Biological Forum – An International Journal **7**(1): 230-241(2015)

ISSN No. (Print): 0975-1130
ISSN No. (Online): 2249-3239

Drought Tolerance of Advanced Bread Wheat Genotypes Based on Different Drought Tolerance Criteria

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(Received 17 May, 2015, Accepted 09 July, 2015)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: In order to study genetic variation and effect of drought stress on grain yield and some agronomical and water relation-traits in bread wheat, an experiment was conducted on 16 advanced genotypes during 2013-2014 cropping season at deputy of Kermanshah Sararood Dry Land Agricultural Research Institute, located on the western part of Iran. The experimental layout was conducted in a randomized complete block design with three replications under two complementary irrigation and dryland conditions. Results indicated that genotype and environment treatments significantly affect the yield and the most of the other evaluated traits whereas, the interaction between genotype and environment was not significant for all evaluated traits with expectation for grain yield. Significant reduction was found in grain yield, number of grain per spike, harvest index, grain crude starch and water relation-traits such as relative water content, leaf water content and excised leaf water retention as a result of the drought, whereas leaf water loss, grain crude protein and grain crude fiber were increased in dryland conditions. According to the results of mean comparison and drought indices, genotypes number 1, 2, 8 and 10 were drought tolerant whereas genotypes number 7, 14, 13 and 16 were drought susceptible. Therefore, genotypes number 1 and 2 can be introduced as a right candidate for the next breeding programs. Moreover, these two genotypes showed a proper performance in the water relation-traits which may caused higher grain yield. In conclusion, this study showed that the effect of drought stress on grain yield was varied which suggested genetic variability for drought tolerance in this materials. Therefore, breeders can select better genotypes based on indices and a combination of different methods of selection.

Keywords: Biplot, Drought indices, Grain yield, Water relation-traits, Protein

INTRODUCTION

World population is increasing apace and important percentage of the needed food for this growing population is depended on agricultural production. Wheat is the second most produced cereal crop as a sustained food which constitutes about 28 % of dietary energy in many parts of the world (Braun *et al.* 2010; Cai *et al.,* 2011). Wheat production is restricted by varied stresses which cause different problems due to great impacts on human nutrition. Therefore, in recent years, studying crop response to environmental stresses has greatly increased due to severe losses caused by these stresses (Blum, 1996). So, one of the main purposes of all nations is reducing these damages simultaneity with the increasing food demands (Mahajan and Tuteja, 2005).

In the natural environments, plants often grow under various stresses which are threats for plants and inhibiting them from reaching to their full genetic potential and limit the crops productivity worldwide (Krishania and *et al.,* 2013). Moreover, these stresses may threat the stability of agricultural industry (Mahajan and Tuteja, 2005).

Current estimates indicate that 25% of the world's agricultural land is now affected by drought stress (Li *et al.,* 2011). Drought as the most important abiotic stress is a worldwide problem which imposes major limits on wheat production and food security in many arid and semi-arid regions such as Iran (Debaeke and Abdellah, 2004; Rajala *et al.,* 2009; Shiri *et al.,* 2010). In these regions, drought reduces more than 50% of average yields for most major crops (Wang *et al.,* 2003).

Wheat is mainly grown on rainfed lands of different regions of the world and Iran too. Iranian farmers cultivate on an average 6.6 million hectares of wheat each year of which about 4.2 million hectares under rainfed (drought stressed) (Rostaei, 2007; Shahryari and Mollasadeghi, 2011). At this circumstance, inadequate rainfall and high temperatures during grain filling period at the end of the growing season greatly restrict grain production (Ghobadi *et al.,* 2011).Nouri-Ganbalani *et al.* (2009) have estimated that drought stress cause average loss of grain by 17 to 70%. Kilic and Yagbasanlar (2010) reported the 61.4% reduction of yield in their study on durum wheat cultivars.

Regarding to increasing world demand for grain of wheat, as a stable food crop, one of the major aims in plant breeding programs is developing new genotypes with traits that could tolerate serious drought stress at various stages of growth and can also produce cost-effective and stable yield at rainless years (Leilah and AL-Khateeb, 2005; Farshadfar *et al.,* 2011).

Study of genetic variation and effective selection of genotypes based on important traits such as productivity, grain yield, grain yield components and physiological traits (Siddique *et al.,* 2000) can be useful for genetic variation studies and may be a convenient and efficient approach to drought tolerant genotypes development (Razzaq *et al.,* 2013).A wide genetic variation have been reported for traits such as grain and biological yield, harvest index and thousands grain's weight between different wheat genotypes under different climatic conditions (Wardlaw, 2002; Ahmadi *et al.,* 2009). It has been found that under the water deficit conditions, those genotypes that show the highest harvest index and highest yield stability are drought tolerant (Rathore, 2005). The knowledge of genetic association between grain yield and its components under water deficit conditions would improve the efficiency of breeding programs by identifying appropriate indices for selecting wheat genotypes (Evans and Fischer, 1999).

As Kilic and Yagbasanlar (2010) stated, some traits such as number of fertile tillers per plant, 1000-grain weight, peduncle length, awn length, plant height, spike length, number of grain per spike, weight of grain per spike, etc. affect the wheat tolerance to the moisture deficiency in the soil (Plaut *et al.,* 2004; Aminzadeh, 2010).Drought stress may reduce all yield components, but particularly the number of fertile spikes per unitarea and the number of grains per spike (Abayomi and Wright, 1999), while grain weight is negatively influenced by high temperatures and drought stress during ripening (Chmielewskiand Kohn, 2000). Noorka *et al.* (2009) reported that fat, protein, gluten, Zeleny, thousand kernel weight and grain yield values showed different response under normal and water stress environments. The quality traits of wheat grain were significantly affected under drought stress conditions.

