



Research Journal of
**Environmental
Sciences**

ISSN 1819-3412



Academic
Journals Inc.

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Comparison of Drought Tolerance Indices of 15 Advanced Winter and Intermediate Cold Hardy Wheat Genotypes in Ardabil, Iran

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Abstract: In this study yield and yield component, Harvest Index (HI), Stress Tolerance Index (STI), Stress Susceptibility Index (SSI), Tolerance Index (Tol), Mean Productivity (MP) and Geometric Mean Productivity (GMP) of 13 advanced winter and intermediate cold hardy wheat genotypes with two advanced genotypes of Shahreyyar and C-79-16 as checks were investigated under normal irrigation and after anthesis drought stress condition in a randomized complete block design experiment with three replications in Ardabil, Iran in 2006-2007. The effect of drought stress on harvest index was significant ($p < 0.01$). The lowest harvest index (38.14%) was observed in genotype KRC66/SERI/KINACT97 and the highest harvest index (45.66%) was observed in genotype FDL4/KAUZ. Genotypes KARL//.../3/F1502W9.01, Appolo/Mhdv and SG-U7067 produced more grain yield under normal irrigation condition compared to checks and mean stress susceptibility indices of genotypes SG-U7067, 885K4.1//MNG/SDV1/3/1D13.1/MLT and GKRAA were lower than checks. On the other hand, under the drought stress condition genotypes SG-U7067, GKRAA and 885K4.1//.../1D13.1/MLT yielded higher than checks and their mean stress susceptibility indices were lower than checks. Genotype SG-U7067 produced the highest yield under both normal irrigation and drought stress conditions. The yield reduction of this genotype was lowest under the drought stress conditions. Genotypes SG-U7067 with mean grain yield of 5.020 t ha^{-1} under drought stress, lowest SSI of 0.82 and highest STI of 0.62 was selected as the best drought stress tolerant genotype among the 15 genotypes that were evaluated.

Key words: Drought, stress, wheat, susceptibility

INTRODUCTION

The wheat crop is very sensitive to water stress and available soil water. Moisture deficiency, specially after anthesis, is one of the main constraints of wheat production in most part of central Asia and the Middle-East including Iran. Therefore, selection and breeding for drought tolerance has been the main challenge of wheat breeders and wheat scientists throughout the last 50 year. Iran, with about 220 mm of average annual rainfall is located in dry part of the world and in most areas of the country wheat crop encounters serious drought stress specially after anthesis (Ehdaie, 1995). Drought stress can reduce grain yield. Edmeades *et al.* (1995) have estimated the average yield loss of 17 to 70% in grain yield due

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to drought stress. Drought stress may occur throughout the growing season, early or late season, but its effect on yield reduction is highest when it occurs after anthesis (Blum, 2005). Morphological characters such as root length, tillering, spike number per m², kernel number per spike, fertile tillers number per plant, 1000 kernel weight, peduncle length, spike weight, stem weight, awn length, grain weight per spike and etc., affect the wheat tolerance to the moisture shortage in the soil (Passioura, 1977; Levitt, 1980; Kramer, 1983; Johnson *et al.*, 1983; Lazar *et al.*, 1995; Boyer, 1996; Moustafa *et al.*, 1996; Plaut *et al.*, 2004; Blum, 2005). Also, some physiological characters of the wheat cultivars, such as rate of root respiration increase in higher abscisic acid and air CO₂ concentrations (Morgan, 1980; Liu and Li, 2004; Wechsung *et al.*, 1999; Kimball *et al.*, 1999; Nguyen *et al.*, 1997; Wall, 2001) and phenological traits such as number of days to heading, anthesis and maturity influence the drought tolerance of the wheat cultivars (Austin, 1987). Selecting wheat genotypes that could tolerate drought stress and produce acceptable yield has been the major challenge for the wheat breeders in the last 50 year (Lopez *et al.*, 2003). It has been found that under the drought stress conditions, those genotypes that show the highest harvest index and highest yield stability is drought tolerant (Rathore, 2005).

