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Full Length Research Paper

Behavior of durum wheat genotypes under normal irrigation and drought stress conditions in the greenhouse

Mostafa Ahmadizadeh[1]*, Mostafa Valizadeh[2], Hossein Shahbazi[3] and Ali Nori[3]

[1]Young Researchers Club, Jiroft Branch, Islamic Azad University, Jiroft Branch, Iran.
[2]Department of Agronomy and Plant Breeding, Faculty of Agriculture, University of Tabriz, Tabriz, Iran.
[3]Islamic Azad University, Ardabil Branch, Iran.

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Drought is a major problem reducing agronomic crop production worldwide. Increasing the genetic potential of yield in water deficit condition is one of the major objectives of durum wheat breeding programs in Iran and other countries. This study was conducted to determine drought tolerant genotypes with high yield in normal and drought stress conditions. Twenty-five durum wheat genotypes were tested in a randomized complete block design with three replications under greenhouse condition during 2010 and 2011. Eight drought tolerance indices mean productivity (MP), tolerance index (TOL), geometric mean productivity (GMP), stress susceptibility index (SSI), yield index (YI), harmonic mean (HARM), yield stability index (YSI) and stress tolerance index (STI) were applied on the basis of grain yield in drought stress (Ys) and normal irrigation (Yp) conditions. Based on different drought indices, pol-dash (1) and chakmak genotypes were more drought tolerant than the other genotypes. 3D graphs, Bi-plot and cluster analysis confirmed these results. Principal components analysis showed two components which explained 98.0% variation. Genotypes were grouped in cluster analysis (using Ward's method) based on Yp, Ys and quantitative indices of drought tolerance. Finally, the results of correlation and other analysis showed that the most suitable indices to screen genotypes in drought stress condition were MP, STI, GMP and HARM.

Key words: Landrace, screening, bi-plot, principal component, cluster analysis**.**

INTRODUCTION

Drought stress is the most important factor limiting yield by restricting most stages of crop growth in arid and semiarid areas (Dadbakhsh and YazdanSepas, 2011). Drought stress affects 40 to 60% of the world's agriculture lands (Shahryari and Mollasadeghi, 2011).

Wheat is one of the agricultural plants which are cultivated in large scale in semi-arid areas; where with varying rainfall in different years. Considering the low heritability of drought tolerance and lack of efficient selection strategies, production of drought tolerant cultivars is difficult (Kirigiwi et al., 2004). Drought exacerbates the effect of the other stresses to which plants are submitted (abiotic or biotic) and several different abiotic stresses result in water stress (like salt and cold stress). Survival under this stressful condition depends on the plant's ability to perceive the stimulus, generate and transmit the signals and initiate various physiological and chemical changes (Sayar et al., 2008; Tas and Tas, 2007). Due to occurrence of different forms of drought stress, during different stages of wheat growth, the average yield which was obtained in such areas every

*Corresponding author. E-mail: ahmadizadeh.mostafa@yahoo.com. Tel: +989194457655. Fax: +983482217835

Abbreviations: TOL, Tolerance index; **MP,** mean productivity; **GMP,** geometric mean productivity; **SSI,** stress susceptibility index; **YI,** yield index; **HARM,** harmonic mean; **YSI,** yield stability index; **STI,** stress tolerance index; **Ys,** yield in drought stress; **Yp,** normal irrigation.

year is 30% of the maximum yield which can be harvested (Denge et al., 2005). Weather fluctuation including the amount, duration, frequency and timing of rain in relation to crop growth stages are primary determinants of the levels of terminal or intermittent drought stress under rain-fed conditions. Significant variation for these seasonal factors and their interaction with genotypes complicate the selection process in field grown nurseries (Pouresmael et al., 2009; Sadeghzadeh-Ahari et al., 2009). Prolonged drought stress condition results in severe decrease of performance in arid and semiarid areas. Reforming drought tolerance in wheat species is one of the most important solutions to fight the drought. Drought tolerance is a quantitative trait and there is no direct measuring method for it. It makes identifying drought tolerant genotypes difficult. On the other side, performance increase in water shortage condition requires identifying drought tolerant genotypes and management affairs to maximize accessible water (Abdolshahi et al., 2010). Risk management is very crucial in the investment and financing decisions for farmers of developing countries and in transition economies. Basic risk management in agriculture includes choosing plant varieties against adverse weather events (Mohammadi et al., 2011).

Many modern cultivars, in wheat and other crops as well, are often genetically similar, with a rather narrow genetic base. Therefore in breeding we need to utilize sources of new diversity. Landraces, which have arisen through a combination of natural selection and the selection performed by farmers, usually have a broader genetic base and can therefore provide valuable characteristics important for breeding. Therefore, it is necessary to investigate genetic diversity in the currently used wheat germplasm in order to maintain a desirable level of genetic variation in future wheat breeding (Ahmadizadeh et al., 2011a). Durum wheat (*Triticum durum*) is grown on 10% of the world wheat areas. More than 11 million ha of durum wheat is grown in the Mediterranean basin under rainfall and temperatures conditions showing for their large and unpredictable fluctuations over years. 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 rain-fed conditions. There is agreement that a high yield potential is advantageous under mild stress, while genotypes with low yielding potential and high drought tolerance may be useful when stress is severe (Mohammadi et al., 2010). Increasing the genetic potential of yield in water deficit condition is one of the major objectives of durum wheat breeding programs in Iran and other countries (Karimizadeh and Mohammadi, 2011). Breeding for drought resistance has long been part of the breeding process in most crops that have been or are being grown under dry land conditions. Drought tolerance improvement has become a breeders' major aim in dry areas. Nevertheless, drought tolerance is a complex trait resulting from the contribution of numerous factors (Merah, 2001). Understanding the plant response in dry environments has great importance and also a fundamental part of producing stress tolerant crops (Mohammadi et al., 2011). Breeding for drought resistance is complicated by the lack of fast, reproducible screening techniques and the inability to create routinely and repeatable water stress conditions when a large amount of genotypes should be evaluated. Achieving a genetic increase in yield under these environments has been recognized to be a difficult challenge for plant breeders while progress in grain yield has been much higher in favorable environments (Talebi et al., 2009). Thus, drought indices measuring yield loss under drought conditions in comparison to normal conditions have been used for screening drought-tolerant genotypes (Dadbakhsh and YazdanSepas, 2011; Talebi et al., 2009). These indices are either based on drought resistance or susceptibility of genotypes.

To differentiate drought resistance genotypes, several selection indices have been suggested on the basis of a mathematical relationship between favorable and stress conditions (Ahmadizadeh et al., 2011b). Rosielle and Hamblin (1981) proposed tolerance index (TOL) and mean productivity (MP). Tolerance index is difference crop yield in two different conditions and MP is mean productivity in drought stress and non-stress condition. High amounts of TOL showed plant susceptibility to drought stress and selection was based on low TOL. High mean productivity also showed more tolerance to stress. The stress susceptibility index (SSI) is determined based on mean yield of plants under suitable and stress condition. A low amount of SSI is due to low change of plant yield in stress condition in comparison with non stress conditions which results in more drought tolerance of the plant (Fischer and Maurer, 1978). Yield stability index (YSI) also was computed as suggested by Bouslama and Schapaugh (1984). This parameter was calculated for a given genotype using grain yield under stressed relative to its grain yield under non-stressed conditions.