Relative yield of a genotype may reflect its performance under drought. Therefore, most widely used criteria for selection are based on yield performance under stress and non-stress conditions. Thus, several drought indices which provide a measure of drought tolerance or susceptibility of genotypes based on mathematical relation between stress and non-stress conditions have been used for screening drought-tolerant genotypes (Mitra, 2001; Talebi *et al.,* 2009).

On the other hand, knowing the physiological processes associated with yield and yield related-trait relationships in modern and advanced wheat genotypes would be the most attractive way to increase grain yield and improve management strategies (Araus *et al.,* 2008; Ye *et al.,* 2011). As Razzaq *et al.* (2013) stated, physiological parameters may be considered as indicators of proper growth and yield under drought stress. For example, plants keeping high relative water content show a positive relation with grain yield (Makoto *et al.,* 1990). Drought stress was found to reduce the relative water content (RWC) in plant leaves. The high RWC and low excised leaf water loss (ELWL) have been suggested as important indicators of water status (El-Tayeb, 2006; Gunes *et al.,* 2008). Khakwani *et al.* (2012) studied growth and yield response of wheat varieties to drought stress at booting and anthes is stages of development. They indicated highly significant differences among genotypes for most of the studied trait such as, relative water content plant height, yield and yield components, biological yield, harvest index, and drought tolerance indices.

Regarding to this fact that selection of genotypes under drought stress conditions is one of the main tasks of plant breeders, the present study was undertaken to: 1) evaluate genetic variation for grain yield and some related traits among 16 advanced bread wheat genotypes, 2) understanding of relationships between traits and grain yield, and their response to drought stress conditions and 3) identify drought tolerant genotypes among 16 advanced bread wheat genotypes using different selection criteria.

MATERIALS AND METHODS

A. Plants materials

Sixteen advanced bread wheat genotypes listed in Table 1 were studied during 2013-2014 cropping season at deputy of Kermanshah Sararood Dry Land Agricultural Research Institute, located on the western part of Iran (Latitude 34º 19' north and longitude 47º 17' east, altitude 1351 m above the sea level)with deep soils of clay-loam texture. The average annual precipitation is estimated to 455 mm. The precipitation at the cropping season of the experiment was 320 mm. The experimental layout was conducted in a randomized complete block design with three replications under two complementary irrigation and dryland conditions. Sowing was done at six row plots, 6 m length, and 0.20 m row spacing as 400 seeds per square meter density. Complementary irrigation was imposed at heading and grain filling stages by 30 mm irrigation.

B. Physiological traits

(i) Leaf relative water content (RWC) was measured at flowering stage using Turner and Kramer (1980) method:

$$RWC\% = \left[\frac{(FW - DW)}{(TW - DW)}\right] \times 100$$

Where, FW = fresh leaf weight; DW = dry weight (In ovenfor 48 h); TW = tumescent weight.

(ii) Clarkeand McCaig (1982) method was used to calculate excised leaf water retention (ELWR):

$$ELWR\% = \left[1 - \frac{(FW - ADW)}{FW}\right] \times 100$$

Where, FW= primary leaf weight; ADW = weight of leaves after 5 hours (wilt leaf).

Table 1: List of the plant materials.

ENT.NO	Source	LAST.Ent.No	Variety/Line
1	AZAR-2	AZAR-2	AZAR-2
2	RIJAW	RIJAW	RIJAW
3	20thARWYT-1	5	Azar-2/TEU2/3/Ures/Fan/kauz IRW92 1D 6 IRBW04-23-54-22-OSAR-OSAR-0SAR-0SAR-1SAR-OSAR
4	20thARWYT-1	9	Cross Alborz/Roshan/3/F12.71/Coc//Gn079 IRBW04-23-54-13-OSAR-OSAR-0SAR-0SAR-2SAR-OSAR
5	20thARWYT-1	10	Azar-2/TEU2/3/Ures/Fan/kauz IRW92 1D 7IRBW04-23-54-22-OSAR-OSAR-0SAR-0SAR-3SAR-OSAR
6	20thARWYT-1	13	Azar-2/pure line BW(38) IRBW04-23-54-25-OSAR-OSAR-0SAR-0SAR-2SAR-OSAR
7	20thARWYT-1	21	Azar-2/GENE BANK-3 IRBW04-23-54-31-OSAR-OSAR-0SAR-0SAR-1SAR-OSAR
8	20thAWYT-91-92	4	VOROBEY
9	20thAWYT-91-92	5	GK ARON/AG SECO 7846//2180/4/2*MILAN/KAUZ//PRINIA/3/BAV92
10	20thAWYT-91-92	6	BAV92/SERI
11	20thAWYT-91-92	8	PROINTA FEDERAL
12	20thAWYT-91-92	24	ATTILA*2/PBW65/6/PVN//CAR422/ANA/5/BOW/CROW//BUC/PVN/3/YR/4/TRAP#1/7/ATTILA/2*PASTOR
13	20thAWYT-91-92	25	ATTILA*2/PBW65/6/PVN//CAR422/ANA/5/BOW/CROW//BUC/PVN/3/YR/4/TRAP#1/7/ATTILA/2*PASTOR
14	20thARWYT-3	9	Azar-2/TEU2/3/Ures/Fan/kauz IRW92 1D 6 IRBW04-23-54-22-OSAR-OSAR-0SAR-0SAR-1SAR-OSAR
15	20thARWYT-3	13	Azar-2/pure line BW(38) IRBW04-23-54-25-OSAR-OSAR-0SAR-0SAR-2SAR-OSAR
16	20thARWYT-3	21	Azar-2/GENE BANK-3 IRBW04-23-54-31-OSAR-OSAR-0SAR-0SAR-1SAR-OSAR

(iii) Leaf water loss (LWL) was measured according to Xing *et al.* (2004) method:

$$LWL\% = \left[\frac{(FW - W2)}{FW}\right] \times 100$$

Where, FW = fresh leaf weight; W_2 = weight of wilt leaf after 2 hours (In incubator 34ºC).

