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Evaluation of drought tolerance of winter bread wheat genotypes under drip irrigation and rain-fed conditions

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Abstract: To evaluate the genetic diversity in 48 winter bread wheat genotypes originating from different countries, an experiment based on randomized complete block design with 4 replications was carried out in drip irrigation and rain-fed conditions at the field station of the Transitional Zone Agricultural Research Institute, Eskişehir, Turkey in 2011 and 2012. Based on grain yield under rain-fed and irrigated conditions, drought tolerance indices, i.e. stress susceptibility index (SSI), stress tolerance index (STI), tolerance index (TOL), mean productivity (MP), and geometric mean productivity (GMP), were calculated to identify genotypes with better yield and drought tolerance. Analysis of variance indicated that there were highly significant differences among the genotypes with regard to all the traits under the two experimental conditions. The correlation coefficients showed that STI, MP, and GMP were the most desirable selection criteria for high yielding and drought tolerant genotypes. Based on principle component analysis and biplot, genotypes numbered as 6, 11, 26, 41, 45, and 47 were susceptible genotypes. The genotypes numbered as 4, 12, 17, 24, 27, 28, 34, 35, 36, 38, and 42 were more stable under rain-fed conditions, while genotypes numbered as 9, 29, 31, and 44 were highly adapted to the irrigated conditions. Cluster analysis classified the genotypes into 3 groups: 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 select stress-resistant wheat genotypes based on the MP, GMP, and STI indices.

Key words: Drought, genetic diversity, tolerance indices, winter bread wheat, multivariate analysis

1. Introduction

Wheat is one of the most grown crops worldwide and provides more than a quarter of the total world cereal output. It also constitutes the main source of calories for more than 1.5 billion people (CIMMYT, 2000). Drought stress is one of the main limiting factors for wheat yield in the semiarid regions of the world. Insufficient precipitation causes water deficits at various growth and development stages (vegetative, reproductive, and grain development) and has a negative influence on the physiological processes of the plant, subsequently affecting yield as well (Abed et al., 2000). The problem of drought is acute in many developing countries, where about 37% of the wheat-growing areas are semiarid and have low soil moisture content, thus presenting a limiting factor for higher yield (Rajaram, 2001).

The impact of drought stress depends on the plant growth stage and may affect potential yield and yield components. Drought stress can reduce grain yield, and an average yield loss of 17% to 70% in grain yield has been estimated due to drought stress (Nouri-Ganbalani et al., 2009). An understanding of yield components and yield compensation strategies of a wheat crop in a particular environment is key for a successful breeding program. Morphological traits, such as number of grains per spike, fertile tillers per plant, 1000 grain weight, peduncle length, spike weight, stem weight, plant height, and grain weight per spike influence the tolerance of wheat (Passioura, 1977). Therefore, grain yield and its components are two important selection criteria in arid regions (Plaut et al., 2004).

Drought indices, which represent a measure of drought stress based on the reduction of grain yield under drought stress conditions in comparison to irrigated conditions, were used for identification of drought-tolerant genotypes (Mitra, 2001).

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There are some methods to identify crop lines that are productive in dry environments. Rosielle and Hamblin (1981) defined stress tolerance index (TOL) as the differences in yield under stress (Ys) and nonstress (Yp) environments, and mean productivity (MP) as the average of Ys and Yp. Fischer and Maurer (1978) proposed a stress susceptibility index (SSI) for the cultivar. Fernandez (1992) defined a stress tolerance index (STI), which can be used to identify genotypes producing a high yield under both stress and nonstress conditions. Another yield-based estimate of drought resistance is the geometric mean (GMP) (Ramirez and Kelly, 1998).

The objective of this study was to determine high yielding and drought tolerant genotypes under rain-fed and irrigated conditions via a range of quantitative traits.