The genotypes with high YSI is expected to have high yield under stressed and low yield under non-stressed conditions (Mohammadi et al., 2010). To reduce the disadvantage due to the significant correlation between SSI and yield under non-stress, Saulescu et al. (1998) suggested the use of deviations from the linear regression of SSI on yield in favorable conditions. Stress tolerance index (STI) function is the basis of yield in each plant in two suitable and stress conditions and mean square of yield in all experimental plant in suitable condition. STI amount is always positive and if STI amount is always higher, it shows high plant tolerance to stress (Eskandary Torbaghan et al., 2008). Kanoni et al. (2002) showed that STI and MP are the best suitable index for varieties recognition with high yield in two conditions of dry land farming (with stress) and irrigated (without stress). Selection based on the SSI and TOL indices favors genotypes with low yield under non-stress conditions and high yield under stress conditions (Golabadi et al., 2006). Selection based on STI and GMP will result in genotypes with higher stress tolerance and yield potential will be selected (Fernandez, 1992).

Ramirez and Kelly (1998) reported that selection based on combination of GMP and SSI may be more efficient for improving drought tolerance in common been. Khalili et al. (2004) showed that based on geometric mean productivity (GMP) and STI indices, corn hybrids with high yield in both stress and non-stress environments can be selected.Kaya et al. (2002) in their study concluded that genotypes with large PC1 and small PC2 have higher yield in both stressed and non stressed conditions (stable) and genotypes with large PC1 and small PC2 have lower yield (unstable). Yan and Rajcan (2002) in their study on soybean plants concluded that the correlation coefficient between the two indices is almost cosine between their vectors, so due to existence of large angle between the indices SSI, TOL, and Ys, this represents a negative correlation between them. There was positive correlation between yield in two environments and GMP, MP and STI indices, the acute angle between them was also representative of this subject. Azizinia et al. (2005) studied 40 wheat genotypes from drought tolerance point of view. They introduced sensitive and tolerant varieties by means of Fernandez (1992) and principle components analysis indices. Fernandez (1992) in his review used biplot method to identify effective drought tolerant indices on evaluation and selection of stress tolerant plants, studying vetch genotypes in different moisture regimes and showed the relationship between genotypes and stress tolerance indices in a graph in average stress conditions, and with respect to the angles between the indices in bi-plot concluded that there is positive and meaningful correlation between Yp and MP and STI indices and also between Ys and STI and MP indices. Therefore, the same indices were introduced as appropriate indices to identify stress tolerant genotypes. Landraces are important genetic resources for improvement of crops in dry areas, since they have accumulated adaptation to harsh environment over long time.Collection and characterization of various agronomic and physiological traits of landraces are primary steps in plant breeding programs. The present study was undertaken to assess the selection criteria for identifying drought tolerance i durum wheat genotypes and high-yielding genotypes in drought stress and non-stress conditions, so that suitable genotypes can be recommended for cultivation in the drought prone area of Iran.

MATERIALS AND METHODS

Experiments were undertaken on 20 durum wheat (*T. durum* Desf.) landraces along with five controls (Korifla, Chakmak, Zardak, Haurani-1 and Omrabi-5). They were grown under irrigated and drought conditions, base on randomized complete block design with three replications. The experiment was carried in the greenhouse of agricultural research station of Islamic Azad University, Ardabil branch, Iran (Northwest of Iran), during the 2010 and 2011. For the experiment, plastic pots which had 20 cm diameter and 30 cm height were selected and they were filled with 10 kg soil. Each plastic pot had been filled with cultivated soil, sand and manure with a ratio of 1:1:1 and four seeds had been planted in 3 cm depth with equal spaces. In three leaves phase, in order vernalization, the pots were moved out of the greenhouse from 21 December until 30 January (40 days). After this period, the pots were moved to the greenhouse once again. All the pots were watered in three days period to reach the irrigation capacity. In flowering phase, drought stress was exerted through every day watering control pots and not watering stress pots until they reached to 80% soil moist evacuation via weight.

Drought tolerance indices were calculated by using the following equations:

$$MP = (YPi + YSi)/2$$ (Rosielle and Hamblin, 1981)

$$HARM = 2(Ypi \times Ysi) \; / \; (Ypi + Ysi)$$ (Jafari et al., 2009)

$$GMP = \sqrt{Ypi \times Ysi}$$ (Fernandez, 1992)

$$STI = (Ypi \times Ysi)/Yp^2$$ (Fernandez, 1992)

$$TOL = (Ypi - Ysi)$$ (Rosielle and Hamblin, 1981)

$$SSI = (1-(Ysi/Ypi))/SI; \; SI = 1-(Ys/Yp)$$ (Fischer and Maurer, 1978)

Yield index $(YI) = Ysi/Ys$ (Gavuzzi et al., 1997; Lin et al., 1986)

Yield stability index $(YSI) = Ysi/Ypi$ (Bouslama and Schapaugh, 1984).

In these equations, Y_{si} and Y_{Pi} are yields of a given genotype under stress and optimum condition, respectively. Y_s and Y_p are average yield of all genotypes under stress and optimal conditions, respectively. Analysis of variance, Duncan's multiple range test ($P < 0.05$) for the mean comparisons, principle component and cluster analysis were performed by SPSS16 and Minitab15 software's.

RESULTS AND DISCUSSION

The results of simple analysis of yield in normal and drought stress conditions and stress tolerance indices showed significant differences among the genotypes in Ys, Yp and stress tolerance indices (Table 1). Nazari and Pakniyat (2010) and Shahryari and Mollasadeghi (2011) in the evaluation of barley wheat genotypes, respectively reported that there were significant differences for all criteria among the genotypes. Genotypes 1, 15 and 2 had the highest grain yield in normal condition. Genotypes 17

Table 1. Analysis of variance of Yp, Ys, and drought tolerance indices for 25 durum wheat genotypes.

S.O.V	df	Ys	Yp	TOL	MP	HARM	GMP	STI	SSI	YI	YSI
Replication	2	1.114***	1.671^{NS}	1.239^{NS}	1.083*	0.817**	0.907*	0.143*	0.696^{NS}	0.26***	0.132^{NS}
Genotype	24	0.86***	5.451***	4.486**	2.034***	1.22***	1.512***	0.303***	0.642***	0.201***	0.122**
Error	48	0.122	1.279	1.485	0.329	0.138	0.197	0.093	0.279	0.28	0.53

ns: non significant differences; *: significant at p<0.05; **: significant at p<0.01; ***: significant at p<0.001
SSI, stress susceptibility index; STI, stress tolerance index; TOL, stress tolerance; MP, mean productivity; GMP, geometric mean productivity; HARM, harmonic mean; YI, yield index; YSI, yield stability index; YS, grain yield under drought condition; YP, grain yield under normal condition.

and 2 had the highest grain yield in stress condition (Table 2).