(iv) Leaf water content (LWC) was calculated using Clarke and McCaig (1982) method:

$$LWC\% = \left[\frac{(FW - DW)}{FW}\right] \times 100$$

Where, FW = fresh leaf weight; DW = leaves placed in an oven at 50º C for 24 h and re-weighed

C. Agronomical traits

After physiological maturity stage, grain yield, numbers of grain per spike and harvest index were measured. Moreover, some grain quality-related traits such as crude protein concentration and also crude starch and fiber percents were measured by near infrared reflectance (NIR) spectrometer method (Osborne *et al.*, 2007).

D. Drought indices

Drought indices were calculated using the following formulas:

1)	Stress susceptibility index = $SSI = \frac{1-(Ys/Yp)}{1-(\bar{Y}s/\bar{Y}p)}$	(Fischer and Maurer, 1978)
2)	TOL = Yp – Ys	(Rosielle and Hambling, 1981)
3)	MP = (Ys+Yp)/2	(Rosielle and Hambling, 1981)
4)	$GMP=\sqrt{(Ys \times Yp)}$	(Fernandez, 1992)
5)	$STI = \frac{(Yp)(Ys)}{(\bar{Y}p)^2}$	(Fernandez, 1992)
6)	YSI = Ys/Yp	(Bouslama and Schapaugh, 1984)
7)	HARM= [2(Ys× Yp)]/(Ys+Yp)	(Kristin *et al.*, 1997)
8)	SDI = (Yp-Ys)/Yp	(Farshadfar and Javadinia, 2011)
9)	$DI = Ys \times \left[\frac{(Ys/Yp)}{\bar{Y}s}\right]$	(Lan, 1998)
10)	$RDI = \frac{(Ys/Yp)}{(\bar{Y}s/\bar{Y}p)}$	(Fischer and Maurer, 1978)
11)	SSPI=[Yp-Ys /2($\bar{Y}p$)]×100	(Moosavi *et al.*, 2008)

Where "Ys" is the yield of genotype under stress, "Yp" is the yield of genotype under irrigated conditions, " " and " " are the mean yields of all genotypes under stressed and non-stressed conditions, respectively, and "1- (/)" is the stress intensity.

E. Statistical software

Analysis of variance was carried out using SAS ver.9.1 software. Duncan multiple range test (DMRT) was used for the mean comparisons. Pearson correlation among traits and cluster analysis were performed by SPSS ver.16. Principal component analysis (PCA) and biplot diagram were carried out by and Stat graphics ver.16.1.11.Ranks (SDR) was measured as:

$$S_i^2 = \frac{\sum_{j=1}^{m}(Rij-\bar{R}i.)^2}{l-1}$$

Where Rij is the rank of drought tolerance indicator and $\bar{R}i$ is the mean rank across all drought tolerance indicators for the ith genotype and SDR= $(S_i^2)^{0.5}$.

Rank sum (RS) = Rank mean ($\bar{R}$) + Standard Deviation of Rank (SDR) (Farshadfar and Elyasi, 2012).

RESULTS AND DISCUSSION

Results of ANOVA under two complementary irrigation and dryland conditions (Table 2) revealed significant differences among genotypes for relative water content (RWC), leaf water loss (LWL), leaf water content (LWC), grain yield (GY), number of grain per spike (NGPS) and harvest index (HI) which indicating the presence of genotypic variability, different responses of genotypes and possible selection genotypes for breeding programs. According of the results of combined analysis of variance (Table 3), genotypes were significant different for all of the studied traits except crude protein (CPr), crude starch (CStr) and crude fiber (CFr) contents. Variation percentage of the traits due to drought stress is shown in Table 4. It should be note that the stress intensity was light (0.1). As can be seen in Table 4, drought stress had the highest effect on excised leaf water content (LWC) by 23.17% reduction. Genotype × environment interaction was not significant for all studied traits with the exception of GY, this means that genotypes for these traits had the same reaction in different environmental conditions. Therefore, only mean comparison of studied traits in two non-stress and stress conditions (combined analysis) is presented (Table 5).

A. Water related-traits

Genotypes were significantly different with respect to RWC, LWL, LWC and ELWR based on combined analysis of variance. In general, these genotypic variations in the traits may be due to differences in the ability to absorb more water from the soil or the ability to control water loss through the stomata's (Khakwani *et al.*, 2011).

Table 2: Analysis of variance for studied traits under complementary irrigation and dryland conditions.