2. Materials and methods

Field experiments were carried out at the field station of the Transitional Zone Agricultural Research Institute, Turkey, at 300 31°N, 390 46°E, 781 m above sea level, and with an annual rainfall of 347 mm during the 2011–2012 growing season under the International Winter Wheat Improvement Program (IWWIP, CIMMYT). The experimental materials consisted of 48 varieties of winter wheat, which originated from different countries and regions (Table 1). This experiment was performed under a randomized complete block design with 4 replicates. Each genotype was planted in 6 rows of 5 m length, 20 cm apart, in October 2011. The genotypes were grown under two treatments: (1) irrigated plots, which received three drip irrigations (30 mm each) during the flowering, heading,

Table 1. The pedigree and origin of the tested winter bread wheat.

No.	Accessions	Origin	No.	Accessions	Origin
1	SG-U 8069	CZ	25	COMP1/5/BEZ//TOB/8156/4/ON/3/TH*6/KF//LEE*6/K/6/TAST/SPRW../7/ALTAY/8/BURBOT-6	TCI
2	GOBUSTAN	AZB	26	AGRI/NAC//ATTILA	MX-CIT
3	KRASNOVODOPADSKAYA 211	KAZ	27	DESTIN	RO-FL
4	PROSTOR	BG	28	DEMIR	TR-ANK
5	GEREK	TR-ESK	29	DYUOPEBUSA	MOL
6	UBILEYNAYA 100	RUS-KR	30	OK00421	USA-OK
7	BAYRAKTAR	TR-ANK	31	ALTAY	TR-ESK
8	HAMSI-1	MX-TCI	32	AKINCI-84	AZB
9	BEZOSTAYA1	TR-ESK	33	GRS1201/TAM202	US-ARS-Lincoln
10	KARAHAN (c)	TR-KON	34	MIMA	BG
11	MVMA/MV12//F2098	HU-MV	35	NIKONIYA	TR-KON
12	STARSHINA	RUS-KR	36	LC924/PETJA	UKR-OD
13	CO 970547-7	USA-CO	37	PODOIMA	BG-SAD
14	ZUBKOV	KYR	38	STEKLOVIDNAYA24	MOL
15	MV06-02	HU-MV	39	DALNITSKAYA	KAZ
16	GLORIA	RO-FL	40	VITA	UKR
17	LC 909 MIMA	BG-KC	41	KHARKOVSKAYA107	RUS-KR
18	TX96V2847	US-TX	42	AZERI	AZB
19	U1254-1-8-1-1/TAM-202	USA-TX	43	453	KAZ
20	SONMEZ (c)	TR-ESK	44	SG-S1915	CZ
21	ARLIN/YUMA	USA-KSU	45	MADSEN/MALCOLM	OSU
22	ERITR 9945	KYR	46	7C/CNO//CAL/3/YMH/4/VP...	OSU
23	GRUIA	RO-FL	47	ID 80-628/3/CER/YMH...	OSU
24	MV DALMA	HU-MV	48	U1254-7-9-2-1/TX86A5616//RINA-6	TCI

c - checks

and grain filling period; and (2) rain-fed plots, which did not receive any irrigation during the experiment, except for natural rainfall. The following traits were included in the study: peduncle length, plant height, heading date, yield, biomass, number of stems, number of spikes, spikelet length, spikelet number, 5 spike seed weight, 5 spike seed number, bundle spike seed weight, and thousand kernel weight (TKW).

Drought tolerance indices were calculated as follows:

STI=(Ypi×Ysi)/2 (Fernández, 1992)

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

GMP=√Ypi×Ysi (Fernández, 1992)

MP=(Ypi+Ysi)/2 (Rosielle and Hamblin, 1981)

$$SSI=1-(\frac{Ys}{Ys})/SI$$ (Fischer and Maurer, 1978)

$$SI=1-(\frac{Ys}{Ys}),$$

where Ysi is the yield of cultivars under stress conditions, Ypi the yield of cultivars under normal conditions, Ys the total yield of mean under stress conditions, and Yp the total yield of mean under normal conditions.

3. Results and discussion

Analysis of variance was used for the identification of significant genotypic differences. The results of ANOVA showed that in rain-fed and irrigated conditions, there is considerable variability among the studied genotypes with regard to traits such as peduncle length, plant height, heading date, grain yield, biomass, stem number, spike number, spikelet length, spikelet number, 5 spike seed weight, 5 spike seed number, bundle spike seed weight, and TKW. The results showed that genotypic differences were highly significant in both conditions. G C interaction was significant for traits such as grain yield, heading date, biomass, spike length, and TKW. This could provide scope for breeding for the traits studied, along with yield and its components, under drought stress conditions. In this study there was no significant genotype × environment interaction for the remaining traits studied (Table 2).