Drought stress has become a common trend in most parts of Iran in the last 20 years. Therefore, intensive researches are being conducted to delineate drought tolerant genotypes for different part of the country. In this research 15 advanced cold hardy wheat genotypes were studied for their drought stress tolerance after anthesis to delineate the most tolerant genotype.

MATERIALS AND METHODS

This study was conducted at the Agriculture and Natural Resource Research Centre of Ardabil, Iran (48°, 20' N; 38°, 15' E) in 2006-2007. The soil texture at the experimental site is clay-loam. The average minimum, maximum and absolute temperature during the experiment were 1.98, 15.18 and 21.58°C, respectively and the long term average rainfall of the region is 310 mm. The effective soil depth (A+B) is 70 cm and the drainage of the soil is considered to be very suitable and the level of underground water is very deep. Ardabil plain has a typical semi-arid cold climatic condition with a long dry summer and cold winter. The soil pH of the experimental site is 7.7 and its EC is one mmhos. The P and K concentrations of the soil are 12 and 400 ppm, respectively. Thirteen advanced winter and intermediate cold hardy wheat genotypes and two advanced genotypes of Shahreyar and C-79-16 as checks to compare their tolerance to the late season drought stress. The experiment was conducted under two different irrigation conditions of (1): normal irrigation, where the plots were irrigated 6 times with an approximately 10 days intervals throughout the growing season started at the end of rainfall season that coincided with April 15th and (2): late season drought stress condition where the last two irrigations were cut off after the heading of the wheat. Each of two experiments was conducted in a randomized complete block design with three replications and 15 wheat genotypes. Each plot consisted of 6 rows of 2.5 m long and 30 cm apart. Plots were sampled twice during the growing season, first at the anthesis and later at the harvest. In each sampling, 20 randomly selected plants including stems, all leaves and heads were hand cut from the ground level, tagged and transferred to the laboratory for further evaluation. Plants were dried under the room temperature and natural light conditions for 5 days in the laboratory and then the yield components and harvest index were determined for each sample by recording grain yield and biomass. Also, 1000 grain weight, peduncle length, plant height, number and weight of grain per spike and fertile tiller number per plant

were determined. Meanwhile the number of days to heading, anthesis and maturity were recorded during the growing season for each genotype.

To determine the Stress Tolerance Index (STI), Stress Intensity (SI), Stress Susceptibility Index (SSI), Tolerance Index (Tol), Mean Productivity (MP) and Geometric Mean Productivity (GMP) at harvest, the outer two rows and 25 cm from each ends of rows were eliminated in each plot and the yield of four remaining rows were harvested, transferred to the laboratory, dried for five days under the room temperature and natural light and its weight was determined. Then, the above indices were calculated using the following formula:

$$STI = \frac{Y_p - Y_s}{(\bar{Y}_p)^2}$$

$$SI = 1 - \frac{\bar{Y}_s}{\bar{Y}_p}$$

$$SSI = \frac{\left(1 - \frac{\bar{Y}_s}{\bar{Y}_p}\right)}{SI}$$

$$TOL = Y_p - Y_s$$

$$MP = \frac{Y_p + Y_s}{2}$$

$$GMP = \sqrt{Y_p \cdot Y_s}$$

where, Y_p is yield under normal irrigation and Y_s is yield under the drought condition.

Analysis of variance was carried out with MSTATC and the results were used to evaluate the effect of drought stress. The means were compared by Duncan's multiple range method using MSTATC software program.

RESULTS AND DISCUSSION

Effect of environmental conditions was found significant on grain yield, harvest index, thousand kernel weight, peduncle length, plant height, number of grain per spike and grain weight per spike (Table 1). Means of yield components of each of wheat genotypes in normal irrigation and after anthesis drought stress conditions are given in Table 2 and comparison of mean values in two conditions are given in Table 3. There was no significant difference

Table 1: Mean squares of components of 15 advanced genotypes under normal irrigation and after anthesis drought stress condition

