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ASSESSMENT OF DROUGHT TOLERANCE INDICES IN BREAD WHEAT GENOTYPES UNDER DIFFERENT SOWING DATES

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ABSTRACT. The capability of a genotype to achieve acceptable yield over a broad range of sub-optimum and suitable conditions is extremely imperative. Late planting and end-season drought stress are two main factors limiting wheat yield in northwest of Iran. In a 2-year field experiment at Miandoab, Iran, the ability of several selection indices to identify drought resistant genotypes under different sowing dates and moisture conditions were evaluated. Six genotypes of differing response to water scarcity were planted at 20-d intervals on three dates from 11 October to 20 November. Drought resistance indices were utilized on the basis of grain yield under end-season drought (Ys) and normal (Y_N) conditions. Evaluation of MP, HARM, GM, STI, TOL, SSI, RDI, YSI and Yr indicated that late sowing (20 Nov) significantly decreased drought tolerance in all investigated genotypes. However, yield comparisons under normal and terminal drought stress conditions revealed that promising lines (C-81-4, C-81-10, C-81-14 and C-82-12) had better performance than local checks (Zarrin and Alvand). Furthermore under both moisture conditions C-81-10 genotype had the greatest grain yield. Based on drought indices like as MP, GMP, STI and HARM C-81-10 genotype introduced as the most tolerant genotype to end-season drought stress. Grain yield showed a positive and significant correlation with HARM, GMP, MP, STI and YI indices were more efficient for recognizing high performance genotypes under different sowing dates and diverse moisture stress.

Key words: Genotypic variation; Grain yield; Moisture stress; Sowing time; *Triticum aestivum.*

INTRODUCTION

Low rainfall and insufficient availability of water for optimum plant growth, i.e. drought, is a major

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restriction to agricultural production in arid and semi arid region (Rajala *et al.,* 2009; Delmer, 2005). Bread wheat is the most widely grown cereal crop and is extensively grown in rainfed area of Iran, where inadequate rainfall and high temperatures during grain filling at the end of the growing season restrict grain production. Intermittent or terminal water scarcity can drastically reduce grain yield in these regions (Sio-Se Marde *et al.,* 2006). The most important management options under sub-optimum condition include development of resistance cultivars and choosing the favorable sowing date to avoid dealing with adverse conditions. Classical breeding programs for introducing drought resistant cultivars are often obstructed by low heritability for drought tolerance, ineffective screening strategies and unfeasibility to create repeatable stress conditions (Kirigwi *et al.,* 2004).

The rainfall pattern (frequency, duration and amount) in the major rainfed wheat growing regions of Iran, west, northwest, and portions of the southwest, is highly variable from year to year. Hence one of the necessities for achieving high yield is the choice of the suitable sowing date since most of the precipitation falls during active growing period. Moreover it should be consider that sowing date depends on the maturity period of the specific wheat variety (Tannerr *et al.,* 1991). Genetic variability exists among winter wheat genotypes in response to sowing dates and late-season drought stress, and thus, the choice of sowing date and cultivar are important management options to optimise grain yields in such semi-arid regions (Turner, 2004).

Occurrence of drought stress and loss of yield are the main concern of plant breeders in rainfed farming systems and they hence looking reliable screening methods for yield performance and drought tolerance in conditions of water scarcity. Drought tolerance is defined as the relative yield of a genotype compared to other genotypes, subjected to the same drought stress. Blum (1988) measured drought susceptibility in each genotype as reduction in yield under drought stress, whilst the mentioned values are baffled with different yield potential of genotypes (Ramirez and Kelly, 1998). However difference in yield potential could cause by factors related to adaptation rather than to drought tolerance by itself (Golabadi *et al.,* 2006). To discriminate drought tolerance genotypes, various selection indices have been proposed on the basis of grain yield in normal and stress conditions (Huang, 2000). Stress tolerance (TOL) has been defined 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 (McCaig and Clarke, 1982). Fischer and Maurer (1978) introduced stress susceptibility index (SSI) for genotype screening. Guttieri *et al.* (2001) declared that SSI less than a unit indicate that genotype is a drought resistant, however SSI more than unit indicate that genotype is susceptible, since its yield reduction in drought condition is higher than the mean yield reduction of all genotypes. Stress tolerance index (STI) suggested by Fernandez (1992), which can be applied to recognize cultivars that produce high yield under both stress and control conditions. Geometric mean (GM) is mostly used by breeders interested in relative yield, because drought stress can vary in time of occurrence, severity and duration in field environment over years (Ramirez and Kelly, 1998). Yield index (YI) (Gavuzzi *et al.,*1997), yield stability index (YSI) (Bouslama and Schapaugh, 1984), harmonic mean (HARM) (Jafari *et al.,* 2009), yield reduction Ratio (YR) (Choukan *et al.*, 2006), Relative drought index (RDI) (Fischer *et al.,* 1979), Drought response index (DRI) (Fernandez, 1992) and superiority measure (P) (Clarke *et al.,* 1992) have all been employed under various conditions.