The genetic variation coefficient of the 13 traits ranged from 5.04% to 33.95% (Table 2). The genetic variation of grain yield, number of stems, number of spikes, length of spikes, seed number, seed weight, TKW, peduncle length, and plant height exceeded 20%. Some traits, such as biomass, spikelet number, and bundle spike weight, ranged

Table 2. Mean squares for studied traits of 48 winter wheat varieties under irrigated and rain-fed conditions.

	S.O.V.					LSD 5%	CV%	GCV%	h^2_{bs}
	Rep	Co	Geno.	G × C	Error				
Df	1	1	47	47	239	-	-	-	-
Grain yield (kg)	**	**	**	**	613938.6	767.9	27.17	29.2	0.537
Heading date	**	**	**	*	1.532	1.19	0.83	5.04	0.4
Biomass (kg)	NS	**	**	*	427.903	20.26	20.54	12.83	0.28
Stem number	NS	**	**	NS	124.31	10.91	20.41	31.76	0.708
Spike number	NS	**	**	NS	120.041	10.74	20.98	33.95	0.72
Spike length (cm)	NS	**	**	*	1.478	1.19	16.15	23.5	0.68
Spikelet number	NS	**	**	NS	1.365	1.14	7.24	15.78	0.83
5 spike seed number	NS	**	**	NS	744.862	26.73	15.78	24.28	0.7
5 spike seed weight (g)	NS	**	**	NS	1.431	1.17	23.01	29.1	0.61
Bundle spike weight (g)	NS	**	**	NS	88.1	9.19	25.78	16.6	0.29
TKW (g)	*	**	**	**	5.803	2.35	8.43	21.06	0.86
Peduncle length (cm)	NS	**	**	NS	6.2	2.43	8.26	32.3	0.94
Plant height (cm)	NS	**	**	NS	15.92	3.9	5.33	23.78	0.95

Rep: replication, Co: conditions (irrigation and nonirrigation), Geno: genotypes, G × C: interaction genotypes with conditions, CV: coefficient of variation, GCV: coefficient of genetic variation, h^2_{bs}: narrow sense heritability; **, * and Ns; significant at 1%; 5% level of probability and nonsignificance, respectively.

between 10% and 20%; the genetic variation coefficient for heading days was lower than 10%. This is an indication of high genetic diversity within the studied genotypes under both conditions.

The progress of a breeding program is conditioned by the degree and nature of the genotypic and nongenotypic variation in the different characters. Since most of the economic traits (yield) are complex in heritability and significantly influenced by various environmental conditions, the study of inheritance and genetic advance is valuable in order to estimate the scope for improvement by selection. Heritability degree indicates the reliability with which the genotype will be recognized by its phenotype expression (Chandrababu and Sharma, 1999).

In this study, the heritability estimate ranged from 0.28 to 0.95. Higher heritability was observed in plant height and peduncle length, indicating the possibility of success in selection. Low heritability estimates were recorded for bundle spike weight (0.29) and biomass (0.28), indicating limited scope for improvement of this trait through selection.

G18 under irrigated conditions and G14 under rain-fed conditions were genotypes with better grain yield than the checks. The highest value of peduncle length was observed in G10, followed by G7, G39, and G48, and the lowest value in G44 under rain-fed conditions. However, under irrigated conditions the highest peduncle length was observed in G5, G7, G10, G25, G31, G43, and G48, and the lowest values were found in G44. Highest plant height was determined in G31, G43, and G48 under irrigated and rain-fed conditions; yet, among these genotypes only ALTAY (G31) was higher than the checks under rain-fed conditions. Within 142 days G28 was early in initiation of heading, while G47 requiring 162 days under irrigated conditions and is thus a late heading cultivar. G4 was early heading, while G47 was late heading under rain-fed conditions. Under rain-fed conditions the highest TKW value was determined in G4 and G3, and the lowest value in G47; under irrigated conditions, the highest TKW was measured in G18 and the lowest was observed in G19.

