selection of barley should be carried out under a drought stress environment. His further investigation reaches to a conclusion that the largest genetic gains in barley were obtained when using landraces and direct selection under severe stress-conditions (Cecarelli, 1998). On the other hand, in soybean Sneller and Dom-bek (1997) reported that selection from irrigated trails would improve yield in drought environment better than selection from nonirrigated trails. The results of present study are inagrement with those of Sneller and Dombek. Kirigwi et al. (2004) studied some alternative moisture selection across F2 to F6 generations in wheat and observed that selection under optimum conditions in F2 enables the identification of lines with responsiveness to increased moisture, while selecting under limited mois-ture in the following generation identifies high-yielding lines carrying traits for performance under stress condi-tions.

Comparison between average grain yield of 25% top of high yielding lines in moisture-stress environment, non-moisture stress environment, TOL, STI, MP and GMP criteria in the drought environment revealed that all the high value indices gave almost similar genotypes under drought environment in different year, because the esti-mates of genetic effects from either non-moisture or moisture conditions appeared equally related to genetic effects in drought environments.

The number of families in common within the top 25% families at E_1 in 2004-05 and those selected using vari-ous indices were compared. The number of families in common mirrored the results for predicted gain from indirect selection as Yp, Ys, and TOL with the fewest families in common (23%) and MP and GMP with the highest families (30%) obtained. Thus drought tolerant indices could be performing comparable with yield perfor-mance (Yp and Ys). Zavala-Garcia et. al (1992) compa-red the top 20% families of sorghum of several alterna-tives environmental stress and those selected using the various indirect procedures. They resulted that the use of the mean performance in the alternative environment was better than any single environment.

Over all, drought stress reduced significantly the yield of some families and some of them revealed tolerance to drought, which suggests the genetic variability for drought resistance in F_3 and F_4 families. Therefore, based on this limited sample of segregating populations and environ-ments, testing and selection under non-moisture (opti-mum) or moisture-stress conditions alone may not be most effective for increasing yield under drought stress. The most desirable approach would be that testing sites also include drought-stress environments so that stress-tolerant genotypes are not lost in early segregating generations due to selection practiced only in favorable environments.

With a careful selection of parents used in hybridization and with application of an appropriate selection method in segregating populations, it could be possible to obtain drought tolerance lines.

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