Sio-Se Mardeh *et al.* (2006) and Golabadi *et al.* (2006) reported that screening for drought tolerant wheat cultivars could be conducted through high MP, GMP and STI under stress and favorable condition. It seems that the appropriateness of indicators is depending on the timing and severity of drought stress in field conditions. Consequently genotypes screening under different sowing dates and thus various severity of drought stress could be one of the main tasks of plant breeders for exploiting the genetic variations to develop the drought tolerance in rainfed area.

The objective of the present study was to assess the screening criteria for recognizing drought tolerance in bread wheat genotypes under different sowing dates in the drought prone area of Iran.

MATERIALS AND METHODS

Site of experiments

In order to screen bread wheat genotypes in end-season drought stress conditions two experiments were carried out during cropping seasons of both 2005/2006 and 2006/2007 at the Miandoab Agricultural and Natural Resources Research Station (MANRRS) farm (1314 m; 36°58'N; 46°9'E) in Iran. The long term average of annual precipitation rate was 290 mm. Some climatic parameters during this research are given in *Table 1*. Soil texture was clay loam with 0.68% organic matter and a pH of 7.5 and EC of 2 dsm^{-2}. The existing cropping pattern was a sugar beet + wheat+ fallow rotation.

Experimental design, treatments and plant culture

Six bread wheat genotypes including Zarrin and Alvand, promising lines of C-81-4, C-81-10, C-81-14 and C-82-12 were chosen for study based on their reputed differences in yield performance under irrigated and non-irrigated conditions and differences in time of maturing.

The experiment was laid out in a 3 × 6 split-plot design with three replicates in both years. three dates of sowing at 20-d intervals (11 October, 18 October, 31 October and 20 November) were the main plot treatments and six cultivars of facultative wheat were used in the sub-plots. Cultivars Zarrin and Alvand are popular early maturing types for the moderate cold and irrigated regions of Iran, whereas, C-81-4, C-81-10, C-81-14 and C-82-12 are relative late-maturing and very responsive to sowing date and recommended for the semi-arid regions in northwest of Iran and has been found to be consistently tolerant of cold stress.

The experimental plot comprised six rows each 5 m long and spaced 20 cm apart, and each plot was 50 cm apart (i.e., without planting between plot space). Seedling density was 450 seeds m^{-2} that were planted along the rows at a depth of 5 cm.

Effect of different sowing dates and genotypes were evaluated under both of irrigated and drought stress field conditions. The irrigated experiment was considered to be a favorable condition so that plots were watered at planting, tillering, jointing, heading, flowering and grain filling stages. Start of differential irrigation was initiated at late of flowering stage and continued through crop maturity.

Nitrogen and phosphor fertilizers were applied prior to sowing at a rate of 50 kg ha^{-1} and additional side dressing of 50 kg N ha^{-1} was applied at jointing stage. The total dry weight and grain yield were measured by harvesting four rows of each plot of each plot at crop maturity.

Grain yield of both irrigated and drought stress experiments were determined after physiological maturity and used as Yp (Y_N) and Ys, respectively.

