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Assessment of yield, yield-related traits and drought tolerance of durum wheat genotypes (*Triticum turjidum* var. *durum* Desf.)

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Abstract

The main objective of this study was to evaluate 11 durum wheat breeding lines and three checks [two durum (Zardak and Saji) and one bread (Sardari) wheat] based on grain yield, agronomic traits and drought tolerance indices under rainfed and irrigated conditions in the west of Iran during the 2008-09 cropping season. A completely randomized block design with three replications was conducted for each environment. Based on grain yield under rainfed and irrigated conditions drought tolerance indices i.e., stress tolerance index, stress susceptibility index, tolerance, yield index, yield stability index, mean productivity and geometric mean productivity were calculated. The results of analysis of variance for relative water content, plant height, biomass, number of grains per spike and grain yield in rainfed and irrigated conditions indicated that genotypic differences were highly significant ($P<0.01$). A positive and significant correlation was observed between yield under irrigated (Yi) and rainfed (Yr) conditions and mean productivity (MP), geometric mean productivity (GMP), and stress tolerance index (STI). Based on principle component analysis a significantly positive correlation was observed between stress susceptibility index and tolerance. These indices were able to select the susceptible genotypes (i.e., G8, G2, G3, and G7). The check cultivars (Zardak and Sardari) and G5 were more stable and related to the rainfed environment while genotypes G11 and G4 were highly adapted to the irrigated conditions. Cluster analysis classified the genotypes into three groups i.e., resistant, susceptible and tolerant to drought conditions. In conclusion, this study showed that drought stress reduced the yield of some genotypes while others were tolerant to drought, suggesting genetic variability of drought tolerance in this material. Therefore, breeders can choose better (i.e., more stress-resistant) wheat genotypes based on some indices (e.g. MP, GMP and STI).

Keywords: Durum wheat, drought resistance indices, principal component analysis, cluster analysis

Abbreviations: RWC – relative water content, PH – plant height, BIO – biomass, NS – number of spikes, NG – number of grains per spike, TKW – 1000-kernel weight, GY – grain yield, Yi – grain yield under irrigated conditions, Yr – Grain yield under rainfed conditions, STI – stress tolerance index, SSI – stress susceptibility index, TOL – tolerance, YI – yield index, YSI – yield stability index, MP – mean productivity, GMP – geometric mean productivity.

Introduction

At present, durum wheat is grown mostly in rainfed areas of the Mediterranean region under stressful and variable environmental conditions (Edmeades et al., 1989). Developing high-yielding wheat cultivars under drought conditions in arid and semi-arid regions is an important objective of breeding programs (Leilah et al., 2005). Drought stress may reduce all yield components, but particularly the number of fertile spikes per unit area and the number of grains per spike (Giunta et al., 1993; Simane et al., 1993; Abayomi and Wright, 1999), while kernel weight is negatively influenced by high temperatures and drought during ripening (Chmielewski and Kohn, 2000). In addition, genetic divergence correlated to environmental differences has been found for emmer wheat (*Triticum turgidum* ssp. *dicoccum* (Schrank) Thell) (Li et al., 2000). Understanding plant responses to drought is of great importance and also a fundamental part of making crops stress tolerant (Reddy et al., 2004; Zhao et al., 2008). The relative yield performance of genotypes in drought-stressed and favorable environments seems to be a common starting point in the identification of desirable genotypes for unpredictable rainfed conditions (Mohammadi et al., 2010). Some researchers believe in selection under favorable conditions (Betran et al., 2003), others in a target stress condition (Rathjen, 1994) while others yet have chosen a mid-point and believe in selection under both favorable and stress conditions (Byrne et al., 1995; Rajaram and van Ginkel, 2001). 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) while 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 and irrigated environments and mean productivity (MP) as the average yield of yield of genotypes under irrigated (Yi) and rainfed (Yr) conditions. Fischer and Maurer (1978) suggested the stress susceptibility index (SSI) for measurement of yield stability that apprehended the changes in both potential and actual yields in variable environments. Fernandez (1992) defined a new advanced index, the stress tolerance index (STI), which can be used to identify genotypes that produce high yield under both stressed and non-stressed conditions. Other yield-based estimates of drought resistance are mean productivity (MP) and TOL. Clarke et al. (1992) used SSI to evaluate drought tolerance in wheat genotypes and found year-to-year variation in SSI for genotypes and could rank their pattern. In spring wheat cultivars, Guttieri et al. (2001), using SSI, suggested that an SSI > 1 indicated above-average susceptibility to drought stress. Golabadi et al. (2006), Sio-Se Mardeh et al. (2006) and Talebi et al. (2009) suggested that selection for drought tolerance in wheat could be conducted for high MP, GMP and STI under stressed and non-stressed environments. Selection of different genotypes under environmental stress conditions is one of the main tasks of plant breeders for exploiting genetic variations to improve stress-tolerant cultivars (Clarke et al., 1984). The present study was undertaken to assess the selection criteria for identifying drought tolerance in durum wheat genotypes, so that suitable genotypes can be recommended for cultivation in drought-prone areas of Iran.