Table 1. Mean squares of components of 15 advanced genotypes under normal irrigation and area under stress drought stress condition										
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SOV	df	Grain yield (t ha ⁻¹)	Harvest index	1000 kernel weight (g)	No. of tiller per plant	No. of fertile tiller per plant	Peduncle length	Plant height	No. of grain per spike	Grain weight per spike
Environment (E)	1	389.520 **	729.04**	5766.880**	30.195	22.110	547.008**	1266.300**	104176.040**	857.040**
Error 1	4	0.622	24.27	44.886	8.142	4.110	16.193	16.193	2446.289	7.847
Genotype (G)	14	0.857*	17.40	56.419*	0.110	0.153	84.805**	84.805**	5702.433**	7.411
G×E	14	0.420	9.99	15.465	0.100	0.090	17.923	17.923	1532.640	4.643
Error 2	56	0.321	13.12	16.014	0.210	0.144	17.752	17.752	1423.500	3.354
CV (%)	-	9.130	8.28	11.050	14.910	13.480	12.430	12.430	15.910	21.340

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

Table 2: Means of yield components of each of 15 wheat genotypes in normal irrigation and after anthesis drought stress condition

Genotypes	Grain yield (t ha ⁻¹)	Harvest index	1000 kernel weight (g)	No. of tiller per plant	No. of fertile tiller per plant	Peduncle length	Plant height	No. of grain per spike	Grain weight per spike (g)
Shahreyyar (C-73-20)	6.044BCD	42.63ABC	35.96ABC	3.1030A	2.8870A	35.190AB	88.380A	23.900BCD	0.8930ABC
C-79-16	6.502ABC	44.93ABC	33.01BCD	3.0670A	2.7670A	36.000A	83.100ABC	22.200BCD	0.7430BC
M-70-4.../K58/Tob/3/Wa	5.853BCD	43.42ABC	38.82A	3.2720A	2.9580A	35.000AB	84.060ABC	23.070BCD	0.9280AB
MV17/Alvand	6.061ABCD	40.75C	32.84BCD	2.8650A	2.5700A	37.920A	84.780ABC	24.520BCD	0.8420ABC
FDL4/NG8675//KINAC197	6.052ABCD	43.73ABC	36.40ABC	3.0320A	2.6880A	34.620AB	81.380BCD	26.400B	1.0030AB
NA160/.../BUC/3/FALKE	6.409ABC	42.04ABC	38.64A	3.1330A	2.7880A	35.690A	73.720F	21.130CD	0.8450ABC
885K4.1...1/MLT	6.705AB	42.86ABC	39.72A	3.1600A	3.0170A	38.560A	86.500AB	21.980BCD	0.8990ABC
TAM200/KAUZ	6.252ABCD	45.70ABC	37.82AB	2.8500A	2.5880A	37.580A	82.620BC	20.250D	0.7830BC
GKRABA	6.474ABC	46.71A	39.79A	3.0500A	2.5500A	26.950C	82.470BC	23.980BCD	0.9570AB
Appolo/Mhdv	6.280ABC	43.86ABC	37.93AB	2.9170A	2.7670A	29.910BC	84.970ABC	24.100BCD	0.9910AB
Vee's/Bow's//40-71-23	5.336D	43.80ABC	30.57D	3.0670A	2.8370A	32.920AB	75.400EF	32.550A	1.0500A
FDL4/KAUZ	6.085ABCD	46.08AB	36.34ABC	3.0330A	2.8600A	33.230AB	80.170CDE	26.200BC	0.9690AB
KARL//CTK/...01	6.236ABC	44.29ABC	34.94ABCD	3.0930A	2.8550A	34.180AB	86.490AB	20.903D	0.7520BC
KRC66/SERI//KINAC197	5.836BCD	41.30BC	31.29CD	3.2000A	2.9830A	35.160AB	86.610AB	20.780D	0.6680C
SG-U7067	6.750A	45.25ABC	39.20A	3.3330A	3.0500A	26.640C	77.170DEF	23.700BCD	0.9530A
LSD5%	0.655	4.19	4.628	0.5313	0.4389	4.873	4.764	4.364	0.2194

In each column, means with different letter(s) are significantly different at 1% probability level