Where $\bar{Y}_S$ and $\bar{Y}_P$ are the mean yields of all cultivars under stress and non-stress conditions, respectively, and $1-\left(\bar{Y}_s/\bar{Y}_p\right)$ is the stress intensity (SI). Drought resistance indices were calculated using the following relationships:

(1) $SSI=\dfrac{1-\left(\bar{Y}_s/\bar{Y}_p\right)}{SI}$ (Fischer and Maurer, 1978)

(2) $MP=\dfrac{Y_s+Y_p}{2}$ (Hossain *et al.,* 1990)

(3) $STI=\dfrac{Y_sY_p}{(\bar{Y}_P)^2}$ (Fernandez, 1992)

(4) $GM=\sqrt{(Y_s\times Y_p)}$ (Fernandez, 1992)

(5) $TOL=\ Y_p-Y_s$ (Hossain *et al.,* 1990)

(6) $HARM=2\dfrac{Y_sY_p}{Y_s+Y_p}$ (Jafari *et al.,* 2009).

(7) $YR=1-(\dfrac{Y_s}{Y_p})$ (Choukan *et al.,* 2006)

(8) $YSI=\dfrac{Y_s}{Y_p}$ (Bouslama and Schapaugh, 1984)

(9) $RDI=\dfrac{(Y_s/Y_p)}{(\bar{Y}_s/\bar{Y}_p)}$ (Fernandez, 1992)

(10) $DRI=(Y_A-Y_{ES})/S_{ES}$ (Fernandez, 1992)

Where Y_A, Y_{ES} and S_{ES} are representative of yield estimate by regression in stress condition, real yield in stress condition and the standard error of estimated grain yield of all genotypes, respectively. Analysis of variances and mean comparison was performed using SAS computer program and Duncan's multiple range test was utilized for the mean comparisons. Correlation analysis and principal component analysis (PCA), based on the rank correlation matrix and biplot analysis were performed by SPSS ver. 16, STATISTICA ver. 8 and Minitab ver.16.

RESULTS AND DISCUSSION

Result showed that there is considerable diversity among genotypes under both different sowing dates and moisture conditions (*Tables 1 and 2*). Evaluation of the genotypes yield under non-stress condition revealed that promising lines could produce higher yield in comparison with local cultivars. However under drought stress conditions only one of the promising lines (C-81-10) significantly was different from the rest. C-82-12 genotype had high grain yield fluctuation and C-81-10 genotype had less grain yield fluctuation in two conditions (*Table 1*).

Stress intensity in the first and second year were approximately similar and it was 0.226) and 0.264, respectively. However, this index is just calculable to measuring drought stress intensity in each experiment and it has no efficiency to measuring stress intensity in different genotypes. Results illustrated that based on ranking of GMP indices C-81-4, C-81-10 and C-82-12 had the best performance during the both years and showed the highest value. According to indices, the highest MP, STI, HARM and YI as well as the lowest Yr and P were related to the C-81-10 genotype.

Table 1 - Rainfall, evaporation and mean temperature in crop seasons of 2005-2007 at Miandoab Agricultural and Natural Resources Research Station

Climatic parameters	Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
Rain fall (mm)	2005-2006	2.74	25.4	12.3	42.6	69.3	24.5	70.9	47.9	0.0	295.6
	2006-2007	143.2	10.2	16.8	39.8	19.6	35.5	54.3	14.4	0.4	334.2
Mean Temp.(°C)	2005-2006	13.4	6.7	4.2	-0.3	5.2	8.2	12.9	16.8	23.5	-
	2006-2007	12.7	1.9	-3.3	-0.8	4.3	6.8	12.6	19.5	23.2	-
Evaporation (mm)	2005-2006	56.5	0.2	0.0	0.0	0.0	0.0	89.3	149.2	288.5	583.7
	2006-2007	41.5	0.0	0.0	0.0	0.0	8.3	119.8	202.6	316.6	688.8

Table 2 - Mean comparison of drought tolerance indices and grain yield of wheat genotypes under both irrigated and drought stress conditions, using Duncan's method