S.O.V	df	Mean Squares									
		RWC		LWL		LWC		ELWR		GY	
		Irrigated	Dryland	Irrigated	Dryland	Irrigated	Dryland	Irrigated	Dryland	Irrigated	Dryland
Rep	2	44.23^{ns}	132.35^{ns}	606.48*	681.57**	6.19^{ns}	87.19*	37.46^{ns}	43.65^{ns}	203806.71^{ns}	482840.04^{ns}
Gen	15	528.18*	395.98*	304.51*	598.22**	471.86**	307.27**	16.43^{ns}	29.62^{ns}	404256.34**	598062.90**
Error	30	206.29	179.10	141.28	108.00	49.22	25.44	15.00	28.01	79281.04	203024.81
C.V.%	--	21.06	22.37	50.29	28.94	24.50	22.92	4.07	5.66	7.43	13.23

S.O.V	df	Mean Squares									
		NGPS		HI		CPr		CStr		CFr	
		Irrigated	Dryland	Irrigated	Dryland	Irrigated	Dryland	Irrigated	Dryland	Irrigated	Dryland
Rep	2	0.79^{ns}	7.26^{ns}	1.38^{ns}	0.76^{ns}	0.88^{ns}	0.29^{ns}	0.01^{ns}	0.01^{ns}	0.02^{ns}	0.03^{ns}
Gen	15	53.07**	56.70*	7.41**	2.90^{ns}	0.36^{ns}	1.00^{ns}	0.30^{ns}	0.34^{ns}	0.06^{ns}	0.06^{ns}
Error	30	15.59	21.03	2.53	1.82	0.72	1.20	0.41	0.35	0.07	0.07
C.V.%	--	14.00	18.50	3.16	2.70	5.24	6.52	0.94	0.88	10.68	10.18

^{ns}, * and **: Non significant, significant at the 5% and 1% probability levels, respectively.
Relative water content (RWC), leaf water loss (LWL), leaf water content (LWC), excised leaf water retention (ELWR), grain yield (GY), numbers of grain per spike (NGPS), harvest index (HI), crude protein (CPr), crude starch (CStr), crude fiber (CFr).

Although drought stress had high significant effect on RWC, LWL and LWC but the interaction between genotype and environment was not significant for all water relations-studied traits (Table 3). Drought significantly caused an average of 12.28, 23.17 and 1.83% decline in rate of RWC, LWC and ELWR traits respectively, and an average of 51.92% increase in LWL (Table 4). According to the mean comparison of studied traits in two conditions, genotypes number 1 and 2 had the highest RWC and ELWR but had the lowest LWL. This means that the ability of these genotypes has been proper in maintaining water status and may indicate some inhibiting mechanisms of leaf water loss under drought stress. This associations is confirmed by correlation coefficients results, so that there was a negative correlation between RWC and LWL under complementary irrigation (r = -0.526*) and dryland (r = -0.723**) conditions, and also between ELWR and LWL under complementary irrigation (r = -0.265) and dryland (r = -0.533*) conditions. Moreover, the correlation between RWC and ELWR was positive under both conditions (Table 6). RWC had the positive correlation with GY under complementary irrigation (r = 0.628**) and dryland (r = 0.403) conditions (Table 6). The correlation between ELWR and GY was negative under both conditions which such correlation is reported in previous studies (Dhanda and Sethi, 2002; Lonbani and Arzani, 2011).

In a study on wheat, it was found that the drought tolerant genotypes have higher RWC and regarding to the high correlation between RWC and grain yield, it was concluded that this trait can be used for identification drought tolerant genotypes in breeding programs (Naroui Rad *et al.*, 2013). Sairam and Srivastava (2001) observed variation in wheat genotypes for RWC and suggested that RWC is a suitable indicator for screening drought tolerant wheat genotypes. Shamsi (2010) observed a decline in wheat RWC due to drought stress and reported the highest RWC in the tolerant genotypes.

Table 3: Combined analysis of variance for studied traits under both complementary irrigation and dryland conditions.

S.O.V	df	Mean Squares									
		RWC	LWL	LWC	ELWR	CPr	CStr	CFr	GY	NGPS	HI
Environment (Env)	1	1683.79*	3613.52^{ns}	1056.09**	73.17^{ns}	7.12*	43.88**	0.002^{ns}	3517373.13*	280.62**	2.62^{ns}
Rep (Env)	4	88.29	644.03	46.69	40.56	0.59	0.01	0.025	343323.38	4.03	1.07
Genotype (Gen)	15	808.31**	800.97**	725.25**	44.12*	1.11^{ns}	0.60^{ns}	0.112^{ns}	733908.59**	92.01**	7.08**
Env× Gen	15	115.85^{ns}	101.76^{ns}	53.88^{ns}	1.94^{ns}	0.25^{ns}	0.03^{ns}	0.004^{ns}	268410.65*	17.77^{ns}	3.23^{ns}
Error	60	192.69	124.64	37.33	21.51	0.96	0.38	0.069	141152.92	18.31	2.18
C.V. %	-	21.69	37.50	24.13	4.92	5.94	0.91	10.43	10.44	16.15	2.94

^{ns}, * and **: Non significant, significant at the 5% and 1% probability levels, respectively.
Relative water content (RWC), leaf water loss (LWL), leaf water content (LWC), excised leaf water retention (ELWR), grain crude protein (CPr), grain crude starch (CStr), grain crude fiber (CFr), grain yield (GY), numbers of grain per spike (NGPS), harvest index (HI).

Table 4: Means and the variations percentage of studied traits under both complementary irrigation and dryland conditions.