Stress intensity (SI) has been given in stress susceptibility index (SSI) formula that it can be at most 1. In this experiment, stress intensity was calculated SI=0.435. The smaller the amount of SSI, the less stress susceptibility index (SSI) and the more relative tolerance of genotype to humidity stress will be. On the other hand, the closer of YS to YP from quantitative point of view, the less the sensitivity of that genotype to drought will be. Genotypes 20, 8, 17, 7, 23, 5, 25, 12, 19, 9, 13 and 16 were more tolerant genotypes based on SSI. Among the genotypes, genotype 17 had the highest yield in stress condition (Table 2). Jabbari et al. (2008) and Ghafari (2008) stated that genotype evaluation through SSI, categorizes experimental materials according to tolerance and stress sensitivity. Through this index, tolerant and sensitive genotypes can be specified without regarding their performance potential. Due to the fact that SSI index leads the selection towards tolerant and less efficient varieties which have less performance variations in both stress and non-stress conditions, referring to the amounts of genotypes grain yield, it was clarified that SSI is not more successful in separating the genotypes of group A from the other groups. Shirinzadeh et al. (2008) also declared that SSI has not been successful in separating the genotypes of group A from the other groups.

Except for genotypes 1, 15, 14, 24, 3, 2 and 22, other genotypes were more tolerant genotypes based on TOL, which low quantity of TOL and SSI identified tolerant genotypes (Table 2). Among these genotypes, genotype 2 had a high yield in both stress and normal conditions. Therefore, it is obvious that TOL index has been relatively successful in both stress and non-stress conditions to select the genotypes which had the high grain yield, and lead the selection towards more efficient and tolerant genotypes. It seems that TOL and SSI had succeeded in selecting genotypes with high yield under both environments and if a given genotypes has high yields under both stress and normal conditions. It suggests that selection based on TOL will result in reduced yield under well-watered conditions. TOL and SSI had a positive and significant correlation with yield in normal irrigation condition, but its correlation with yield in drought stress condition was not significant. Since genotypes which had lower amounts of this index, identified as tolerant genotypes, selection process according to this index lead to choosing genotypes which had high yield in drought stress conditions, but their yield is low in normal irrigation condition. So this index and SSI cannot be helpful to identifying tolerant genotypes. Similar results were reported by Clark et al. (1992) and Sio-Se Mardeh et al. (2006).

Genotypes 1, 2, 15 and 17 had the most MP (Table 2). So, MP index leads the selection towards more efficient genotypes in both stress and non-stress conditions. The results of this study correspond to the results of Moghaddam and Hadizadeh (2002) and Shirinzadeh et al. (2008) which stated that MP index acts better in selecting stress tolerant genotypes compared to SSI and TOL. The highest YSI was in genotypes 20, 8, 17, 7, 23, 5, 25, 12, 19, 9, 13 and 6 (Table 2). In drought stress condition, YSI had a positive and non-significant correlation with grain yield (YS) while it had a negative and significant correlation with grain yield (YP) in normal condition. So, it cannot be a proper index for selecting the genotypes which have a high yield in two ideal irrigation and drought stress conditions (Sio-Se Mardeh, 2006; Jabbari et al., 2008). This parameter is calculated for a given genotype using grain yield under stressed relative to its grain yield under non-stressed conditions. The genotypes with high YSI is expected to have high yield under stressed and low yield under non-stressed conditions. Genotype 17 had high yield in stress condition, but it didn't have high yield in normal condition.

Genotypes 2 and 1 had the most stress tolerance index (STI). The high amount of STI in these genotypes indicates high drought tolerance and high potential yield. Genotypes 2, 1 and 17 had the most GMP. Genotypes 2 and 17 had the most HARM and YI (Table 2). Categorizing the genotypes according to two STI and GMP indices showed that the belonging rank to these two indices was similar. Course regarding calculating formula of these two indices, this result was not expected, so selection accuracy of these two indices is the same in selecting the genotypes. STI had specified the more tolerant genotypes in stress condition and GMP index is able to identify the genotypes which have the higher yield in stress and non-stress conditions (Fernandez, 1992).

Also, Najafian (2009) concluded that MP, GMP and STI (mostly GMP and STI) indices are preferred for practical usage. The observed relations were in consistence with those reported by Fernandez (1992) in mung bean,

Table 2. Drought tolerance indices of durum wheat genotypes under stress and non-stress conditions. The numbers in the parentheses are the genotype ranks for each index.

