J. Agric. Sci. Technol. (2008) Vol. 10: 109-121

Evaluation of Wheat (*Triticum aestivum* L.) Genotypes under Pre- and Post-anthesis Drought Stress Conditions

A. Sanjari Pireivatlou[1]* and A. Yazdansepas[2]

ABSTRACT

The responses of yield and yield components of 24 advanced bread wheat genotypes to pre- and post-anthesis drought stress conditions were studied at Ardabil Agricultural Research Station during the 1997-2000 cropping seasons. Results showed that genotypes produced significantly lower spikes No./m^2, seeds No./spike and grain yield under pre- than in post-anthesis drought stress conditions. However, an average of 1,000 kernel weight of genotypes under pre-anthesis was higher than under non-stress and post-anthesis drought stress conditions. Selection based on TOL and SSI identified the drought tolerant genotypes with low grain yield. However, selection based on MP, GMP and STI identified drought tolerant genotypes with a high yield. Genotypes No. 13, 14 and 21 were determined as desirable genotypes based on their high grain yield under non-stress, pre-anthesis and post-anthesis drought stress conditions. The interaction effect of genotype x year was significant for membrane stability and membrane damage, however, the interaction effect of genotypes×stages of measurement (booting and heading) were not significant. On the basis of these results, genotypes No. 13, 14 and 21 with low membrane damage were also identified as drought tolerant genotypes. It can be concluded that the laboratory test can be an useful tool in a breeding program for improving drought tolerance in wheat.

Keywords: Bread wheat, Drought stress, Grain yield.

INTRODUCTION

Interest in crop responses to environmental stresses has increased greatly, because of experiencing severe losses from heat, cold, drought and high concentrations of toxic mineral elements (Lewis and Christiansen, 1981; Blum, 1985). Several studies have been conducted with spring and winter wheat to evaluate the effect of limited irrigation on crop production. Yield is reduced mostly when drought stress occurs during the heading or flowering and soft dough stages. Drought stress during maturity resulted in about 10 % decrease in yield (Bauder, 2001), while, moderate stress during the early vegetative period has essentially no effect on yield (Bauder, 2001). An important source of carbon for grain filling under stress conditions is stem reserve and, under mild conditions, current assimilates may be limited for normal grain filling. In a three-year study conducted in Connecticut, it was estimated that canopy respiration and grain dry matter accumulation were approximately equal sinks for photosynthate and, together, were greater than canopy photosynthesis late in grain filling (Gent, 1994). Thus, stem reserves were essential for completed grain filling (Gent, 1994). Water deficit did not affect kernel number in wheat, while high temperatures reduced it significantly (Plaut *et al*., 2004). According to Plaut *et al.* (2004) the rate of dry matter accumulation by kernels was considerably decreased by water deficit in wheat cultivars. Rates of transport (probably of non-

1. Agricultural Research Station of Ardabil, P. O. Box: 35156-545, Ardabil, Islamic Republic of Iran.
2. Seed and Plant Improvement Institute, Karadj, Islamic Republic of Iran.
* Corresponding author, e-mail: amirgholis@yahoo.com

structural carbohydrates) from the vegetative organs to kernels were much higher in Suneca than in Batavia wheat cultivars during drought stress conditions (Plaut *et al*., 2004). Plaut *et al.* (2004) also reported that the thousand-kernel weight (TKW) and weight of kernels per spike were more severely decreased by water deficit than by heat in both wheat varieties, and less in Batavia than in Suneca cultivars. Shafazadeh *et al.* (2004) in their study on 20 wheat genotypes under post-anthesis drought stress conditions, reported significant differences for genotypic and irrigation effects, and also for irrigation×year, genotype×irrigation and genotype×year interaction effects when grain yield was considered. It was reported that membranes of cells and organelles are primary sites for desiccation injury (Tan and Blake, 1993; Fan and Blake, 1994). Loss of membrane integrity has been shown by the increase of electrolyte leakage under drought stress (Tan and Blake, 1993; Fan and Blake, 1994). Determination of cell membrane damage reported by Rizza *et al.* (1994) on barley genotypes under low and freezing temperatures made it possible more accurately to estimate defenses in the extent of stress-induced injury.

The main objectives of this study were (1) identifying the high yielding genotypes, tolerant to pre- and post-anthesis drought stress conditions and (2) investigating the variation among wheat genotypes for cell membrane damage.

MATERIALS AND METHODS

The field experiments using 24 bread wheat genotypes with winter and facultative growth habits (Table 1) were conducted at Agricultural Research Station of Ardabil (38° 15´N, 48° 20´E, with an elevation about 1,350 m above sea level) during the 1997-2000 cropping seasons. The climate in this part of Iran is semi-arid with an average rainfall of 270 mm (Table 2). The experimental design was a randomized complete block with three replications. Drought treatment in the pre-anthesis stage was carried out by irrigation from plant emergence up to anthesis, and in the post-anthesis drought stress condition by terminating irrigation after anthesis. The control treatment was normal irrigation throughout the growing season (Table 2). The total amount of irrigated water in the control and water deficits in pre-anthesis and post-anthesis experiments were 436.8 mm, 250.2 mm and 272.8 mm, respectively (Table 2).