Materials and methods

Plant material and experimental setup

Eleven durum wheat (*Triticum turgidum* var. *durum* Desf.) breeding lines, which were selected from the durum breeding joint project of Iran/ICARDA (International Center for Agricultural Research in the Dry Areas), along with two durum wheat checks (Zardak and Saji) and one bread wheat check (Sardari), were chosen for the study based on their reputed differences in yield performance under irrigated and non-irrigated conditions in two sites (Table 1). Experiments were conducted at the Dryland Agricultural Research sub-Institute (DARSI), Sararood Station, Kermanshah Province, Iran in 2008-2009. The experimental layout was a randomized complete block design with three replications. Sowing was done by an experimental drill in 1.2 m × 6 m plots, consisting of six rows 20 cm apart at 400 seeds m^{-2} for each site. Fertilizer was applied at 41 kg ha^{-1} N and 46 kg ha^{-1} P_2O_5 and planting was according to the provincial soil test recommendations before sowing. Irrigation was performed in the non-stressed site at the flowering stage.

Table 1. Name and pedigree of genotypes used for drought tolerance assessment.

No	Code/Name	Origin*
G1	D-83A2-84B1	DARSI
G2	D-83A1-84B13	DARSI
G3	D-83A6-84B4	DARSI
G4	D-83A10-84B8	DARSI
G5	D-83A11-84B9	DARSI
G6	D-83A4-84B11	DARSI
G7	D-83A17-84B12	DARSI
G8	D-83A3-84B14	DARSI
G9	D-83A15-84B15	DARSI
G10	D-83A16-84B16	DARSI
G11	D-83A19-84BT18	DARSI
G12	Saji	DARSI
G13	Zardak	DARSI
G14	Sardari	DARSI

*DASRI= Dryland Agricultural Research Sub-Institute

Sampling, measurements and data analysis

For the purpose of this study, the relative water content (RWC) was estimated according to the method adopted by Turner and Kramer (1980) using the following equation: RWC = [(FW– DW) / (TW-DW)] × 100.
The total dry weight, grain yield (GY; g m^{-2}), and the thousand-kernel weight (TKW) were measured at crop maturity. Five plants were randomly chosen from each plot to measure the number of grains per spike (NG) and plant height (PH). The number of spikes (NS) per m^2 was determined at maturity from a sample of 1 m of a central row on each plot. Drought resistance indices were calculated using the following relationships:

$$SSI = [1 - (Yr / Yi)] / SI \; ; SI = 1 - \frac{\bar{Y}r}{\bar{Y}i}$$

(Fischer and Maurer, 1978)
Where Yr is the yield of cultivar under stress, Yi the yield of genotypes under irrigated condition, $\bar{Y}$r and $\bar{Y}$i are the mean yields of all genotypes under stressed and non-stressed conditions, respectively, and $1 - \frac{\bar{Y}r}{\bar{Y}i}$ is the stress intensity. The irrigated experiment was considered to be a non-stressed condition in order to have a better estimation of the optimum environment.
TOL = Yi – Yr (Hossain et al., 1990),
MP = (Yr + Yi) / 2 (Hossain et al., 1990)

$$GMP = \sqrt{(Yi)(Yr)}$$ (Fernandez, 1992)

STI = (Yr)(Yi) /($\bar{Y}$ i) ^{2} (Fernandez, 1992)
Yield index (YI) = $Yr / \bar{Y}r$ (Gavuzzi et al., 1997; Lin et al., 1986)

Table 2. Mean squares for yield and related traits of wheat genotypes.