S/N	landraces	Yp	Ys	TOL	MP	HARM	GMP	STI	SSI	YI	YSI
1	kordgheshlaghi	2.30 A (1)	7.25 BC(4)	4.94 A(25)	4.77 A(1)	3.49 BC(3)	4.08 A(2)	1.25 AB(2)	1.56 AB(24)	1.11 BC(4)	0.31 DE(24)
2	sari boghda	3.49 A-C(3)	5.83 A(2)	2.33 B-D(20)	4.66 A(2)	4.36 A(1)	4.50 A(1)	1.50 A(1)	0.91 A-D(16)	1.68 A(2)	0.59 B-E(16)
3	ardabil(1)	1.83 B-E(5)	4.39 C-E(14)	2.55 B-D(21)	3.11 B-F(9)	2.56 D-H(22)	2.82 C-G(11)	0.60 D-I(11)	1.34 A-C(22)	0.88 C-E(14)	0.41 C-E(22)
4	omrabi-5(control)	1.75 D-G(18)	2.78 C-E(17)	1.02 C-E(10)	2.27 D-I(18)	2.15 F-J(17)	2.21 E-J(18)	0.36 F-J(18)	0.84 A-D(15)	0.84 C-E(17)	0.63 B-E(15)
5	langan(1)	1.81 E-G(20)	2.42 C-E(15)	0.61 C-E(6)	2.11 E-I(20)	2.02 G-J(20)	2.07 F-J(20)	0.32 G-J(20)	0.53 B-E(6)	0.87 C-E(15)	0.76 A-D(6)
6	chakmak(control)	2.53 B-G(10)	3.87 B(3)	1.33 C-E(12)	3.20 B-E(7)	3.01 CD(4)	3.10 BD(6)	0.72 C-F(6)	0.78 A-E(12)	1.22 B(3)	0.65 A-E(12)
7	zardak(control)	1.81 E-G(21)	2.26 C-E(16)	0.44 C-E(5)	2.03 F-I(21)	1.99 G-J(21)	2.01 G-J(21)	0.31 H-J(21)	0.38 C-E(4)	0.87 C-E(16)	0.83 A-C(4)
8	korifla(control)	1.74 FG(24)	2.01 C-E(20)	0.27 C-E(3)	1.87 HI(23)	1.78 IJ(24)	1.82 IJ(24)	0.26 IJ(24)	-0.01 DE(2)	0.84 C-E(20)	1.00 AB(2)
9	germi(1)	1.75 D-G(17)	3.14 C-E(18)	1.38 C-E(13)	2.44 C-I(17)	2.15 F-J(18)	2.29 D-J(17)	0.40 E-J(17)	0.78 A-E(10)	0.84 C-E(18)	0.65 A-E(10)
10	samrein(1)	1.75 D-G(15)	3.22 C-E(19)	1.46 C-E(14)	2.48 C-I(16)	2.25 E-J(15)	2.36 C-J(16)	0.43 D-J(16)	1.02 A-D(20)	0.84 C-E(19)	0.55 B-E(20)
11	germi(2)	1.96 C-G(13)	3.72 B-E(12)	1.76 C-E(16)	2.84 B-I(14)	2.47 D-I(13)	2.64 C-I(13)	0.51 D-J(13)	0.99 A-D(19)	0.94 B-E(12)	0.56 B-E(19)
12	haurani-1(control)	1.42 FG(23)	2.05 E(25)	0.62 C-E(7)	1.74 I(25)	1.68 J(25)	1.71 J(25)	0.21 J(25)	0.70 A-E(8)	0.68 E(25)	0.69 A-E(8)
13	germi(3)	2.22 D-G(14)	3.48 B-D(8)	1.25 C-E(11)	2.85 B-I(13)	2.65 D-G(9)	2.74 C-H(12)	0.56 D-J(12)	0.78 A-E(11)	1.07 B-D(8)	0.65 A-E(11)
14	ardabil(2)	2.19 B-D(4)	4.88 B-D(9)	2.68 BC(23)	3.53 BC(5)	2.85 C-F(6)	3.16 BC(5)	0.79 CD(4)	0.97 A-D(17)	1.05 B-D(9)	0.57 B-E(17)
15	moghoan(1)	1.70 AB(2)	5.98 C-E(22)	4.28 AB(24)	3.84 AB(3)	2.63 D-G(10)	3.18 BC(4)	0.78 C-E(5)	1.62 A(25)	0.82 C-E(22)	0.29 E(25)
16	langan(2)	2.29 B-F(9)	4.12 BC(6)	1.83 C-E(17)	3.21 B-E(7)	2.91 C-E(5)	3.05 B-E(7)	0.69 C-H(8)	0.99 A-D(18)	1.10 BC(6)	0.56 B-E(18)
17	pol dash(1)	3.70 B-G(10)	3.87 A(1)	0.17 DE(2)	3.78 AB(4)	3.72 B(2)	3.75 AB(3)	1.05 BC(3)	0.01 DE(3)	1.78 A(1)	0.99 AB(3)
18	germi(4)	2.27 C-G(12)	3.76 BC(7)	1.48 C-E(15)	3.02 B-G(11)	2.78 D-F(8)	2.89 C-F(9)	0.63 D-I(9)	0.79 A-D(13)	1.10 BC(7)	0.65 B-E(13)
19	samrein(2)	2.29 B-E(6)	4.36 BC(5)	2.06 B-E(18)	3.33 B-D(6)	2.80 D-F(7)	3.05 B-E(8)	0.70 C-G(7)	0.77 A-E(9)	1.11 BC(5)	0.66 A-E(9)
20	langan(3)	1.96 G(25)	1.81 B-E(11)	-0.15 E(1)	1.89 HI(23)	1.87 H-J(22)	1.88 H-J(23)	0.26 IJ(23)	-0.24 E(1)	0.95 B-E(11)	1.10 A(1)
21	ahar	1.68 D-G(19)	2.66 C-E(23)	0.97 C-E(8)	2.17 E-I(19)	2.03 G-J(19)	2.09 F-J(19)	0.32 G-J(19)	0.81 A-D(14)	0.81 C-E(21)	0.64 B-E(14)
22	germi(5)	1.93 B-F(7)	4.25 B-E(13)	2.32 B-D(19)	3.09 B-F(10)	2.63 D-G(11)	2.85 C-G(10)	0.61 D-I(10)	1.21 A-C(21)	0.93 B-E(13)	0.47 C-E(21)
23	goli bagholia	1.70 FG(22)	2.11 C-E(21)	0.41 C-E(4)	1.90 G-I(22)	1.87 H-J(23)	1.89 H-J(22)	0.27 IJ(22)	0.40 C-E(5)	0.82 C-E(21)	0.82 A-C(5)
24	magholan(2)	1.54 B-F(8)	4.21 DE(24)	2.66 BC(22)	2.88 B-H(12)	2.24 E-J(16)	2.53 C-J(15)	0.49 D-J(14)	1.40 A-C(23)	0.74 DE(24)	0.38 C-E(23)
25	pol dash(2)	2.15 D-G(16)	3.17 B-D(10)	1.02 C-E(9)	2.66 C-I(15)	2.45 D-I(14)	2.55 C-J(14)	0.49 D-J(15)	0.53 B-E(7)	1.03 B-D(10)	0.76 A-D(7)

SSI, Stress susceptibility index; STI, stress tolerance index; TOL, stress tolerance; MP, mean productivity; GMP, geometric mean productivity; HARM, harmonic mean; YI, yield index; YSI, yield stability index; YS, grain yield under drought condition; YP, grain yield under normal condition.

Talebi et al. (2009), Mohammadi et al. (2010), Golabadi et al. (2006) and Ahmadizadeh et al. (2011b) in durum wheat. Indices which had high correlation with grain yield in both stressed and non-stressed conditions have been selected as the best ones, because these were able to separate and identify genotypes with high grain yield in both conditions. With respect to the results of correlation coefficients of different indices and grain yield in two drought stress and normal irrigation conditions, we observed that indices STI, MP, GMP, YI and HARM had the above-mentioned characteristic. These indices had positive and significant correlation with grain yield of genotypes at probability level of 1% in two drought stress and normal irrigation conditions (Table 3). Therefore, genotypes which had higher amount of these indices were identified as the most tolerant genotypes. Golparvar et al. (2004) and Golabadi et al. (2006) in their studies showed that MP, GMP and STI indexes had positive and more significantly wit grain yield in stress and none stress condition and they acted successfully than other indexes. Shafa Zadeh et al. (2004) in

Table 3. Correlation coefficients between Ys, Yp and drought tolerance indices.

Parameter	Ys	Yp	TOL	MP	HARM	GMP	STI	SSI	YI	YSI
Ys	1									
Yp	0.422*	1								
TOL	0.027	0.918**	1							
MP	0.670**	0.956**	0.760**	1						
HARM	0.883**	0.781**	0.474*	0.926**	1					
GMP	0.787**	0.888**	0.634**	0.982**	0.980**	1				
STI	0.797**	0.867**	0.607**	0.969**	0.976**	0.991**	1			
SSI	-0.180	0.733**	0.887**	0.541**	0.284	0.426*	0.379	1		
YI	1.000**	0.422*	0.027	0.670**	0.883**	0.787**	0.797**	-0.180	1	
YSI	.180	-0.733**	-0.887**	-0.541**	-0.284	-0.426*	-0.379	-1.000**	0.180	1

* and ** Significantly at $p < 0.05$ and < 0.01, respectively. SSI, Stress susceptibility index; STI, stress tolerance index; TOL, stress tolerance; MP, mean productivity;
GMP, geometric mean productivity; HARM, harmonic mean; YI, yield index; YSI, yield stability index; YS, grain yield under drought condition; YP, grain yield under normal condition.