Trait	Irrigated	Dryland	Variations (%)
Relative Water Content (RWC) (%)	68.20	59.82	12.28
Leaf Water Loss (LWL) (%)	23.64	35.91	-51.92
Leaf Water Content (LWC) (%)	28.64	22.00	23.17
Excised Leaf Water Retention (ELWR) (%)	95.23	93.48	1.83
Crude Protein (CPr) (%)	16.24	16.79	-3.35
Crude Starch (CStr) (%)	68.04	66.69	1.99
Crude Fiber (CFr) (%)	2.51	2.52	-0.34
Grain Yield (GY) (Kg.ha^{-1})	3789.67	3406.83	10.10
Numbers of Grain Per Spike (NGPS)	28.20	24.78	12.12
Harvest Index (HI) (%)	50.38	50.05	0.66

Munjal and Dhanda (2005) found the high levels of RWC and ELWR in the selection of drought tolerant wheat genotypes.

B. Grain quality traits

The effects of genotype and the interactions between genotype and environment were not significant for quality studied traits, but the effect of environment was significant for grain crude protein (CPr) and crude starch (CStr) percents (Table 3). Mean comparison of studied traits in both conditions is presented in Table 5. Grain CPr ranged from 15.90 to 17.23%, with a mean value of 16.51%. Genotypes number 13, 7 and 5 by at least 17% hadthe highest grain CPr, respectively. Grain CStr ranged from 66.86 to 67.82%, with an average of 67.37%. Grain CFr ranged from 2.26 to 2.67%, with an average of 2.51%. Highest grain CStr and grain CFr were observed in genotypes number 9 and 10, respectively (Table 5). Drought stress increased grain CPr and grain CFr by 3.35 and 0.34% and decreased grain CStr by 1.99% compared with complementary irrigation (Table 4).Cox *et al.,* (1989) concluded that change in the quality of wheat is caused by non genetic factors such as changes in environment. In an investigation, effects of restricted water availability was evaluated for grain filling, drying and quality of winter wheat and has been reported that protein content increased by drought stress before the end of grain growth because the nitrogen harvest index was less severely affected than the dry matter harvest index (Gooding *et al.,* 2003). Guttieri *et al.,* (2005) also observed that genotype, nitrogen fertilizer and irrigation affected grain protein concentration. So, much rainfall during the period of grain development results in low concentration, whereas dry conditions during that period causes high protein concentration (Souza *et al.,* 2004). At the present study, the drought stress increased grain CPr which has also been reported by other researchers (Mary *et al.,* 2001; Noorka *et al.,* 2009).

C. Agronomic traits and assessment of drought tolerant genotypes

Grain yield of the genotypes was significantly ($P<0.05$) affected (Table 3), and reduced an average of 10.10% by drought stress (Table 4). The means of grain yield ranged from 4290 kg.ha^{-1} for genotype "15" to 3237 kg.ha^{-1} for genotype "16" under complementary irrigation conditions (non-stress) and ranged from 4069 kg.ha-1 to 2699 kg.ha-1 for genotypes "2" and "14" under dryland conditions (stress), respectively (Table 7). According to the results, the mean of grain yield were 3789 and 3407 kg/ha in non-stress and stress conditions, respectively. Therefore, the stress intensity was 0.10.It could be noticed that this index is just calculable to measuring drought stress intensity in the experiment and it is not applied to measuring stress intensity in genotypes (Fischer and Maurer, 1978).In non-stress conditions, genotypes 15, 6, 1 and 10had the highest and genotypes 16, 13, 4 and 5 showed the lowest grain yield, respectively. In stress conditions, genotypes 2, 8, 10 and 1 had the highest and genotypes 14, 7, 13 and 16 showed the lowest grain yield, respectively (Table 7). Therefore, genotypes 1 and 10 gave the best performance and genotypes 16 and 13 showed the worst performance in both conditions. These results for genotype number 1 indicated that this genotype in addition to having a high genetic potential and having good status regarding to the water related-trait, has been able to use the mechanisms of drought tolerance and to prevent yield loss.

As reported by several researchers, in general there is a linear relationship between available water and grain yield, where reduction in available water limits evapotranspiration and consequently reduced grain yield (Sokoto and Singh, 2013). According to the results study of Elhafid *et al.* (1998), drought leads to reducing inoculation of flower and this affects number of produced grain. Foulkes *et al.* (2002) reported that the grain yield in stress conditions has significant reduction at anthesis stage and after that relative to non-stress conditions.

Table 5: Mean comparison of studied traits in two complementary irrigation and dryland conditions.