The information of correlations among traits can be of a great use to breeders, as it points out traits to which selection should be directed in order to increase the yield under certain environmental conditions. Genetic correlations point out the cohesion of traits after variations due to environmental effects that are eliminated, thus providing a basis for indirect selection (Van Ginkel et al., 1998).

Correlation coefficients between studied traits under irrigated and rain-fed conditions are presented in Table 3. Grain yield positively and significantly correlated with spike number, spike weight, and bundle spike weight under irrigated conditions. We can conclude that the traits of spike number, spike weight, and bundle spike weight, all of which have a significant effect on seed yield, can be used as criteria for the selection of genotypes in irrigated agriculture.

A highly negative and significant correlation was observed between yield and heading days under irrigated and rain-fed conditions. The significant negative correlation between grain yield and heading date confirms that earliness has played a very important role in the stability of bread wheat yield within the dry areas, characterized by excessive temperature and hot winds during the period of grain filling.

Under rain-fed conditions, positive significant correlations were observed between yield and TKW. Guttieri et al. (2001) reported that the selection of drought tolerant genotypes leads to reconnaissance genotypes with high 1000 grain weight. There was also a positive correlation between grain yield and bundle spike weight under rain-fed conditions.

The grain yield, a major selection criterion for drought stress tolerance, is a complex trait that is determined by several physiological, biochemical, and metabolic plant processes, and the gene associations and genetic regulation of this trait are highly ambiguous. Traits such as TKW and bundle spike weight had significant and positive correlation coefficients with grain yield under rain-fed conditions, indicating its importance for selection for drought tolerance and higher yields. According to the results of the correlation analysis (Table 3), more focus should be given to quantitative traits such as TKW and bundle spike weight, which have a highly significant correlation with grain yield under rain-fed conditions. These traits should also be utilized in drought resistance breeding programs.

Among the yield-related traits, plant height had a positive and significant interaction with heading days, spike length, biomass, and peduncle length under both conditions. Peduncle length showed a positive and significant correlation with biomass and spike length under both irrigated and rain-fed conditions. Under rain-fed conditions, a significant negative correlation was observed between TKW and heading days. Under both irrigated and rain-fed conditions, there was a highly significant positive correlation between TKW and 5 spike seed weight (5 SSW).

The correlation analysis was performed based on the grain yield under irrigated and rain-fed conditions for some drought tolerance indices such as stress susceptibility index (SSI), stress tolerance index (STI), TOL, mean productivity (MP), geometric mean productivity (GMP), Yp, and Ys (Table 4). The grain yield under water stress conditions had positive and significant correlations with the grain yield under nonstress conditions. With

Table 3. Correlation coefficients between 13 investigated morphological traits under normal (C1) and drought (C2) conditions.