An individual plot was 5 m long with six rows spaced 20 cm apart and sown by a small-plot planter (Wintersteiger) at a density of 500 seeds/m^2. The harvested plot size for grain yield was 6 m^2 and the grain yield of each individual plot was separately harvested and measured. The data were analyzed, using SAS (1988). For estimating the tolerance and susceptibility of genotypes the following indices were used:

Stress Susceptibility Index (SSI): (Ficher and Maure, 1978), $SSI = \dfrac{1-\dfrac{Y_s}{Y_p}}{1-\dfrac{\bar{Y}_s}{\bar{Y}_p}}$

Tolerance (TOL): (Rasielle and Hamblin, 1978), $TOL = Y_p - Y_s$

Mean Productivity (MP): (Rasielle and Hamblin, 1978), $MP = \dfrac{Y_p + Y_s}{2}$

Geometric Mean Productivity (GMP): (Rasielle and Hamblin, 1978), GMP= $\sqrt{Ys \times Yp}$

Stress Tolerance Index (STI): (Fernandez, 1992), $STI = \dfrac{Y_p \times Y_s}{(\bar{Y}_p)^2}$

Where: $Yp =$ Mean yield of the genotype under non-stress conditions; $Ys =$ Mean yield of the genotype under stress conditions, $\bar{Yp} =$ Mean yield of all genotypes under non-stress conditions and $\bar{Ys} =$ Mean yield of all genotypes under stress conditions.

[DOR: 20.1001.1.16807073.2008.10.2.1.5]

Table 1. Pedigrees and growth habit of bread wheat genotype studied under non-stress, pre- and post-anthesis drought stress conditions.

No.	Genotypes	Growth habit (GH)
1	MV17	W [a]
2	Alamoot	W
3	F13011.1321.Rom/Fdi	W
4	ID13/Mlt.S.WM1274.Mex/Tur…	W
5	Au/3/Minn//llK/4/XMh/Era/5/Dhf	F [b]
6	Horis	S [c]
7	GK-zuyloy	W
8	Ymh/Tob/Mcd/3/Lira	W
9	Ayt94-Tjb788-1080/A/dem/3/Resk//Eno/G11Wre86099	W
10	Hkng.SXL-7044/Bow//ksa 74681/SXL/cit…	W
11	Mach//Bez/GGrk/cit89067-ose…	W
12	Ba/6529.13	W
13	Jup/4/cllf/3/111.53/odino//ci18431/Waos477w	W
14	Jup/4/cllf/3/111.53/odino//ci18431/Wa…	W
15	OWL184524-3H-OH OH– ND/P101//Bb..	W
16	Sbn//Sannina/Ald S	F
17	Stepinak/Karvana	W
18	Vratza/wisc245	W
19	Agri/Nac (ES91-81)Swm6595…	F
20	Agri/Nac-Swm65-99-20H-1H-3P-0P-8m-MW-owm	F
21	Gaspard	W
22	Toos	F
23	Shahriar	W
24	Sabalan	W

[a] Winter wheat; [b] Facultative wheat, [c] Spring wheat.

Also, the biplot display was used to identify tolerant and high yielding genotypes. Membrane damage and stability of the membrane of the genotypes at booting and heading stages were also studied in pre-anthesis drought stress, by experimentally taking plant samples. Each plant sample contained 0.5 cm diameter segments of 10 flag leaves from each plot. Samples were placed in a vial containing 15 ml of de-ionized water, degassed under vacuum for 20 minute and stirred at 25°C for 2.1/2 hours. A digital conductivity meter measured the ion release. The membrane damage was measured by using the formula MD= $(C1-C_w)/(C2-C_{w},)$ where C_1 and C_2 are the electro-conductance values before and after autoclave, respectively, and C_w is the electro-conductance value of the de-ionized water (Rizza *et al.*, 1994).

RESULTS AND DISCUSSION

Results of the combined ANOVA showed significant differences ($P<0.05$) for the experimental years for both drought and genotypic effects. Moreover, interaction effects of drought×year, genotype×year, genotype ×drought and genotype×year×drought were found significant ($P<0.05$)

The mean yield of 24 genotypes under non-stress, pre-anthesis and post-anthesis drought stress conditions were 6.99, 4.65 and 5.20 t ha^{-1}, respectively (Table 3). As the results show, genotypes produced significantly less grain yield under pre-anthesis drought stress condition than non-stress and post-anthesis drought stress conditions. These findings are not in agreement with the results of Calhoun *et al.* (1994) and Van

[DOR: 20.1001.1.16807073.2008.10.2.1.5]

Table 2. Amount of precipitation and irrigated water for non-stress, pre-and post- anthesis drought stress conditions during the 1997 to 2000 cropping seasons.