Gen	RWC (%)	LWL (%)	LWC (%)	ELWR (%)	CPr (%)	CStr (%)	CFr (%)	GY (Kg.ha^{-1})	NGPS	HI (%)
1	86.38^{a}	2.05^{b}	37.96^{bc}	98.86^{a}	16.29^{a}	67.44^{abc}	2.46^{ab}	4032.0^{a}	26.98^{bcdef}	53.17^{a}
2	82.50^{a}	2.91^{b}	30.30^{cde}	97.28^{ab}	16.88^{a}	66.86^{c}	2.38^{ab}	4084.2^{a}	29.65^{b}	49.01^{b}
3	70.41^{abc}	40.48^{a}	31.96^{cde}	95.06^{abc}	16.95^{a}	66.93^{bc}	2.45^{ab}	3631.5^{abc}	27.80^{bcde}	50.00^{b}
4	52.68^{cde}	41.33^{a}	24.15^{ef}	95.61^{abc}	16.24^{a}	67.67^{abc}	2.57^{ab}	3450.2^{bcd}	26.33^{bcdef}	50.00^{b}
5	62.32^{bcde}	36.13^{a}	29.50^{de}	95.79^{abc}	17.00^{a}	66.96^{bc}	2.50^{ab}	3276.4^{cd}	25.37^{bcdef}	48.85^{b}
6	78.51^{ab}	27.48^{a}	15.08^{gh}	95.98^{abc}	16.77^{a}	67.25^{abc}	2.26^{b}	3839.5^{abc}	23.48^{cdef}	50.00^{b}
7	69.73^{abcd}	36.90^{a}	18.92^{fg}	94.07^{abcd}	17.06^{a}	67.05^{abc}	2.56^{ab}	3442.9^{abc}	37.08^{a}	50.00^{b}
8	63.79^{bcde}	28.75^{a}	14.16^{gh}	91.61^{bcd}	16.07^{a}	67.59^{abc}	2.57^{ab}	4008.1^{a}	29.23^{bc}	50.00^{b}
9	68.05^{abcd}	27.93^{a}	32.36^{bcd}	93.05^{abcd}	16.15^{a}	67.82^{a}	2.65^{a}	3421.1^{bcd}	21.72^{f}	50.00^{b}
10	68.63^{abcd}	34.42^{a}	15.34^{gh}	88.09^{d}	16.67^{a}	67.52^{abc}	2.67^{a}	4041.1^{a}	26.00^{bcdef}	52.47^{a}
11	52.91^{cde}	35.59^{a}	14.63^{gh}	94.36^{abc}	16.27^{a}	67.08^{abc}	2.27^{b}	3402.9^{bcd}	30.08^{b}	50.00^{b}
12	56.11^{cde}	26.06^{a}	14.22^{gh}	95.57^{abc}	16.05^{a}	67.74^{ab}	2.52^{ab}	3429.6^{bcd}	23.17^{def}	50.00^{b}
13	56.34^{cde}	31.34^{a}	47.02^{a}	93.13^{abcd}	17.23^{a}	67.25^{abc}	2.73^{a}	3102.3^{d}	28.05^{bcd}	50.00^{b}
14	57.17^{cde}	34.16^{a}	10.58^{h}	96.50^{ab}	15.90^{a}	67.55^{abc}	2.40^{ab}	3346.6^{bcd}	22.98^{def}	50.00^{b}
15	50.76^{de}	33.33^{a}	39.64^{b}	90.07^{cd}	16.64^{a}	67.48^{abc}	2.64^{a}	3990.8^{a}	22.08^{ef}	50.00^{b}
16	47.93^{e}	37.50^{a}	29.29^{de}	94.64^{abc}	16.07^{a}	67.72^{ab}	2.57^{ab}	3072.8^{d}	23.87^{cdef}	50.00^{b}

Means, in each column, followed by at least one letter in common are not significantly different at the 5% probability level-using Duncan's Multiple Range Test.

Relative water content (RWC), leaf water loss (LWL), leaf water content (LWC), excised leaf water retention (ELWR), grain crude protein (CPr), grain crude starch (CStr), grain crude fiber (CFr), grain yield (GY), numbers of grain per spike (NGPS), harvest index (HI).

Table 6: Pearson correlation coefficients between different traits in16 advanced bread wheat genotypes under complementary irrigation and dryland conditions (n=16).

		RWC	LWL	LWC	ELWR	CPr	CStr	CFr	GY	NGPS	HI	
RWC	Complementary irrigation	1	-0.723**	0.311	0.395	0.359	-0.379	-0.269	0.403	0.241	-0.058	Dryland
LWL		-0.526*	1	-0.434	-0.533*	-0.031	0.055	0.201	-0.478	0.05	0.37	
LWC		-0.160	0.067	1	0.091	0.437	-0.054	0.428	0.148	-0.042	-0.147	
ELWR		0.311	-0.265	-0.005	1	-0.144	-0.19	-0.629**	-0.157	-0.125	-0.492	
CPr		0.398	0.110	0.295	0.004	1	-0.794**	0.146	-0.05	0.500*	-0.165	
CStr		-0.268	0.141	-0.182	-0.299	-0.470	1	0.468	0.05	-0.454	0.401	
CFr		-0.335	0.275	0.448	-0.564*	0.027	0.359	1	-0.064	-0.024	0.361	
GY		0.628**	-0.359	-0.256	-0.113	0.191	-0.182	-0.253	1	0.035	0.026	
NGPS		0.130	-0.096	-0.106	0.222	0.183	-0.437**	-0.116	0.050	1	-0.086	
HI		0.462	-0.624**	0.059	0.109	-0.110	0.070	0.045	0.433	0.049	1	

* and **: Significant at the 5% and 1% probability levels, respectively.

Based on each agronomic trait the response of genotypes was varied. The highest NGPS value was observed for genotype 7 and the lowest value for genotype 9. The highest HI was assigned to genotypes 1 and 10,while the other genotypes showed the lowest HI (Table 5). Drought stress caused reductions in NGPS and HI by 12.12 and 0.66%, respectively (Table4). These results coincide with the other findings which have been observed that drought caused reductions most agronomic traits such as grain yield, number of grain per spike and etc (Chandler and Singh, 2008; Bayoumi *et al.,* 2008; Khakwani *et al.,* 2011).At the present study, HI was not remarkably affected by drought stress. As Austin (1994)stated, the high harvest index may be dueto improved tolerance to drought by making the plants more capable to enhancing the supply of assimilates to the young spikes (Khakwani *et al.,* 2011). Austin (1987) believed that the grain yield can be increased up to 20% by selection of high harvest index. Among all studied traits under both conditions, only RWC had a positive and significant correlation with GY at non-stress conditions (Table 6).It isrevealed that genotyes with higher RWC are more drought tolerant and gave higher yield than others (Khakwani *et al.,* 2011).