Traits	Co.	Y	HD	B	SN	SpN	SL	Spi N	5 SSN	5 SSW	BSW	TKW	PL	PH
HD	C1	−0.4**	1	-	-	-	-	-	-	-	-	-	-	-
	C2	−0.45**	1	-	-	-	-	-	-	-	-	-	-	-
B	C1	0.07	0.35*	1	-	-	-	-	-	-	-	-	-	-
	C2	0.07	−0.01	1	-	-	-	-	-	-	-	-	-	-
SN	C1	0.3*	−0.35*	0.3*	1	-	-	-	-	-	-	-	-	
	C2	0.2	−0.24	0.41**	1	-	-	-	-	-	-	-	-	-
SpN	C1	0.33*	−0.35*	0.28	0.99**	1	-	-	-	-	-	-	-	-
	C2	0.22	−0.28	0.36*	0.97**	1	-	-	-	-	-	-	-	-
SL	C1	0.03	0.46**	0.52**	−0.18	−0.23	1	-	-	-	-	-	-	-
	C2	−0.04	0.38**	0.2	−0.18	−0.22	1	-	-	-	-	-	-	
SpiN	C1	−0.19	0.35*	0.06	−0.462**	−0.5**	0.41**	1	-	-	-	-	-	
	C2	−0.13	0.29*	−0.09	−0.55**	−0.57**	0.37**	1	-	-	-	-	-	
5 SSN	C1	−0.28	0.52**	0.21	−0.55**	−0.57**	0.41**	0.64**	1	-	-	-	-	
	C2	−0.26	0.32*	−0.04	−0.59**	−0.6**	0.29*	0.59**	1	-	-	-	-	-
5 SSW	C1	−0.04	0.17	0.19	−0.63**	−0.66**	0.49**	0.61**	0.77**	1	-	-	-	-
	C2	0.07	−0.18	0.04	−0.43**	−0.39**	0.167	0.43**	0.6**	1	-	-	-	-
BSW	C1	0.35*	−0.06	0.71**	0.43**	0.45**	0.14	−0.13	−0.06	0.002	1	-	-	-
	C2	0.4**	−0.44**	0.65**	0.49**	0.53**	−0.12	−0.16	−0.15	0.18	1	-	-	-
TKW	C1	0.28	−0.28	0.14	−0.35*	−0.33*	0.20	0.07	−0.11	0.46**	0.24	1	-	-
	C2	0.39**	−0.56**	0.06	−0.23	−0.2	−0.11	0.03	−0.11	0.5**	0.33*	1	-	
PL	C1	0.18	0.11	0.55**	0.19	0.16	0.56**	−0.21	−0.04	0.09	0.24	0.20	1	-
	C2	0.06	−0.17	0.44**	0.19	0.18	0.36*	−0.32*	−0.18	−0.07	0.16	0.07	1	
PH	C1	0.15	0.34*	0.62**	0.07	0.04	0.68**	−0.06	0.07	0.14	0.23	0.19	0.89**	1
	C2	−0.09	0.22	0.48**	−0.02	-0.07	0.55**	−0.04	0.03	−0.08	-0.06	−0.1	0.82**	1

Co: condition, Y: grain yield, H.D: heading date, B: biomass, SN: stems number, SpN: spikes number, SL: spikes length, SpiN: spikelet number, 5 SSN: 5 spike seed number, 5 SSW: 5 spike seed weight, BSW: bundle spikes weight, TKW: thousand kernel weight, PL: peduncle length, PH: plant height, * and ** significantly at $P < 0.05$ and $P < 0.01$, respectively.

Table 4. Correlation coefficients between Yp, Ys, drought tolerance indices, and first and second components.
Yp: yield under normal conditions; Ys: yield under stress conditions; MP: mean productivity; GMP: geometric mean productivity; STI: stress tolerance index; TOL: tolerance index; and SSI: stress susceptibility index; PRIN1: first component; PRIN2: second component.

Traits	Yp	Ys	TOL	STI	MP	GMP	SSI	PRIN1	PRIN2
Yp	1								
Ys	0.30*	1							
TOL	0.42**	−0.74**	1						
STI	0.55**	0.96**	0.52**	1					
MP	0.73**	0.87**	−0.31*	0.97**	1				
GMP	0.58**	0.95**	−0.5**	0.99**	0.98**	1			
SSI	0.04	−0.94**	0.92**	−0.79**	−0.64**	−0.79**	1		
PRIN1	0.43**	0.99**	-0.64**	0.97**	0.93**	0.98**	−0.88**	1	
PRIN2	0.90**	−0.14	0.76**	0.15	0.38**	0.17	0.46**	0.008	1

increasing grain yield of genotypes in nonstress conditions, grain yield under water stress conditions increased as well. Therefore, high yield performance of genotypes under irrigated conditions would be an effective means of selecting genotypes for drought-affected environments as well. These observations are in agreement with the results of Golmoghani Asl et al. (2011) in wheat, Ajalli and Salehi (2012) in barley, and Abdi et al. (2013) in sunflower.