		Mean of Square						
	DF	GY	TKW	NS	BIO	NG	PH	RWC
Stressed condition								
Replication	2	39.89	47.05	5088.09	11136.72	44.61	1.04	108.79
Genotypes	13	2933.91**	19.96*	30203.66**	54644.79**	34.46**	51.69**	237.76**
Error	26	134.2	8.43	1547.07	3217.93	7.37	1.92	79.17
Irrigated condition								
Replication	2	116.76	4.81	206635.71	3503.57	11.45	0.162	160.04
Genotypes	13	4251.33**	41.93**	19295.421*	205003.33**	105.94**	197.5**	119.46**
Error	26	531.68	3.01	8430.58	9308.45	23.7	52.70	35.41

*and ** Significant at the 5%and 1% levels of probability, respectively
GY - grain yield, TKW - 1000-kernel weight, NS - number of spikes, BIO - biomass, NG - number of grains per spike, PH - plant height, RWC - relative water content.

Yield stability index (YSI) = Yr/Yi (Bouslama and Schapaugh, 1984)

Data was analyzed using MSTAT-C for analysis of variance and mean comparison of traits. Principal component analysis (PCA) was used to classify the screening methods as well as the genotypes. All statistical analyses were carried out using SPSS software version 16.0 (SPSS, 2007).

Results

The results of analysis of variance for RWC, PH, BIO, NG and GY (g m^{-2}) in rainfed and low-irrigated conditions indicated that genotypic differences were highly significant (P<0.01). Significantly variation (P<0.05) among genotypes was observed for TKW in the stress condition and NS in the irrigated condition (Table 2). In the case of GY under rainfed condition no superior genotypes were better than the checks. However, under irrigated condition, G4 was better than the checks. Based on each agronomic trait the response of genotypes at each condition differed. Under rainfed condition the highest TKW value was observed for G14 and the lowest value for G3 while under irrigated condition highest TKW was assigned to G8 and the lowest TKW was observed in G1. Highest NG was observed in G12 and G5 under rainfed condition and for G12 under irrigated condition. The highest NS under rainfed condition was observed for G14 followed by G13 and G6 and under irrigated condition the highest values were for G5, followed by G11, G14 and G13. Highest biomass was observed for G9 followed by G13 and G14 under rainfed condition and for G11, G4 and G9 under irrigated condition. Highest PH was observed for G14, G13 and G5 under rainfed condition and for G13, G14 and G12 under irrigated condition. Among all genotypes, G14 and G13 had the highest RWC value under rainfed condition; the same was true for G14, followed by G12 and G5 under irrigated condition (Table 3). Resistance indices were calculated on the basis of GY of genotypes (Table 4). As shown in Table 4, a greater TOL value was related to G4, indicating that this genotype had a larger GY reduction under rainfed condition and higher drought sensitivity; lowest

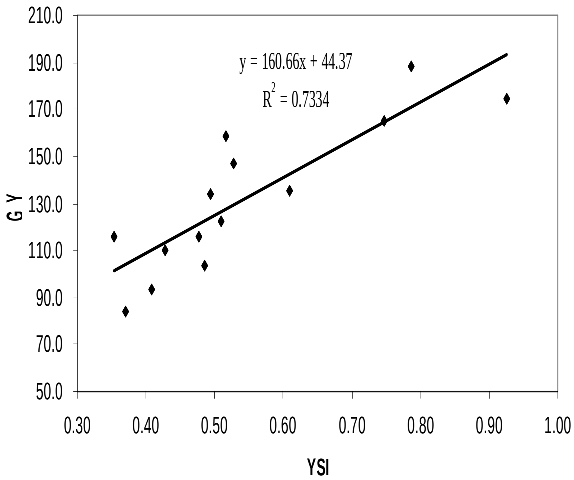

Fig 1. Relationship between drought stress grain yield and yield stability index (YSI).