In order to evaluate drought tolerance of the genotypes, grain yield under both conditions and also different indices including SSI, TOL, MP, GMP, STI, YSI, HARM, SDI, DI, RDI and SSPI were calculated (Table 7).The results revealed that genotypes 2, 10, 1 and 8 were the tolerant genotypes based on MP, GMP, STI and HARM, which their high quantity is indicating tolerant genotypes. Based on these current indices, genotypes 16 and 13 were the most susceptible genotypes. Based on SSI, TOL, YSI, SDI, DI, RDI and SSPI, genotypes 2, 8 and 10 were the most and genotypes 14 and 7 were the least tolerant genotypes. Although genotype number 4 was superior based on SSI, TOL, YSI, SDI, DI, RDI and SSPI, but due to low performance under irrigated conditions it cannot be introduced as drought tolerant,.

D. Ranking method for drought indices

The estimates of different drought tolerance indices showed that the identification of drought-tolerant genotypes was contradictory based on a single criterion.

Table 7: Drought tolerance indices, ranks (R), ranks mean ($\bar{R}$), standard deviation of ranks (SDR) and rank sum (RS) of drought tolerance indicator.

Gen	Yp (kg/ha)		Ys (kg/ha)		Variations (%)		SSI		TOL (kg/ha)		MP (kg/ha)	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank
1	4139	3	3926	4	5.15	8	0.51	8	213	8	4033	3
2	4100	5	4069	1	0.76	2	0.07	2	31	2	4085	1
3	3701	9	3562	6	3.76	5	0.37	5	139	5	3632	7
4	3378	14	3523	7	-4.29	1	-0.43	1	-145	1	3451	8
5	3396	13	3157	12	7.04	9	0.70	9	239	9	3277	14
6	4254	2	3425	8	19.49	14	1.93	14	829	14	3840	6
7	4085	6	2801	15	31.43	15	3.12	15	1284	15	3443	9
8	4027	7	3990	2	0.92	3	0.09	3	37	3	4009	4
9	3509	12	3333	10	5.02	7	0.50	7	176	7	3421	11
10	4109	4	3973	3	3.31	4	0.33	4	136	4	4041	2
11	3574	10	3232	11	9.57	10	0.95	10	342	11	3403	12
12	3512	11	3348	9	4.67	6	0.46	6	164	6	3430	10
13	3332	15	2873	14	13.78	12	1.37	12	459	12	3103	15
14	3994	8	2699	16	32.42	16	3.22	16	1295	16	3347	13
15	4290	1	3692	5	13.94	13	1.38	13	598	13	3991	5
16	3237	16	2909	13	10.13	11	1.01	11	328	10	3073	16

Gen	TOL (kg/ha)		MP (kg/ha)		GMP (kg/ha)		STI		YSI		HARM (kg/ha)	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank
1	213	8	4033	3	4031	3	1.132	3	0.949	8	4030	3
2	31	2	4085	1	4084	1	1.162	1	0.992	2	4084	1
3	139	5	3632	7	3631	7	0.918	7	0.962	5	3630	7
4	-145	1	3451	8	3450	8	0.829	8	1.043	1	3449	8
5	239	9	3277	14	3274	14	0.747	14	0.930	9	3272	13
6	829	14	3840	6	3817	6	1.015	6	0.805	14	3795	6
7	1284	15	3443	9	3383	12	0.797	12	0.686	15	3323	12
8	37	3	4009	4	4008	4	1.119	4	0.991	3	4008	4
9	176	7	3421	11	3420	10	0.815	10	0.950	7	3419	10
10	136	4	4041	2	4040	2	1.137	2	0.967	4	4040	2
11	342	11	3403	12	3399	11	0.805	11	0.904	10	3394	11
12	164	6	3430	10	3429	9	0.819	9	0.953	6	3428	9
13	459	12	3103	15	3094	15	0.667	15	0.862	12	3086	15
14	1295	16	3347	13	3283	13	0.751	13	0.676	16	3221	14
15	598	13	3991	5	3980	5	1.103	5	0.861	13	3969	5
16	328	10	3073	16	3069	16	0.656	16	0.899	11	3064	16

Gen	SDI		DI		RDI		SSPI		$\bar{R}$	SDR	RS
	Value	Rank	Value	Rank	Value	Rank	Value	Rank			
1	0.051	8	1.093	4	1.05	8	2.811	8	5.64	2.47	8.11
2	0.008	2	1.185	1	1.10	2	0.409	2	1.79	1.05	2.84
3	0.038	5	1.006	6	1.07	5	1.834	5	6.00	1.24	7.24
4	-0.043	1	1.078	5	1.16	1	-1.913	1	4.64	4.22	8.86
5	0.070	9	0.861	10	1.03	9	3.154	9	10.93	2.23	13.16
6	0.195	14	0.809	12	0.90	14	10.940	14	10.29	4.36	14.64
7	0.314	15	0.564	15	0.76	15	16.944	15	13.29	2.81	16.10
8	0.009	3	1.160	2	1.10	3	0.488	3	3.43	1.22	4.65
9	0.050	7	0.929	9	1.06	7	2.323	7	8.64	1.82	10.47
10	0.033	4	1.128	3	1.08	4	1.795	4	3.29	0.91	4.20
11	0.096	10	0.858	11	1.01	10	4.513	11	10.64	0.63	11.28
12	0.047	6	0.937	7	1.06	6	2.164	6	7.57	1.83	9.40
13	0.138	12	0.727	14	0.96	12	6.057	12	13.36	1.45	14.80
14	0.324	16	0.535	16	0.75	16	17.089	16	14.64	2.31	16.95
15	0.139	13	0.933	8	0.96	13	7.891	13	8.93	4.45	13.37
16	0.101	11	0.767	13	1.00	11	4.328	10	12.93	2.53	15.45

Therefore, the ranking method can be used to have an overall judgment. In this method, mean rank, standard deviation of ranks and rank sum (RS) of all criteria is calculated to determine the most desirable drought tolerant genotype according to the all indices.