Table 3: Comparison of mean values for yield and yield components of 15 advanced genotypes under normal irrigation and drought stress condition

Environmental condition	Grain yield (t ha ⁻¹)	Harvest index	1000 kernel weight (g)	No. of tiller per plant	No. of fertile tiller per plant	Peduncle length	Plant height	No. of grain per spike	Grain weight per spike (g)
Normal irrigation	8.266	46.60	44.16	3.66	3.41	36.37	86.27	27.11	1.26
Drought stress	4.128	41.04	28.21	2.50	2.32	31.91	78.77	20.31	0.58
Difference	4.138	5.56	15.95	1.16	1.10	4.46	7.50	6.80	0.68

between the genotypes in their harvest index, but the effect of drought stress on harvest index was significant ($p \leq 0.01$, Table 1), therefore the drought stress had reduced the harvest index of the genotypes. Under drought stress, the lowest HI (38.14%) was observed in genotype KRC66/SERI//KINAC197 and the highest HI (45.66%) was observed in genotype FDL4/KAUZ (Table 4). Other scientists also have found that drought stress before anthesis causes reduction in the number of seeds per spikes and kernel's weight therefore reduces the harvest index (Clarke *et al.*, 1991; Rajaram *et al.*, 1995; Reynolds *et al.*, 2000). Ehdaie (1995) has reported that the harvest index of wheat is reduced under the drought stress. Blum (2005) have also concluded that harvest index was reduced under drought stress and it was mostly dependent to the amount of photosynthetic transfer from the stem to the kernels after anthesis. Hasanpanah (1996) has also achieved similar results with 22 wheat genotypes in Iran.

The indices for drought stress tolerance and susceptibility are given in Table 4. Stress intensity with regard to the total yield under normal irrigation condition was about 50%. The mean grain yield was reduced from 8.266 t ha⁻¹ under normal irrigation condition to 4.128 t ha⁻¹ under the drought stress condition. The mean rainfall throughout the growing season (from planting date to harvesting date) was 307 mm and mean lowest and highest temperature during the growing season were 1.98 and 21.58°C, respectively. Therefore, it was concluded that yield loss was only due to the drought stress condition. Most genotypes produced the highest grain yield under the normal irrigation condition as it could be expected (Table 4). Genotypes KARL//CTK/VEE/3/F1502W9.01, Appolo/Mhdv and SG-U7067, produced more grain yield under normal irrigation condition compared with Shahreyyar (check) and mean stress susceptibility indices of genotypes SG-U7067, 885K4.1//MNG/SDV1/3/1D13.1/MLT and GKRABA were lower than Shahreyyar (Table 4). Under drought stress condition, genotypes SG-U7067, GKRABA and 885K4.1//.../1D13.1/MLT yielded higher than Shahreyyar (check) and their susceptibility indices were lower than Shahreyyar. Genotype SG-U7067 with mean grain yield of 5.020 t ha⁻¹ under drought stress condition and SSI = 0.82 performed better than all other genotypes

Table 4: Stress susceptibility (SSI) and drought tolerance indices of 15 winter and intermediate cold hardly wheat genotypes