Yield under normal conditions shows a positive and meaningful correlation with tolerance (r = 0.42**), stress tolerance index (r = 0.55**), mean productivity (0.73**), and geometric mean productivity (0.56**) at 1% probability level. These results are compatible with Rosielle and Hamblin (1981) and Mohammadi et al. (2006). Yield under rain-fed conditions showed a positive and meaningful correlation with stress tolerance index (r = 0.95**), mean productivity (r = 0.87**), and geometric mean productivity (r = 0.95**) at 1% significance level; however, it showed a negative and meaningful correlation with susceptibility index (r = –0.94**) and tolerance index (r = –0.74**) at 1% significance level. Among the stress tolerance indicators, a higher value of TOL and SSI represent higher sensitivity to stress, thus smaller values of TOL and SSI are preferable. Selection based on these two indices favors genotypes with low yield under nonstress conditions and high yield under stress conditions (Golabadi et al., 2006). On the other hand, selection based on GMP and STI will result in the selection of genotypes with higher stress tolerance and yield potential (Fernandez, 1992). Some researchers state that the best suitable index for stress tolerant varieties is an index that is highly correlated with grain yield under both stress and normal conditions. Therefore, it might be possible to identify the most suitable index by comparing the correlation rate between grain yield and stress tolerance under both conditions. 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 stress and nonstress environments.

Principal component analysis was performed to determine the relationship between genotypes and drought stress index. According to principal component analysis, 2 components accounted for 99.70% of the total variance (Table 5). The first component justified most of the variance between the genotypes (73.66%). Indices that correlated with the first component included Yp (r = 0.43**), Ys (r = 0.99**), STI (r = 0.98**), MP (r = 0.93**), and GMP (r = 0.97**) (Table 4). Moreover, under the first component, indices such as GMP, MP, STI, and Ys showed the highest positive coefficient. Therefore, selection for high yield genotypes is possible on the basis of indices under the first principal component. Thus, this component can be referred to as yield component under drought conditions. The second principal component justified 26.03% of the remaining variation and showed positive and high correlation with TOL, SSI, and Yp. Therefore, we can refer to this component as tolerance index. As such, the second principal component plays an important role in distinguishing groups of cultivars under normal conditions for the purposes of yield.

Table 5. Principal component loadings for the measured traits of winter wheat genotypes.

Traits	PRIN	
	PRIN1	PRIN2
Yp	0.19	0.67
Ys	0.44	–0.11
TOL	–0.28	0.57
STI	0.43	0.11
MP	0.41	0.27
GMP	0.43	0.13
SSI	–0.39	0.34
Variation %	73.66	26.03
Total variation %	73.66	99.70

A biplot diagram derived from the first and second factor components is shown in Figure 1. The biplot diagram is divided into four categories named A, B, C, and D on

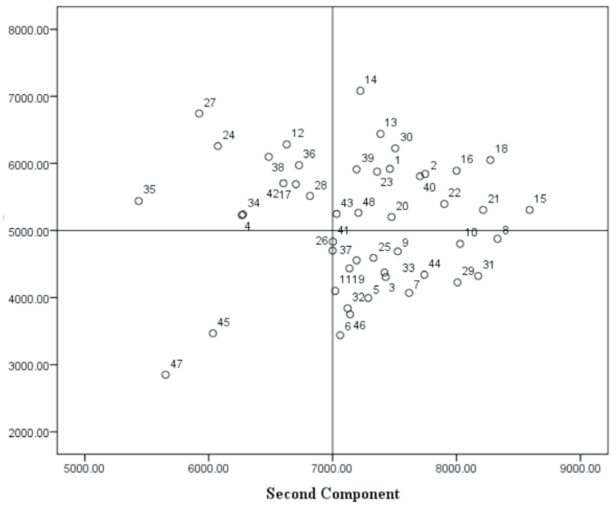

Figure 1. Dispersion of the genotypes under study according to first and second component of principal components, over drought tolerance indices of 48 wheat genotypes under normal irrigation and drought stress conditions.