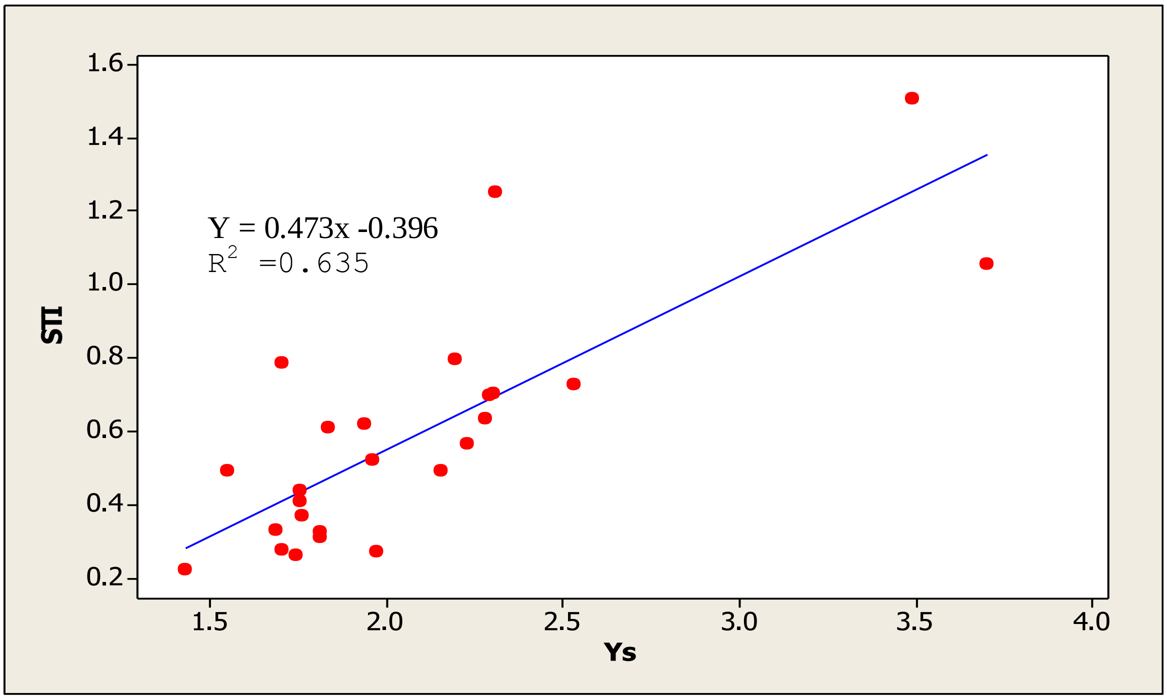

Figure 1. Relationship between grain yield (Ys) and stress tolerance index (STI).

evaluation of wheat genotypes reported that there is positive and highly meaningful correlation between yield in stressed environment and indices MP, GMP and STI and also stated that there is positive and meaningful correlation between yield in non-stressed environment and all drought tolerance and drought sensitive indices

.Karimizadeh and Mohammadi (2011) in evaluation of durum wheat genotypes under supplementary irrigated and rainfed conditions reported the significant and positive correlation of YP, MP, GMP, SSI, STI and canopy temperature depression (CTD) showed that these indices were more effective in identifying high yield genotypes under both conditions. Nazari and Pakniyat (2010) in evaluation of barley genotypes reported that there were significant differences for all criteria among the genotypes. The correlation coefficients indicated that STI, MP and GMP are the best criteria for selection of high yielding genotypes both under stress and non-stress conditions.

Figure 1 shows liner regression equation between yields in stress (Ys) condition with STI index. Based on it, more than 63% of changing in STI index with (Ys) is

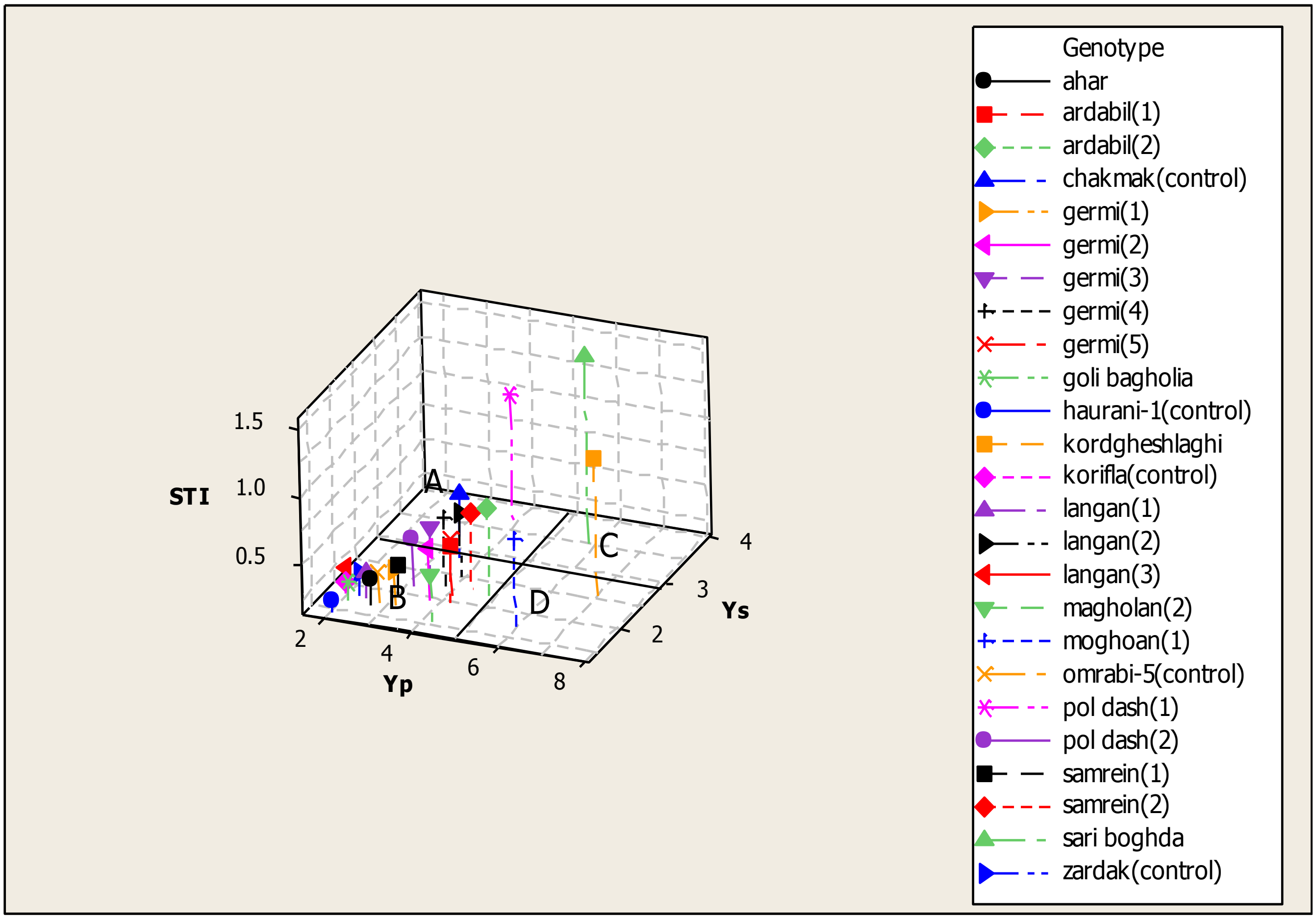

Figure 2. Scatter plot between Yp, Ys and STI.