Genotypes	Harvest index (%)	Grain yield under normal irrigation (t ha^{-1})	Grain yield under drought stress (t ha^{-1})	SSI	Tol	STI	MP	GMP
Shahreyyar (C-73-20)	39.41	8.237	3.850	1.07	4.39	0.46	6.04	5.63
C-79-16	40.45	8.457	4.546	0.92	3.91	0.56	6.50	6.20
M-70-4..../K58/Tob/3/Wa	40.12	7.959	3.474	1.06	4.21	0.44	5.85	5.46
MV17/Alvand	38.39	8.303	3.819	1.08	4.48	0.46	6.06	5.63
FDL4/NG8675//KINAC197	40.61	8.473	3.631	1.14	4.84	0.45	6.05	5.55
NA160/..../BUC/3/FALKE	40.22	8.337	4.481	0.93	3.86	0.55	6.41	6.11
885K4.1....1/MLT	41.62	8.456	4.954	0.83	3.50	0.61	6.71	6.47
TAM200/KAUZ	41.91	8.032	4.472	0.89	3.56	0.53	6.25	5.99
GKRABA	44.91	8.243	4.704	0.86	3.54	0.57	6.47	6.23
Appolo/Mhdv	44.09	8.508	4.051	1.05	4.46	0.50	6.28	5.87
Vee"s"/Bow"s"//40-71-23	39.49	7.993	2.738	1.31	5.26	0.32	5.37	4.68
FDL4/KAUZ	45.66	8.266	3.904	1.06	4.36	0.47	6.09	5.68
KARL//CTK/....01	38.79	8.574	3.951	1.08	4.62	0.50	6.26	5.82
KRC66/SERI//KINAC197	38.14	7.678	4.047	0.95	3.63	0.45	5.86	5.57
SG-U7067	41.82	8.479	5.020	0.82	3.46	0.62	6.75	6.52
Mean	41.04	8.266	4.128	1.00	4.12	0.50	6.20	5.83

under the drought stress condition (Table 3). Some genotypes including SG-U7067, 885K4.1//MNG/....1/MLT and GKRABA with stress tolerance indices of 0.62, 0.61 and 0.57, respectively performed much better than Shahreyyar ($\text{STI} = 0.46$) and the remaining genotypes (Table 4) and their grain yields were also higher than the other genotypes (Table 4). Selecting the genotypes based on STI drives selection in the direction of selecting the genotypes with higher yield and higher stress tolerance. Based on geometric mean productivity, genotypes SG-U7067, 885K4.1//MNG/....1/MLT and GKRABA with GMP of 6.52, 6.47 and 6.23 t ha^{-1} also performed better than Shahreyyar ($\text{GMP} = 5.63$) and other genotypes (Table 4). The mean grain yields of these genotypes were also higher than the other genotypes. With respect to the tolerance index (Tol) genotype Vee"s"/Bow"s"//40-71-23 with Tol of 5.26 performed much better than the other genotypes and check and considered to be stress tolerant genotypes. Genotypes SG-U7067, GKRABA and 885K4.1//MNG/....1/MLT were selected for their drought tolerance and higher yield, higher STI, lower SSI and higher GMP indices and genotype SG-U7067 was selected as the best genotype for its highest yield under the drought stress condition (5.020 t ha^{-1}), lowest stress susceptibility index ($\text{SSI} = 0.82$), highest stress tolerance index ($\text{STI} = 0.62$) and highest GMP (6.52 t ha^{-1}) (Table 4).

Ehdaie (1993) in his studies on the drought stress susceptibility of 10 wheat cultivars of Khuzestan province of Iran concluded that among these cultivars Chenab and Arvand were the most susceptible and Shoeleh, was the most tolerant wheat genotype to drought stress. He found no correlation between yield and stress susceptibility index, that is to say none of these cultivars had simultaneously higher yield and lower SSI. Hasanpanah (1996), who studied drought stress resistance of 22 wheat cultivars native to the cold regions of Iran concluded that genotype SXL/Glenson produced highest yield under the drought stress condition, but it proved to be very susceptible to the stress with $\text{SSI} = 1.673$. His results revealed that none of this cultivars had the potential for higher yield and lower SSI at the same time. In our studies genotype SG-U7067 produced highest yield under drought stress condition (5.020 t ha^{-1}), showed lowest susceptibility index ($\text{SSI} = 0.82$) and ranked 5th with respect to harvest index ($\text{HI} = 41.82$), therefore this genotype was selected to be the best genotype for after anthesis drought stress condition in Ardabil region of Iran.

CONCLUSION

Genotype SG-U7067 produced the highest yield under both normal irrigation and drought stress conditions. The yield reduction of this genotype was lowest under the drought stress conditions. Genotypes SG-U7067 with mean grain yield of 5.020 t ha⁻¹ under drought stress, lowest SSI of 0.82 and highest STI of 0.62 was selected as the best drought stress tolerant genotype among the 15 genotypes that were evaluated.

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