Results showed that genotypes number 2, 8 and 10 exhibited the lowest RS respectively; hence they were identified as the most drought tolerant genotypes, while genotypes number 14, 7, 13 and 16 identified as the most sensitive (Table 7).

The same procedures have been used for screening indicators of drought tolerance in the other study (Mohammadi *et al.* 2011; Khalili *et al.*, 2013).

E. Biplot method for drought indices

The associations among different drought tolerance indices are displayed in a biplot of PCA1 and PCA2 (Fig. 1). The PCA1 and PCA2 axes which explain 99.94% of total variation, mainly distinguish the indices in different groups. Fernandez (1992) classified plants according to their performance in stress and non-stress environments in four groups: genotypes with good performance in both environments (Group A); genotypes with good performance only in non-stress environments (Group B) or genotypes with good performance in stress environments (Group C); and genotypes with weak performance in both environments (Group D).Genotypes 2, 8, 10 and 1 were superior genotypes under both stress and non-stress conditions. These genotypes had stable performance in the circumstances of low sensitivity to drought stress. So, they are belonging to group A. Genotypes 6 and 15 could be known as group B. These genotypes are suitable for non-stress conditions. Genotypes 14 and 7 are drought susceptible and had low yield in both conditions (Group D). Genotypes 13, 16, 5, 11, 9, 12, 4 and3 with high amount of yield stability index (YSI) had a relatively low yield in both conditions, but they were more stable genotypes than the others (Group C).

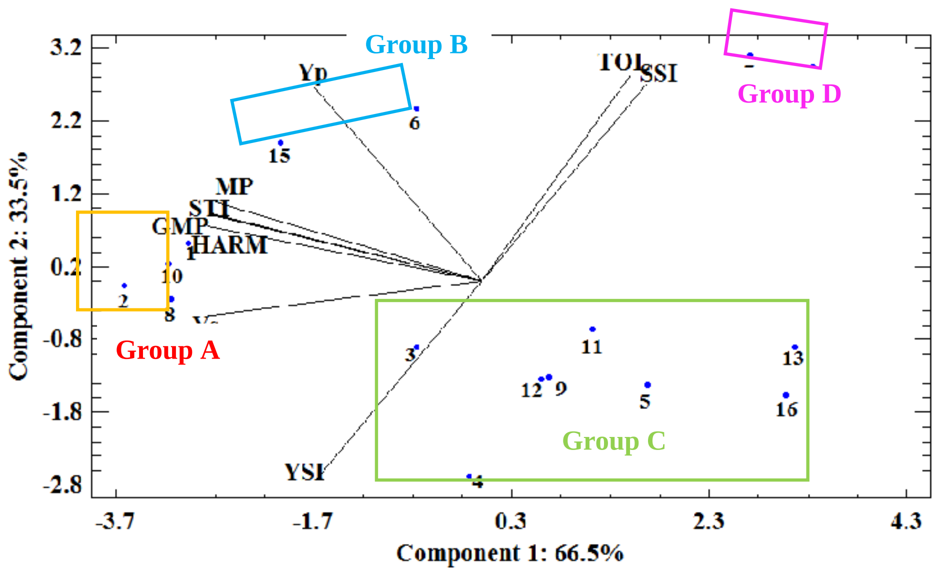

Fig. 1. Biplot display tolerance and sensitivity to drought in 16 advanced wheat genotypes based on first two principal components.

CONCLUSION

At the present study, a genotypic variation was observed for grain yield and the other studied traits under both conditions, especially complementary irrigation conditions. Results indicated that genotype and environment treatments significantly affect the yield and the most of the other evaluated traits. Significant reduction was found in grain yield, number of grain per spike, harvest index, grain crude starch and water relation-traits such as relative water content, leaf water content and excised leaf water retention as a result of the drought, whereas leaf water loss, grain crude protein and grain crude fiber were increased in dryland conditions. This study supports this idea that grain yield and water relation-traits can be utilized to screen wheat genotypes for drought tolerance. According to the results of mean comparison and drought indices, genotypes number 1, 2, 8 and 10 were drought tolerant whereas genotypes number 7, 14, 13 and 16 were drought susceptible. Therefore, genotypes number 1 and 2 can be introduced as a right candidate for the next breeding programs. Genotypes number 1 and 2 had the highest grain yield, and showed a proper performance in the water relation-traits. It appears that these two drought-tolerant genotypes can exploit physiological mechanisms, such as lower leaf water lose and higher relative water content and excised leaf water retention, to improve their performance under dryland conditions. In conclusion, this study showed that the effect of drought stress on grain yield of genotypes was varied which suggested genetic variability for drought tolerance in this materials. Therefore, breeders can select better genotypes based on indices and a combination of different methods of selection.

ACKNOWLEDGMENTS

The authors would like to thank Mr. Rahman Rajabi and Kermanshah Sararood Dry Land Agricultural Research Institute for their help and guidelines.

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