Indices	Genotypes					
	Zarrin	Alvand	C-81-4	C-81-10	C-81-14	C-82-12
Yp	5.95 bc	5.78 c	6.49 ab	6.71 a	6.13 ab	6.73 a
Ys	4.68 b	4.51 b	4.81 b	5.55 a	4.60 b	4.92 b
GMP	5.25 bc	5.09 c	5.54 ac	6.04 a	5.28 bc	5.71 ab
SSI	0.88 ab	0.91a	1.07 a	0.54 b	1.13 a	0.91 a
STI	0.80 b	0.79 b	0.98 ab	1.06 a	0.80 b	0.93 ab
HARM	5.19 b	5.04 b	5.45 ab	5.99 a	5.20 b	5.60 ab
TOL	1.27 a	1.27 a	1.64 a	1.09 a	1.53 a	1.81 a
MP	5.32 bc	5.15 c	5.63 ac	6.09 a	5.37 bc	5.82 ab
RDI	1.03 a	1.03 a	0.97 a	1.14 a	0.96 a	1.02 a
Yr	0.20 a	0.21 a	0.25 a	0.12 b	0.25 a	0.21 a
YI	0.98 b	0.94 b	0.97 b	1.14 a	0.94 b	1.03 b
YSI	0.79 a	0.79 a	0.74 a	0.87 a	0.74 a	0.78 a
DRI	10.54 a	10.55 a	10.66 a	10.22 a	10.69 a	10.94 a
P	2.32 ab	2.43 a	1.46 ac	0.94 c	1.77 ac	1.36 bc

Table 3 - Changes in tolerance and susceptibility indices of bread wheat genotypes under different sowing dates

Indices	Sowing dates		
	11 October	31 November	20 November
Y_N	9.128 a	5.479 b	4.242 c
Ys	6.981 a	4.465 b	2.999 c
GMP	7.964 a	4.964 b	3.543 c
SSI	0.993 a	0.571 c	1.172 a
STI	1.689 a	0.615 b	0.341 c
HARM	7.875 a	4.908 b	3.467 c
TOL	2.147 c	0.914 a	1.247 b
MP	8.055 a	5.022 b	3.623 c
RDI	1.003 b	1.137 a	0.946 b
Yr	0.230 a	0.128 b	0.273 a
YI	1.469 a	0.911 b	0.620 c
YSI	0.770 b	0.872 a	0.727 b
DRI	10.113 c	10.503 b	11.196 a
P	1.944 a	1.305 b	1.903a

Mean comparison of yield under different sowing dates showed that the highest potential yield was achieved by early sowing date and this superiority was also observed in stress conditions (*Table 3*). Based on HARM, GMP, MP, STI and YI indices 11 October recommended as the most suitable sowing date. However, drought indices like as Yr, TOL and SSI introduced the second sowing date (31 November) as the best planting time. This may resulted from very minor changes of grain yield under stress and non-stress condition.

It seems that in addition to sowing date, genotype earliness is the critical aspect in the management of wheat in Mediterranean climates (Barradas and López-Bellido, 2009). In early mature genotypes Initiation of the active growth can be occurred during late of winter, since coincidence of growth and precipitation increase rainfall effectiveness. Earlier flowering is important in area with end-season water scarcity as it provides a better balance between pre-anthesis and post-anthesis water use so that grain filling can be completed under more favorable conditions (Khakwani *et al.,* 2011).

Cereal grain yield is a complex trait of interrelated components: plants per unit land area, spikes per plant, spikelets per spike, grains per spikelet, and single grain weight. Terminal drought occurring during the grain filling period is known to induce grain abortion and reduce grain filling capacity, i.e. sink strength adjust to reduce source capacity (Yang *et al.,* 2001; Rajal *et al.,* 2009). It seems that delaying sowing date may worsen the mentioned effect through shortening of some phenological periods. Another hand the lat sowing date may encounter the critical growth stage with high temperature. At grain filling, high temperature has been reported to reduce grain number (Calderini and Reynolds, 2000).

Correlation analysis among grain yield under two environments and drought tolerant indices were executed. Result revealed that GM, STI, HARM, MP, YI and P indices that were correlated with grain yield under two conditions and during the both years (*Tables 4 and 5*) and they can be the appropriate indices for screening wheat genotypes. These findings are in accordance with the results of Mohammadi *et al.* (2011) in bread wheat. The significant correlations between quantitative drought resistance indices such as MP, GMP, STI and HM with yield in stress and nonstress conditions.are in consistent with those reported by Ganjeali *et al.* (2011) in chickpea and Sio-Se Mardeh *et al.* (2006) in bread wheat. Khakwani *et al.* (2011) observed positive and significant correlation of some yield components with GMP in wheat varieties Golabadi *et al.* (2006) showed that there were positive and significant correlations among Y_N and (MP, GMP and STI) and Ys and (MP, GMP and STI) in both years and hence recommended them as better predictors of Y_N and Ys in comparison with TOL and SSI. SSI showed a negative correlation with yield under stress in both years (*Tables 4, 5*).