TOL was found in G3, followed by G14 and G5. Therefore, these genotypes had a lower GY reduction under rainfed condition. SSI was highest in G4 and lowest in G13. Highest MP, GMP and STI indices were observed in G12 and the least values in G8 followed by G3 and G2. The highest YI and YSI indices were observed for G14 and G13, respectively. To determine the most desirable drought-tolerant criteria, the correlation coefficients between Yi, Yr and other quantitative indices of drought tolerance were calculated (Table 5). The results indicate that there were positive, significant correlations among Yi and (MP, GMP, TOL, SSI and STI) and Yr and (MP, YI, GMP, YSI and STI). SSI and TOL under rainfed condition was negatively and highly significantly (P<0.01) correlated with Yr. In the present study, a positive correlation was found between RWC and GMP, STI and MP under irrigated condition. RWC also had a positive correlation with YI, GMP, YSI and STI under rainfed condition. A negative correlation was observed between RWC and SSI and TOL under rainfed condition (Table 6). These results indicate that genotypes with high RWC usually have high stress tolerance under both irrigated and rainfed conditions.

Table 3. Mean comparison of yield and related traits under irrigated and rainfed conditions.

		GY (gm^{-2})	TKW	NS	BIO	NG	PH	RWC
Irrigated condition	G1	239.87ce	25.17h	500.00ac	25.17de	38.47ac	72.44c	86.00be
	G2	212.93ef	29.27dg	470.00bc	29.27cd	32.73d	73.33c	80.03e
	G3	229.13df	26.65gh	516.67ac	26.65f	27.67e	76.33c	83.00ce
	G4	327.03a	32.03ce	676.67a	32.03a	33.47d	71.22c	97.12a
	G5	221.43ef	34.80bc	436.67c	34.80de	35.93bd	74.00c	93.80ac
	G6	278.37bc	34.17bc	513.33ac	34.17de	38.80ab	78.33bc	85.92be
	G7	256.93ce	36.43ab	586.67ac	36.43c	33.20d	71.56c	81.47de
	G8	228.03df	37.95a	476.67bc	37.95ce	34.73cd	73.33c	75.32e
	G9	222.00ef	30.15df	566.67ac	30.15b	27.60e	76.00c	83.42be
	G10	243.47ce	32.43cd	456.67c	32.43ef	35.47bd	73.56c	83.53be
	G11	271.97bd	34.50bc	640.00ab	34.50a	36.07bd	74.89c	92.37ad
	G12	307.27ab	28.87ef	613.33ac	28.87cd	40.87a	76.89bc	94.57ab
	G13	188.30f	28.42fg	636.67ab	28.42ce	22.00f	100.67a	84.26be
	G14	239.47ce	30.63df	640.00ab	30.63ce	21.67f	89.56ab	81.03de
Rainfed condition	G1	122.23ef	23.30bc	390.00df	642.87fg	23.80ab	50.37e	70.57ab
	G2	103.33fh	25.93bc	270.00h	505.90h	22.20ac	52.51de	64.70ac
	G3	93.40gh	21.40c	363.33fg	634.30fg	14.33e	59.40ab	53.64c
	G4	115.60ef	23.23bc	336.67fh	699.23fg	17.87ce	51.80de	59.50bc
	G5	165.37bc	24.33bc	376.67fg	628.70fg	24.07a	55.10c	74.97ab
	G6	147.03cd	24.43bc	500.00c	725.00ef	21.07ad	50.87de	72.68ab
	G7	109.93fg	25.57bc	380.00eg	663.37fg	16.07de	51.00de	65.27ac
	G8	84.33h	26.88ac	306.67gh	610.57g	16.47de	53.11cd	52.98c
	G9	135.13de	27.13ab	460.00cd	971.63a	20.07ad	46.00f	73.10ab
	G10	116.23ef	28.27ab	396.67df	822.60ce	18.80be	53.33cd	66.87ac
	G11	134.17de	28.13ab	370.00fg	831.33cd	23.40ab	50.13e	74.57ab
	G12	158.57bc	25.00bc	450.00ce	733.97df	25.20a	50.73de	73.67ab
	G13	174.30ab	23.88bc	570.00b	947.83ab	21.27ad	58.67b	80.47a
	G14	188.40a	31.47a	636.67a	854.00bc	17.47ce	61.20a	81.57a

GY - grain yield, TKW - 1000-kernel weight, NS - number of spikes, BIO - biomass, NG - number of grains per spike, PH- plant height, RWC - relative water content.