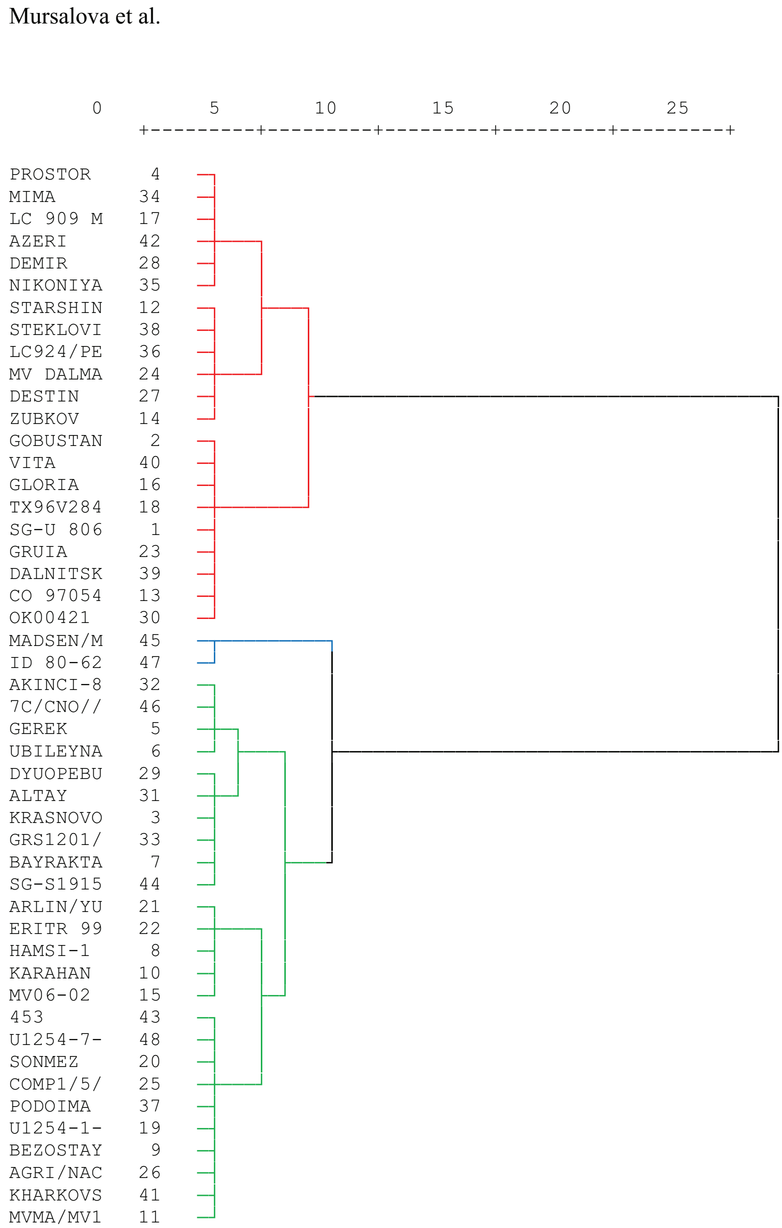

Figure 2. Dendrogram of wheat genotypes based on cluster analysis using various drought tolerance indices.

the basis of the two first principal components. Genotypes which are placed in area A, such as MV DALMA, DESTIN, MIMA, NIKONIYA, STARSHINA, STEKLOVIDNAYA24, AZERI, LC 909 MIMA, LC924/PETJA, PROSTOR, and DEMIR show high yield under drought stress and drought tolerance conditions. Therefore, these genotypes can be introduced as tolerant genotypes into subsequent breeding programs for the selection of drought tolerant and high-yielding genotypes under stress conditions. Genotypes located in area B have suitable potential under both irrigated and drought stress conditions. On the other hand, genotypes that are placed in area D have high yield under irrigated conditions.

Golabadi et al. (2006) obtained similar results for drought tolerance in segregating populations of durum wheat. They reported that the first and second principal components, which explained 70% and 28% of the variation, were related to yield potential and stress tolerance, respectively. Nazari and Pakniyat (2010) also reported that barley varieties can be distinguished from drought tolerance based on the biplot method.

Cluster analysis based on drought tolerance indices and grain yield under stress and nonstress conditions classified the genotypes into three groups with 21, 2, and 25 genotypes, respectively (Figure 2). Group 1 consisted of genotypes with higher Yp, Ys, MP, GMP, and TOL values, and is considered as a drought-susceptible group with high yield performance under favorable environments. Group 2 contained the genotypes with lowest values of first and second principal components; therefore, G45 and G47 are not suitable wheat genotypes for both conditions. Group 3 consisted of genotypes that show high performance under irrigated conditions.

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