Table 4 - The correlation coefficients between Y_N, Ys and tolerance indices during the first year

	Y_N	Ys	GM	SSI	STI	HARM	TOL	MP	RDI	YR	YI	YSI	P
YS	0.83*												
GM	0.95**	0.97**											
SSI	-0.11	-0.63*	-0.41										
STI	0.95**	0.96**	1.00**	-0.42									
HARM	0.94**	0.97**	1.00**	-0.44	1.00**								
TOL	0.34	-0.23	0.03	0.89*	0.03	-0.01							
MP	0.96**	0.96**	1.00**	-0.38	1.00**	1.00**	0.06						
RDI	0.11	0.63*	0.41	-1.00**	0.42	0.44	-0.89*	0.38					
YR	-0.11	-0.63*	-0.41	1.00**	-0.42	-0.44	0.89*	-0.38	-1.00**				
YI	0.83*	1.00**	0.97**	-0.63	0.96**	0.97**	-0.23	0.96**	0.63	-0.63			
YSI	0.11	0.63*	0.41	-1.00**	0.42	0.44	-0.89*	0.38	1.00**	-1.00**	0.63		
P	-0.97**	-0.89*	-0.97**	0.23	-0.96**	-0.96**	-0.19	-0.98**	-0.23	0.23	-0.89	-0.23	
DRI	-0.23	-0.72*	-0.52	0.97**	-0.52	-0.55	0.83*	-0.49	-0.97**	0.97*	-0.72*	-0.97*	0.37

* and ** significant at 5% and 1% probability levels , respectively

Table 5 - The correlation coefficients between Y_N, Ys and tolerance indices during the second year

	Y_N	Ys	GM	SSI	STI	HARM	TOL	MP	RDI	YR	YI	YSI	P
YS	0.54												
GM	0.81*	0.93**											
SSI	-0.36	-0.88**	-0.75*										
STI	0.76*	0.91**	0.97**	-0.74*									
HARM	0.76*	0.96**	1.00**	-0.77*	0.97**								
TOL	0.42	-0.53	-0.18	0.58	-0.22	-0.27							
MP	0.87*	0.89*	0.99**	-0.71*	0.95**	0.98*	-0.08						
RDI	0.36	0.88*	0.75*	-1.00**	0.74*	0.77*	-0.58	0.71*					
YR	-0.36	-0.88*	-0.75*	1.00**	-0.74*	-0.77*	0.58	-0.71*	-1.00**				
YI	0.54	1.00**	0.93**	-0.88*	0.91**	0.96**	-0.53	0.89*	0.88*	-0.88*			
YSI	0.36	0.88*	0.75*	-1.00**	0.74*	0.77*	-0.58	0.71*	1.00**	-1.00**	0.88*		
P	-0.91**	-0.83*	-0.98**	0.63*	-0.95**	-0.96**	-0.02	-0.99**	-0.63*	0.63	-0.83*	-0.63*	
DRI	0.42	-0.51	-0.17	0.48	-0.20	-0.26	0.98**	-0.07	-0.48	0.48	-0.51	-0.48	-0.03

* and ** significant at 5% and 1% probability levels , respectively

The genotypes (C-81-4 and C-81-14) with relatively high yield under terminal drought stress could not significantly maintain their superiority under non-stress conditions and produced comparatively lower yield under stress and showed the lowest SSI.

Three dimensional scatter graph was used where yield in stress (Ys), yield in non-stress (Y_N) and drought resistance indices were placed in X, Y and Z axis. In this graph, X and Y surfaces have been separately fractioned to four equal parts according to Fernandez (1992). This researcher in assessment of genotypes performance under stress and non-stress condition divided them into four groups according to their yield responses to environmental situation (A) genotypes with high performance under both stress and non-stress conditions, (B) genotypes with high yield under non-stress, (C) genotypes with poor yield under stress and (D) genotypes with poor performance under both stress and non-stress conditions. Also it was suggested that the indices which are able to separate group A from the other groups are the best for screening drought tolerant genotypes. Three-dimensional plots (Ys, Y_N and STI, HARM) were presented to show the interrelationships among these three variables to separate the group A Genotypes (the high yielding genotypes under both drought stress and irrigated conditions), from the other groups (groups B, C, D), and to illustrate the advantage of STI and HARM indices as selection criterion for identifying high-yielding and stress tolerant genotypes during the different years.