justifiable with equation. To select drought tolerant genotypes and the genotypes which had a high yield in both conditions, this 3-dimensional graph was used (Farshadfar et al., 2001; Jamshidimoghadam et al., 2007; Pouresmael et al., 2009). Three dimensions graphs (scatter) showed relationship between three variable, yield in stress condition (Ys), yield in none stress condition (Yp) and STI (Figure 2) and HARM (Figure 3) because HARM had highest correlation among other indices. In three dimensions scatter graph with distribution of low surface scatter (surface of X with Y) to four equal parts, treatments were divided to four separate groups. Group (A) had high yield in two conditions (stress and none stress), group (B) had high yield in none stress condition and low yield in none stress condition, group (C) had high yield in stress condition and low yield in none stress condition and finally, group (D) had low yield in two conditions. Fernandez (1992) announced that the best index foe evaluation to stress is index that can separate group (A) from other groups. Results of evaluation (Figures 2 and 3) showed that pol-dash (1) and chakmak genotypes were in group (A), two genotypes moghan(1) and kordgheshlaghi were in group (D) and one genotype sariboghda was in group (c). Other experimental genotypes were in group (B).

In further evaluation of relations between genotypes and drought tolerance indices, principal components analysis was performed. Table 4 shows latent roots and special vector of under-study genotypes for two first components, the most variations between data expressed by two components (98.00%). The first vector showed 68.0% of variations and showed that indices GMP, MP, HARM, Yp and STI in the formation of this component has the highest positive coefficient, since high amounts of these indices was optimal and considering the positive relation of the first component with these indices, if we selected the top level, the genotypes were selected which had high and stable yield in different environments (drought stress, non-stress). So this component was named as drought tolerant component (Farshadfar et al., 2001; Kanouni et al., 2002; Zabet et al., 2003; Pouresmael et al., 2009). The second component had 30.0% of these variations. This component has high and positive correlation with Ys, YI and YSI. Naroui-Rad et al. (2010) obtained similar results in first principal component analysis of drought tolerance.

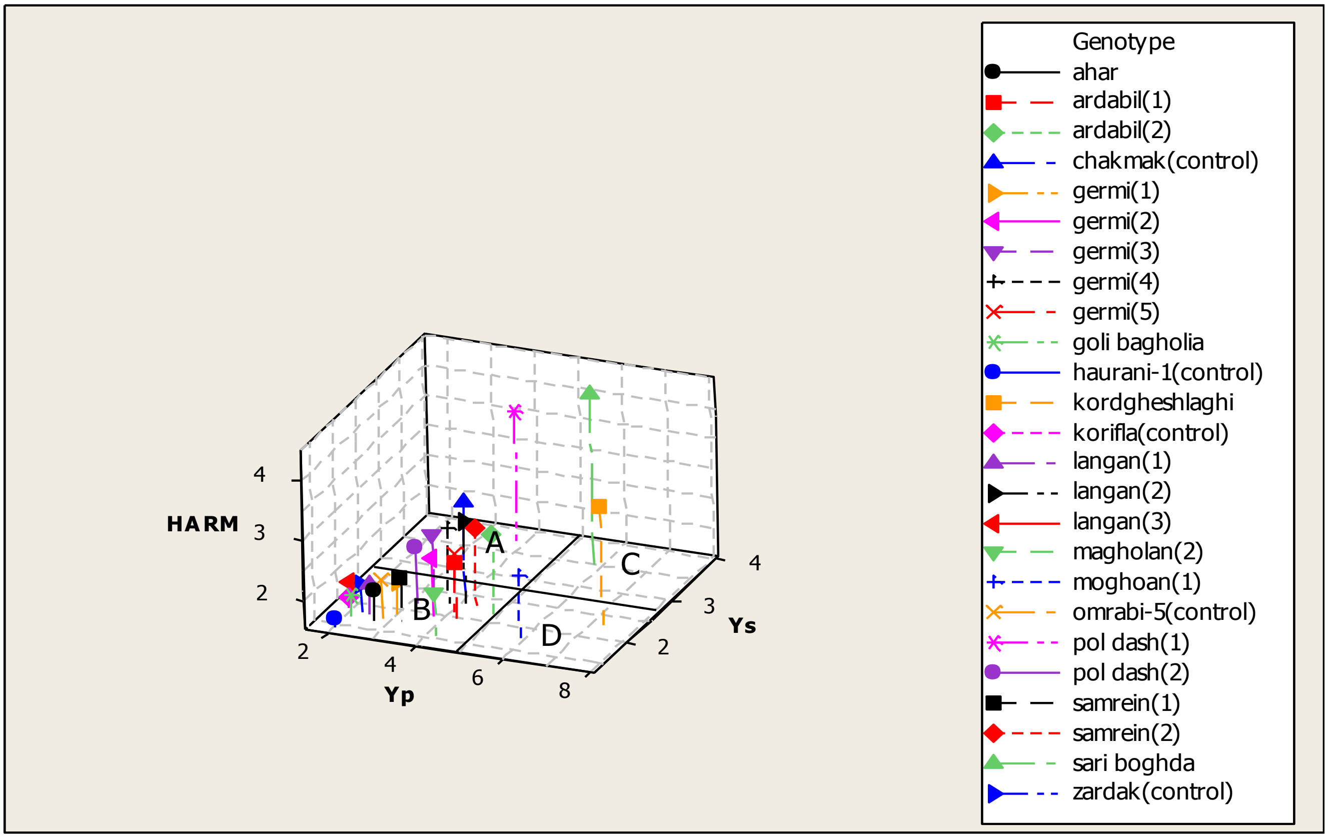

Figure 3. Scatter plot between Yp, Ys and HARM.

Table 4. Principal components and those coefficients for each indices and yield in stress and normal irrigation condition.

Component	Ys	Yp	TOL	MP	HARM	GMP	STI	SSI	YI	YSI	Cumulative (%)
PC1	0.261	0.363	0.286	0.382	0.360	0.378	0.373	0.216	0.261	-0.216	68.0
PC2	0.420	-0.166	-0.367	0.000	0.189	0.093	0.114	-0.463	0.420	0.463	30.0
											98.0

SSI, Stress susceptibility index; STI, stress tolerance index; TOL, stress tolerance; MP, mean productivity; GMP, geometric mean productivity; HARM, harmonic mean; YI, yield index; YSI, yield stability index; YS, grain yield under drought condition; YP, grain yield under normal condition.

After principal components analysis was drawn to reviewing relationships between variables based on biplot first and second components (Figures 4 and 5), the horizontal axis was related to first component and the vertical axis were related to the second component. Based on component values, the location of genotypes and their grouping were determined in top of biplot. Biplot had been used by many researchers in comparing different genotypes. Kaya et al. (2002), Dadbakhsh and YazdanSepas (2011) and Abdolshahi et al. (2010) were able to reveal that bread wheat 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). If the angle between vectors or lines which in yield in two environments and indices are located on the end, are closer to each other, in other words the angle between them is less than 90°C, this represents a positive correlation, and if the angle between the lines is more than 90°C, this indicated the correlation is negative. The correlation coefficient between two indices is almost angle cosine of their vectors (Yan and Rajcan, 2002).