The check genotypes (Zardak and Sardari), which had the lowest difference between yields in both conditions (TOL) and stress susceptibility (SSI), also had the highest RWC value under rainfed condition. In the case of PH, a positive correlation was observed between this trait and YI, YSI and STI and a negative correlation was found between PH and TOL. STI and GMP had a positive correlation with NS and GY under both conditions, which indicates that these parameters are suitable for both conditions. A perfect negative correlation was observed between the YI and GY under rainfed condition which suggests that this parameter is suitable for selecting genotypes under drought condition. In this study, a general linear model regression of GY under drought stress on YSI revealed a positive correlation between this criterion with a similar coefficient of determination (R^2= 0.733) (Fig. 1). Selection based on a combination of indices may provide a more useful criterion for improving drought resistance of wheat although correlation coefficients are useful to find the degree of overall linear association between any two attributes (Golabadi et al., 2006; Talebi et al., 2009). Thus, a better approach than a correlation analysis such as a biplot is needed to identify superior genotypes for both stressed and non-stressed environments. The first two PCAs accounted for about 99.5% of total variation. PCA indicated that the indices could discriminate the wheat genotypes. A significantly positive correlation was found between SSI and TOL, indicating that these indices are able to select susceptible genotypes (i.e., G8, G2, G3, and G7). These indices had a negative correlation with MP, STI and GMP, based on which G12 and G6, both tolerant genotypes, could be discriminated. No association was found between yield under rainfed and irrigated conditions, indicating that genotypes under rainfed condition do not have a good response under irrigated conditions. In other words, these two conditions discriminate genotypes independently. The check cultivars (Zardak and Sardari) and G5 were more stable and related to the unfavorable environment (rainfed) while G11 and G4 were highly adapted to irrigated

Table 4. Resistance indices of wheat genotypes under rainfed and poorly-irrigated conditions. The numbers in the parentheses are the genotype ranks for each index.

Genotype No.	Yi	Yr	MP	TOL	GMP	STI	YI	YSI	SSI
G1	239.87(7)	122.2(8)	181.1(9)	117.6(9)	171.2(9)	0.478(9)	0.93(8)	0.51(7)	1.05(8)
G2	212.93(13)	103.3(12)	158.1(13)	109.6(10)	148.3(12)	0.359(12)	0.78(12)	0.49(8)	1.10(6)
G3	229.13(9)	93.4(13)	161.3(12)	135.7(6)	146.3(13)	0.349(13)	0.71(13)	0.41(12)	1.27(3)
G4	327.03(1)	115.6(10)	221.3(2)	211.4(1)	194.4(4)	0.617(4)	0.88(10)	0.35(14)	1.38(1)
G5	221.43(12)	165.4(3)	193.4(6)	56.1(12)	191.4(5)	0.597(5)	1.25(3)	0.75(3)	0.54(12)
G6	278.37(3)	147.0(5)	212.7(4)	131.3(7)	202.3(3)	0.668(3)	1.11(5)	0.53(5)	1.01(10)
G7	256.93(5)	109.9(11)	183.4(7)	147.0(3)	168.1(11)	0.461(11)	0.83(11)	0.43(11)	1.23(4)
G8	228.03(10)	84.3(14)	156.2(14)	143.7(4)	138.7(14)	0.314(14)	0.64(14)	0.37(13)	1.35(2)
G9	222.00(11)	135.1(6)	178.6(11)	86.9(11)	173.2(8)	0.489(8)	1.02(6)	0.61(4)	0.84(11)
G10	243.47(6)	116.2(9)	179.9(10)	127.2(8)	168.2(10)	0.462(10)	0.88(9)	0.48(10)	1.12(5)
G11	271.97(4)	134.2(7)	203.1(5)	137.8(5)	191.0(6)	0.595(6)	1.02(7)	0.49(9)	1.09(7)
G12	307.27(2)	158.6(4)	232.9(1)	148.7(2)	220.7(1)	0.795(1)	1.20(4)	0.52(6)	1.04(9)
G13	188.30(14)	174.3(2)	181.3(8)	14.0(14)	181.2(7)	0.535(7)	1.32(2)	0.93(1)	0.16(14)
G14	239.47(8)	188.4(1)	213.9(3)	51.1(13)	212.4(2)	0.736(2)	1.43(1)	0.79(2)	0.46(13)

Yi - grain yield under irrigated conditions; Yr – Grain yield under rainfed condition, MP – mean productivity , TOL –tolerance, GMP – geometric mean productivity, STI – stress tolerance index, YI – yield index, YSI – yield stability index, SSI – stress susceptibility index

Table 5. Correlation coefficients between Yi, Yr, and resistance indices.