Assessment of three dimensional scatter graphs for STI and HARM during the first year (*Fig. 1- A and C*) indicated that genotype numbers 4, 3 and 6 (C-81-10, C-81-4 and C-82-12) are placed on group A. These genotypes are firstly superior for yield in stressed and non-stressed conditions and are secondly superior for quantitative tolerance indices than others, so they were recommended as candidate genotypes for tolerance to drought. Despite genotype 5 (C-81-14) having high yield in irrigated conditions and its yield was relatively low under terminal drought stress, so was placed on group B. However genotype numbers 1 and 2 (Zarrin and Alvand) has been classified as group D. Nevertheless, the result of second year was somewhat different so that genotype numbers 1 and 4 (Zarrin and C-81-10) were placed on group A. Conversely, yield potential in genotype numbers 3 and 6 (C-81-4 and C-82-12) were high but their yields in stressed conditions were poor, so these genotypes were classified as drought susceptible genotypes. During the second year genotype numbers 5 and 2 (C-81-14 and Alvand) showed a poor performance under both stress and non-stress conditions and classified as group D (*Fig. 1 – B and D)*. Favored genotype was C-81-10 (No. 4) that fall in the A group, this genotype had high and stable grain yield in both environments and years. The similar trends observed for other drought indices like as MP, GMP and YI (data not presented) during the both years.

It seems that selection based on high yield and adaptability through stress indices provides a measure to recognize stress tolerance genotype. This is because yield reduction is the major concern from the farming standpoint. However in the presence of genotype × year interaction, powerful selection will need molecular markers since the molecular markers expressions are less susceptible to environmental properties during the different years (Benmahammed *et al.,* 2010).