According to the biplot (Figure 5), there was positive correlation between indices MP, GMP, HARM and STI and yield in two environments, and this confirming the simple correlation. Accordingly, these mentioned three indices were the most appropriate indices to screening genotypes. Two indices GMP and STI had similar value, since they were close to each other. The results of this study are compatible with Fernandez (1992), Gol-Abadi

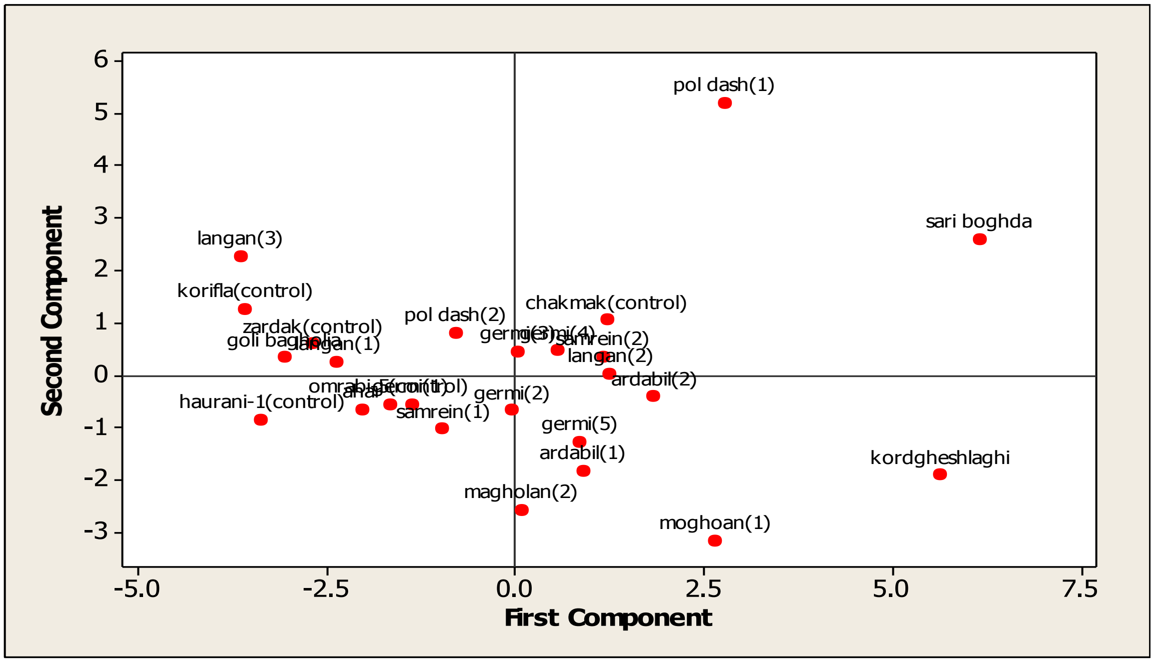

Figure 4. Biplot of durum wheat genotypes and drought tolerant indices based on first and second components in drought stress and normal irrigation conditions

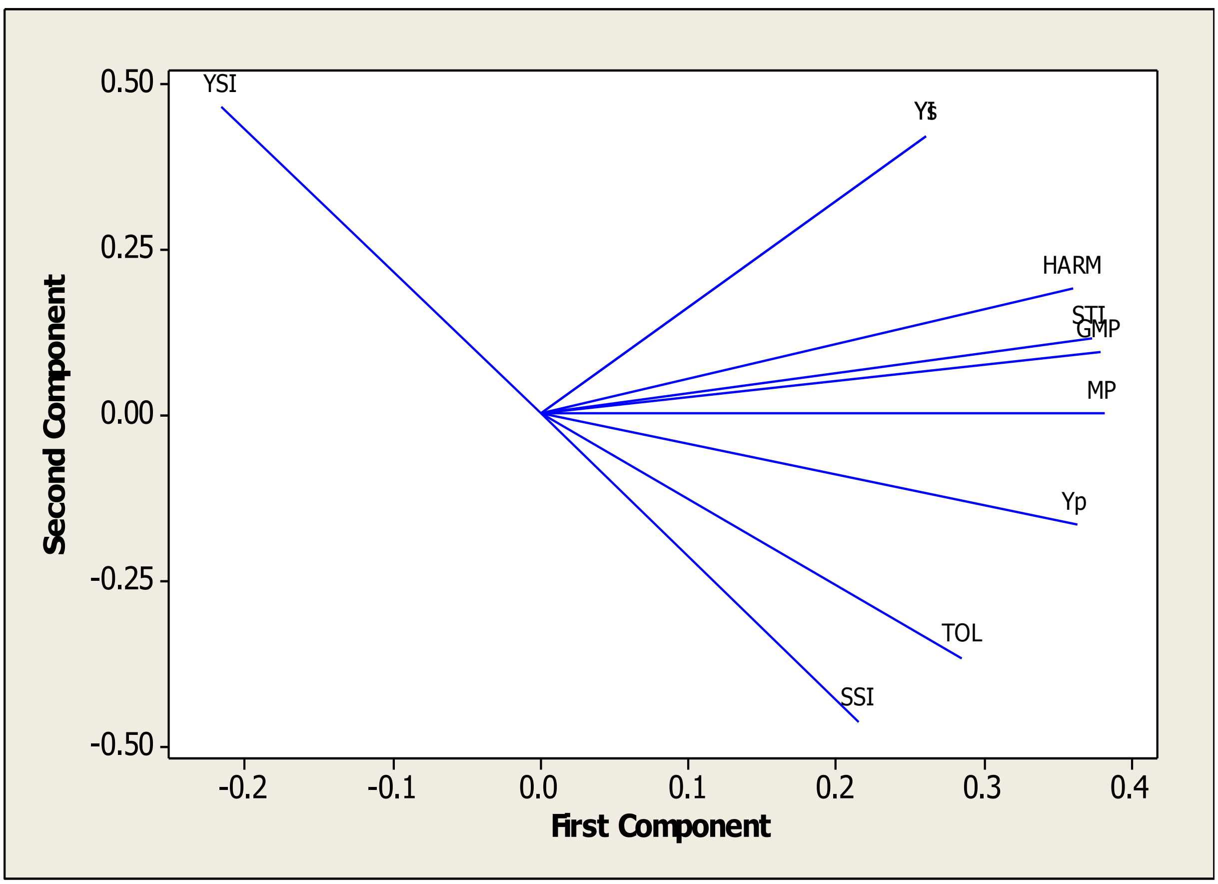

Figure 5. Biplot of drought tolerant indices based on first and second components in drought stress and normal irrigation conditions.