	Yi	Yr	MP	TOL	YI	GMP	YSI	SSI	STI
Yi	1.00								
Yr	-.036	1.00							
MP	.760**	.623*	1.00						
TOL	.779**	-.655*	.184	1.00					
YI	-.036	1.00**	.622*	-.655*	1.00				
GMP	.548*	.813**	.958**	-.097	.813**	1.00			
YSI	-.527	.855**	.143	-.935**	.855**	.399	1.00		
SSI	.523	-.856**	-.147	.933**	-.856**	-.403	-1.00**	1.00	
STI	.557	.804**	.959**	-.083	.803**	.998**	.382	-.385	1.00

*And ** Significant at the 5% and 1% levels of probability, respectively

Table 6. Simple correlation coefficients between resistance indices and relative water content, plant height, biomass, number of spike, number of grain per spike and grain yield of wheat genotypes in irrigated (i) and rainfed (r) conditions.

	TOL	YI	GMP	YSI	SSI	STI	MP
RWC(i)	.270	.347	.659*	.007	-.013	.642*	.731**
RWC(r)	-.676**	.921**	.710**	.822**	-.824**	.688**	.498
Plant height (i)	-.744**	.678**	.294	.828**	-.828**	.292	.112
Plant height (r)	-.464	.295	-.004	.451	-.448	.014	-.097
Biomass (i)	.354	.025	.293	-.179	.170	.270	.400
Biomass (r)	-.421	.565*	.415	.544*	-.549*	.389	.299
Number of spikes (i)	.097	.383	.545*	.159	-.166	.540*	.598*
Number of spikes (r)	-.610*	.832**	.621*	.751**	-.752**	.616*	.450
Grains/spike (i)	.594*	-.287	.113	-.558*	.558*	.119	.241
Grains/spike (r)	-.231	.461	.464	.330	-.331	.454	.362
1000-grain weight (i)	.221	-.147	-.032	-.222	.219	-.032	.037
1000-grain weight (r)	-.243	.289	.210	.213	-.215	.218	.125
Grain yield [gm^{-2}] (i)	.779**	-.036	.548*	-.527	.523	.557*	.760**
Grain yield [gm^{-2}] (r)	-.655*	1.000**	.813**	.855**	-.856**	.803**	.622*

* p<0.05, ** p<0.01

conditions (Fig. 2). Cluster analysis showed that the genotypes, based on TOL, MP, GMP, SSI, YI, STI and YSI, tended to group into three groups with 7, 4 and 3 genotypes, respectively (Fig. 3). In this analysis, the second group had the highest MP, GMP and STI, and was thus considered to be the most desirable cluster for both growth conditions. The third group had higher Yr, YI and YSI values. Therefore, the genotypes of this group were considered to be stable in rainfed conditions. In the first group, all genotypes had high SSI and TOL, thus they were susceptible to drought and only suitable for irrigated conditions.