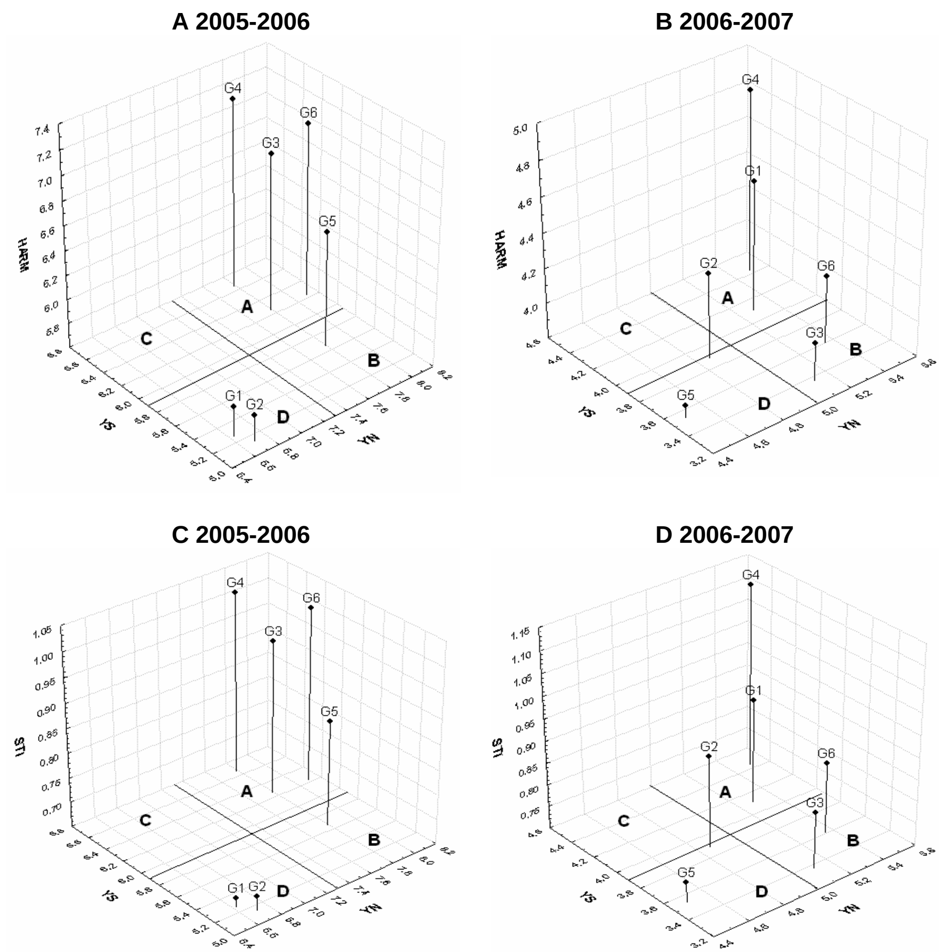

Figure 1 - Three dimensional scatter graph for showing the relationship between yield in stress (Ys), yield in non-stress (Y_N) and drought resistance indices (HARM and STI) for six genotypes of bead wheat at Miandoab (2005–2007)

In order to further investigation of relations among drought tolerance indices, principal component analysis were performed (*Fig. 2*). Results demonstrated that there is had positive and high significant correlations with yield in stressed and stress-free conditions with some indices such as MP, HARM, GM, STI and YI, but this component had negative correlation with DRI during both years (R2 = −0.88 and R2 = −0.76 for first and second year, respectively). Also a high and significant negative correlation was observed between SSI and Yr with RDI and YSI. this was consistent with result of Farshadfar *et al.* (2012) who reported that Ys, DI, YI, STI, GMP and MP exhibited strong correlation with Ys and Yp, therefore, they can discriminate drought tolerant genotypes with high grain yield at the same manner under stress and stress-free conditions.

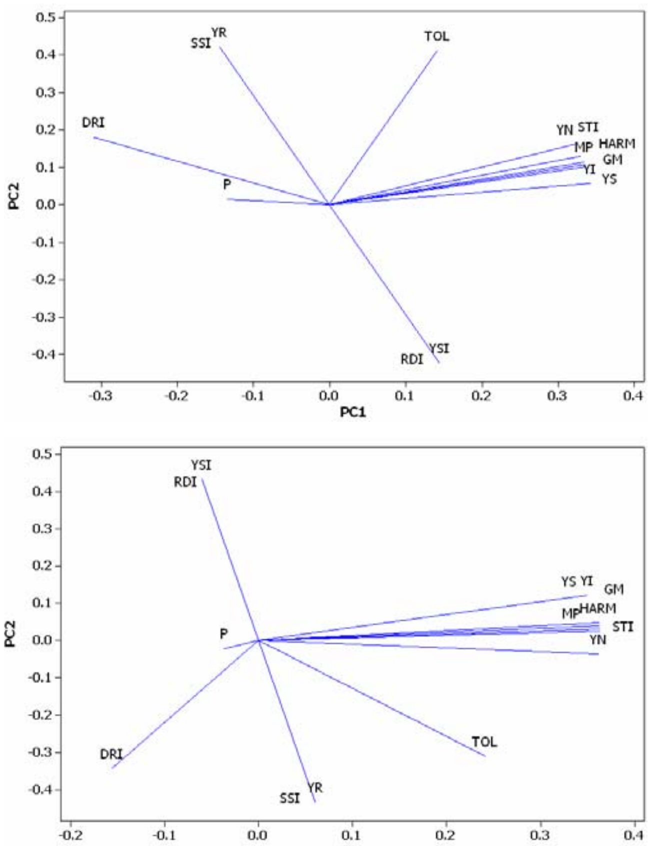

Figure 2 - Principal component analysis of drought resistance indices (up) for the first year (low) and the second year

CONCLUSIONS

Considering the results of this study, it was observed that terminal drought stress decreased grain yield up to 1.435 t ha^{-1} over stress-free condition. Delaying the sowing dates had a clear impact on grain yield in winter wheat genotypes, so that per day delaying in sowing date could reduce grain yield up to 112 kg ha^{-1}. Genotype C-81-10 showed the highest performance in first sowing date under drought stress condition. However in the second planting date genotype C-81-10 and C-81-14 showed a significant superiority over other genotypes. Genotype C-81-10 during two years in both terminal drought stress and irrigation conditions, in comparison with other genotypes, had higher yields. It was also desirable in terms of HARM, GMP, MP, STI and YI indices, so it can be recommended as candidate genotype for drought resistance in cold regions with end-season water scarcity.

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