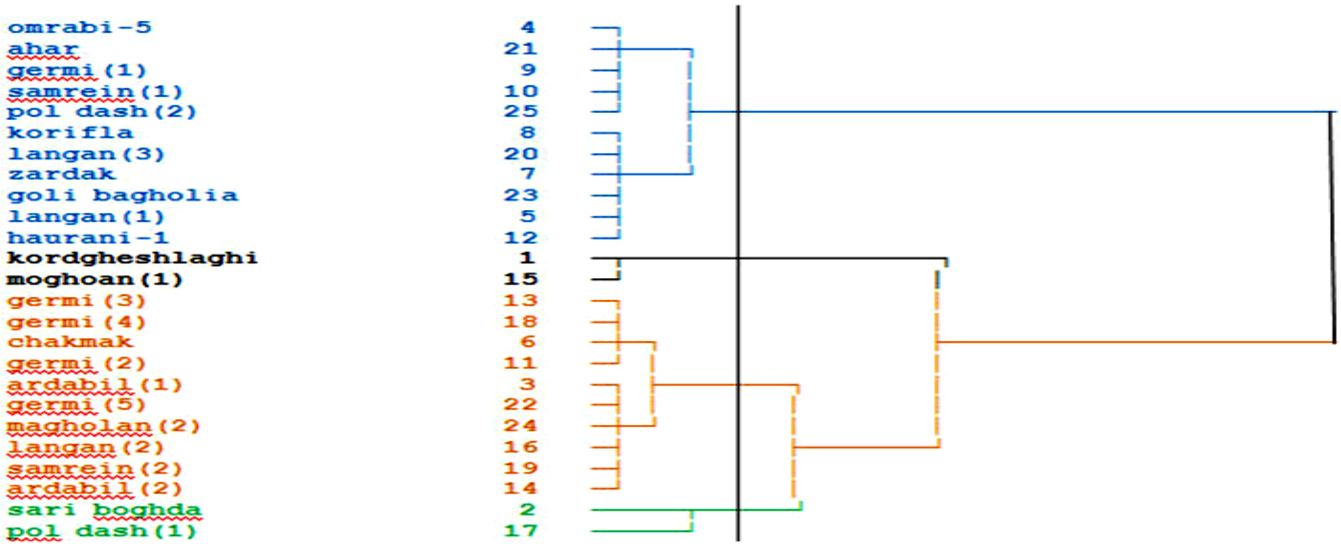

Figure 6. Clustering of durum wheat genotypes using Ward's method based on Yp, Ys and drought tolerance indices.

et al. (2006), Kaya et al. (2002), Dadbakhsh and YazdanSepas (2011). According to Biplot (Figure 4), genotypes pol-dash (1), sari-boghda and chakmak had stable and higher yield, genotype sari-boghda had large PC1 and its PC2 was almost small, so it is superior as compared to other genotypes.

Naroui-Rad et al. (2010) in evaluation of Lentil genotypes reported that STI and GMP had positive and significant correlation in 1% level with yield in drought and normal condition and principal components analysis showed two components explained 82.94% variation. Shahryari and Mollasadeghi (2011) in evaluation of wheat genotypes under end seasonal drought reported that correlation analysis between indices and mean of yield in both conditions showed that the most suitable indices to screen genotypes in drought stress condition were MP, STI, GMP and HARM. According to stress tolerance indices, principal component analysis divided genotypes into two groups (drought tolerant and drought susceptible).

Cluster analysis has been widely used for description of genetic diversity and grouping based on similar characteristics (Souri et al., 2005; Golestani et al., 2007; Malek-shahi et al., 2009; Golabadi et al., 2006). Separate cluster analysis (using Ward's method) based on Yp, Ys and other quantitative indices of drought tolerance were performed for durum wheat genotypes. Using the discriminate function analysis allowed the highest differences among groups when genotypes were categorized into four groups (Figure 6). Mean values of durum wheat genotypes groups in cluster analysis are presented in Table 5. Group (IV) Ys and majority of the drought tolerance showed maximum deviance of total means and this group may recommend as superior groups (Figure 6). Also cluster analysis supported the results of principal component analysis because genotypes 2 and 17 were in this group. Nouri et al. (2011) in evaluation of durum wheat genotypes reported that there was a positive and significant correlation between YI, MP, GMP and STI. Based on principle component analysis, a significantly positive correlation was observed between stress susceptibility index and tolerance. Cluster analysis classified the genotypes into three groups that is, resistant, susceptible and tolerant to drought conditions.

Ahmadizadeh et al. (2011b) in evaluation of thirty seven durum wheat landraces from Iran and Azerbaijan republic in field conditions on the basis of indices chakmak (2), Naxcevan (26), Ardabil-bagh oliya (15), Naxcevan (28) and xanlar (29) genotypes showed the highest tolerance than the other genotypes. Principal components analysis showed two components which explained 99.8% variation. Genotypes were grouping cluster analysis based on Yp, Ys and the other quantitative indices of drought tolerance which are categorized into four groups. Mohammadi et al. (2011) in evaluation of bread wheat genotypes under dry-land and supplemental irrigation conditions indicated bi-plot display and cluster analysis cleared superiority of these genotypes in both years. Their results showed that MP, GMP and STI indices were more effective in identifying high yielding cultivars in diverse water scarcity.

Conclusion

If the strategy of breeding program is to improve yield in stress or non-stress environment, it may be possible to explain local adaptation to increase gains from selection conducted directly in that environment (Atlin et al., 2000;

Table 5. Yield mean and drought parameter values of durum wheat genotypes groups issued from cluster analysis.

Group		Ys	Yp	TOL	MP	HARM	GMP	STI	SSI	YI	YSI
4, 21, 9, 10, 25, 8, 20, 7, 23, 5, 12	Mean	1.778	2.514	0.735	2.146	2.027	2.084	0.335	0.524	0.859	0.771
	difference %	-16.63	-45.82	-116.4	-33.73	-25.23	-29.21	-74.9	-52.33	-16.62	15.5
1, 15	Mean	2.004	6.62	4.615	4.312	3.067	3.634	1.017	1.593	0.968	0.305
	difference %	-3.51	44.61	65.5	33.42	17.24	25.87	42.39	49.91	-3.5	-114
13, 18, 6, 11, 3, 22, 24, 16, 19, 14	Mean	2.109	4.106	1.997	3.108	2.694	2.888	0.636	1.007	1.019	0.56
	difference %	1.676	10.718	20.27	7.64	5.78	6.73	7.88	20.77	1.68	-16.3
2, 17	Mean	3.595	4.85	1.254	4.222	4.044	4.132	1.283	0.464	1.736	0.797
	difference %	42.29	24.39	-26.9	32.01	37.22	34.8	54.36	-71.82	42.3	18.24
Total	Mean	2.074	3.666	1.592	2.87	2.538	2.694	0.585	0.798	1.002	0.651

Hohls, 2001). The findings of this study showed that the breeders should choose the indices on the basis of stress severity in the target environment; GMP, HARM, MP and STI are suggested as useful indicators for durum wheat breeding and on basis of this indices genotypes pol-dash(1) and chakmak were introduced as tolerant genotypes. Also, drawing bi-plot graph, three dimensional graphs and study of the correlation between grain yield in drought stress condition showed that the best indices for selecting tolerant species are GMP, STI and HARM. Therefore, genotypes which had higher amount of these indices were identified as the most tolerant genotypes. They showed considerable potential to improve drought tolerance in durum wheat breeding programs.

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