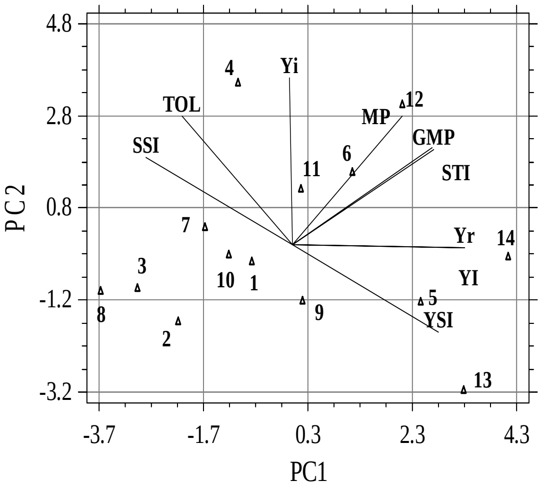

Fig 2. Principal Component analysis of drought resistance indices

Discussion

Variation due to genotypes was significant for all characters in two conditions (rainfed and poorly-irrigated). This suggested that the magnitude of differences in genotypes was sufficient to provide some scope for selecting genotypes to improve drought tolerance. The mean comparison of traits which was observed in this study in an irrigated site showed that G4 had the highest GY value. This genotype also had the highest biomass and RWC. This result confirms a previous finding on durum wheat and bread wheat (Mekliche et al., 1992) that showed the effect of water stress on RWC in wheat plants. The highest value for GY, TKW, NS, PH and RWC was also found for G14 followed by G13 under rainfed condition. Similar results were reported by del Blanco et al. (2001) and Ozturk and Aydin (2004), who showed positive correlations between TKW and GY in hexaploid wheat. Moayedi et al. (2009) also noted that the main yield components, which were associated with yield reduction, were NG and number of fertile tillers. In the NS line similar results for winter wheat were also reported by Garcia del Moral et al. (2005), who indicated that irrigation during the reproductive development stage was a key factor affecting NS. STI, GMP and MP were strongly correlated with yield under both conditions (Table 5), suggesting that these parameters are suitable to screen drought-tolerant, high-yielding genotypes (e.g. G12) in both rainfed and irrigated conditions. Similar results were reported by Fernandez (1992), Mohammadi et al. (2003), Golabadi et al. (2006), Sio Se-Mardeh (2006) and Mohammadi et al. (2010), all of whom found these parameters to be suitable for discriminating the best genotypes under

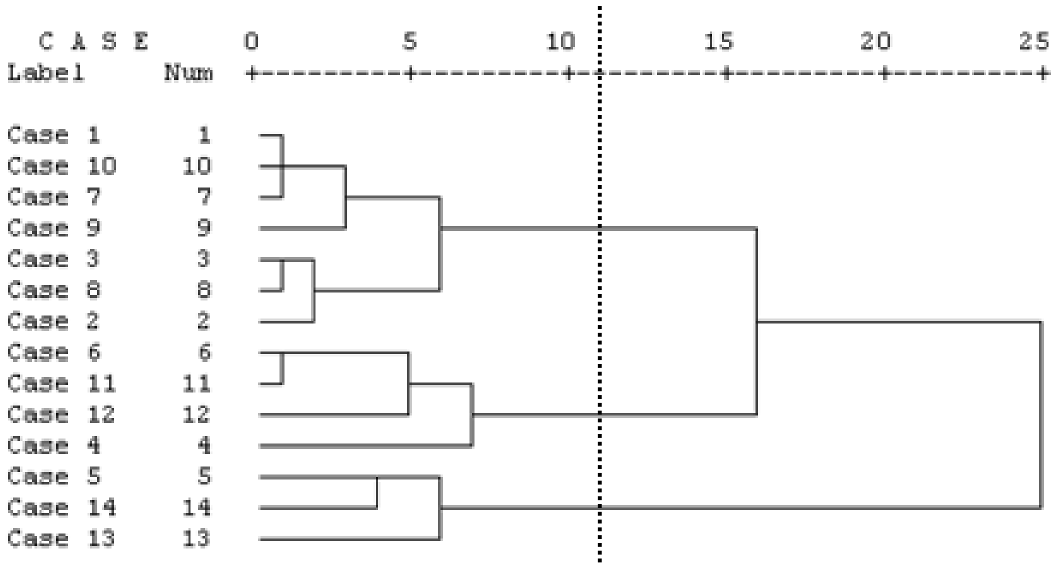

Fig 3. Dendrogram using average linkage between groups showing classification of genotypes based on resistance indices (The dotted line represents grouping based on discriminate analysis). The X-axis is a rescaled distance cluster combined.

stress and irrigated conditions. These three parameters, under moderate stress, were positively correlated with yield under both conditions (Mohammadi et al., 2010). Najafian (2009) concluded that MP, GMP and STI (mostly GMP and STI) indices are preferred for practical use. Based on our study the check genotypes (Zardak and Sardari) had high YI and YSI, which were had a highly significant positive correlation with GY under rainfed condition (r = 1.0 and 0.855 for GY under rainfed condition and YI and YSI, respectively); therefore, these two parameters had good tolerance to rainfed condition (Table 6). YSI was a more useful index to discriminate drought-resistant from drought-susceptible genotypes (Mohammadi et al., 2010). A significantly positive correlation was found between TOL and GY under irrigated conditions (Yi) and NG (P<0.01 and P<0.05, respectively), but this correlation was negative under rainfed conditions (Yr) (Table 6), indicating that the genotypes with high GY and NG under irrigated condition have a high reduction in yield under stress condition so that G4 in irrigated condition had the highest GY value, but this genotype had a high TOL. Similar results were reported by Mohammadi et al. (2010), who showed that selection based on TOL will result in yield reduction under rainfed condition. Shamsuddin (1987), Simane et al. (1998) and Del blanco et al. (2001) also reported direct selection for NS per m^{-2} and/or a large number of GS would be enough to increase GY in bread wheat. Clarke et al. (1992) used SSI to evaluate drought tolerance in wheat genotypes and found a year-to-year variation in SSI for genotypes and their ranking pattern. In wheat, SSI and GY were used as stability parameters to identify drought-resistant genotypes (Bansal and Sinha, 1991). In this study, G13 and G14 had the lowest SSI value and therefore these genotypes have low drought susceptibility and high yield stability in both conditions, whereas genotype G4 followed by G8 and G3 with SSI values higher than unit can be identified as having high susceptibility to drought. Similar results were reported by Golabadi et al. (2006) and Talebi et al. (2009), who showed that SSI can be a more useful index in discriminating better genotypes under rainfed condition. In the present study SSI and TOL were negatively correlated with Yr (r = -0.86 and -0.655, respectively). Larger TOL and SSI values represent relatively more sensitivity to stress, thus smaller TOL and SSI values are favored. Selection based on these two criteria favors genotypes with high yield potential under non-stressed conditions and low yield under stressed conditions (Fernandez, 1992). PCA was performed to assess the relationships between all attributes at once. The correlation coefficient among any two indices was approximated 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 biplots were: (i) a strong negative association between SSI and TOL with Yr, YI and YSI as indicated by the large obtuse angles between their vectors, (ii) a zero correlation between Yi with Yr and YI, as indicated by the perpendicular vectors and (iii) a positive association between Yi and Yr with MP, GMP, and STI, as indicated by the acute angles. The results obtained from biplots confirmed correlation analyses. Thomas et al. (1996) observed that some 25 accessions of meadow fescue from seven countries investigated in four experiments could be distinguished based on a biplot display. The observed relations were also in agreement with those reported by Fernandez (1992) in mungbean, Farshadfar and Sutka (2002) in maize and Golabadi et al. (2006) in durum wheat. In the present study, G14 and G13 (Sardari and Zardak) were the best genotypes under rainfed conditions such that had highest value of RWC, NS and GY also had the highest values for YI and YSI and the lowest values for SSI and TOL. Using STI and GMP, the check cultivar (Saji) was found to be the most drought-tolerant genotype. Finally, the parameters GMP and STI can be used to select drought-tolerant genotypes. RWC, as a physiological trait, and NS among yield components, are suitable for selecting the best genotypes under irrigated and rainfed conditions because these parameters are highly correlated with STI and GMP. SSI, YSI and YI can also be useful parameters for discriminating genotypes that have higher stability and lower susceptibility to stresse conditions.

Conclusion

Yield and yield-related traits under rainfed conditions were independent of yield and yield-related traits under irrigated conditions. STI, GMP and MP were used to identify tolerant genotypes that produced high yield under both conditions. YSI and YI were also found to be more useful indices to discriminate resistant genotypes that are stable in different conditions and produce high GY under stressed conditions. The genotypes with high TOL and SSI had high yield only under irrigated conditions. In conclusion, this study showed that drought stress significantly reduced the yield of some genotypes while others were tolerant to drought, which suggested genetic variability for drought tolerance in this material. Therefore, breeders can choose better genotypes, under rainfed condition, and compare this with performance under normal condition based on some indices (e.g. MP, GMP and STI) and a combination of different methods of selection.

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