Water management and precipitation	Months of growing seasons during 1997-2000											
	Year	Oct	Nov	Dec	Jan	Feb	March	April	May	June	July	Total
Rainfall (mm)	1997-98	20.1	21.9	13.5	67.3	55.3	23.5	39.1	54.5	18.0	5.1	318.3
	1998-99	16.4	8.3	17.7	30.9	4.6	21.5	41.7	50.8	3.3	0.0	195.2
	1999-2000	69.2	22.6	2.8	34.5	27.3	98.3	15.3	17.2	5.9	5.3	298.4
	Mean	**35.2**	**17.6**	**11.3**	**44.2**	**29.1**	**47.8**	**32.0**	**40.8**	**9.1**	**3.5**	**270.6**
Irrigation in non-stress condition (mm)	1997-98	110 (26 Oct)	0	0	0	0	0	97.3 (14Ap)	62.9 (11May)	65.0 (14 June) 55.0 (28June)	0	390.2
	1998-99	110 (26 Oct)	0	0	0	0	0	0	120 (5 May) 115 (25May)	115 (8June) 120 (26June)	0	580.0
	1999-2000	0	0	0	0	0	0	0	73.4 (5 May) 67.2 (16May)	78.8 (1June) 69.0 (15June)	60.3 (3Jul)	348.7
	Mean	**73.3**	**0**	**0**	**0**	**0**	**0**	**32.4**	**146.2**	**167.6**	**20.1**	**439.6**
Irrigation in pre-anthesis drought stress condition (mm)	1997-98	110 (26 Oct)	0	0	0	0	0	0	0	88.8 (14June) 56.8 (28June)	0	255.6
	1998-99	110 (20 Oct)	0	0	0	0	0	0	0	122 (8June) 121 (25June)	0	353.0
	1999-2000	0	0	0	0	0	0	0	0	66.0 (15June)	77.0 (3jul)	143.0
	Mean	**73.3**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**151.5**	**25.7**	**250.5**
Irrigation in post-anthesis drought stress condition (mm)	1997-98	110 (26 Oct)	0	0	0	0	0	97.4 (14Ap)	65.3 (11May)	0	0	272.7
	1998-99	110 (20 Oct)	0	0	0	0	0	0	120 (5 May) 116 (25May)	0	0	346.0
	1999-2000	0	0	0	0	0	0	0	68.8 (5 May) 68.1 (16May)72 (30May)	0	0	208.9
	Mean	**73.3**	**0**	**0**	**0**	**0**	**0**	**32.5**	**170.1**	**0**	**0**	**275.9**

The anthesis time of wheat was at the beginning of June in three years of experiment.

Table 3. Mean of grain yield and yield components of the genotypes under non-stress (Yp), pre (Ys_1) and post-anthesis (Ys_2) drought stress conditions during the 1997-2000 cropping seasons .

Genotypes	Grain yield (t ha^{-1})			Seeds/spike			1000 KW (gr)			Spike/m^2		
	Yp	Ys_1	Ys_2	Yp	Ys_1	Ys_2	Yp	Ys_1	Ys	Yp	Ys_1	Ys_2
1	7.22	4.80	5.58	38.4	35.9	40.5	42.2	45.3	35.5	583.0	400.4	540.0
2	7.21	5.03	5.02	39.3	32.4	41.3	42.6	48.1	33.5	705.9	478.9	535.6
3	6.92	4.42	5.03	36.6	34.7	42.1	36.0	37.9	32.5	667.4	445.6	646.7
4	7.83	5.08	5.90	33.0	30.5	31.1	40.7	44.2	35.0	657.4	570.4	624.1
5	6.51	3.91	5.07	34.6	30.2	37.8	40.8	40.6	35.8	688.5	472.6	542.6
6	6.66	5.32	4.43	36.1	29.5	25.9	43.4	45.5	34.6	721.1	514.4	599.0
7	7.25	4.75	5.27	34.5	36.2	31.5	38.4	39.2	34.0	717.0	519.6	639.6
8	7.59	4.91	5.58	31.7	28.9	34.4	41.0	45.8	34.5	725.2	503.7	665.9
9	6.03	4.23	4.94	30.6	29.0	29.8	41.5	44.6	35.7	758.9	575.9	619.6
10	7.15	4.42	5.41	36.3	27.8	33.3	39.8	42.9	34.2	743.7	580.7	746.3
11	7.25	4.74	5.17	33.1	27.3	30.2	45.3	44.3	34.3	780.4	526.3	625.6
12	6.81	4.55	5.37	27.5	28.9	29.7	47.7	47.5	40.6	611.5	422.2	586.7
13	7.82	5.27	5.53	35.1	31.1	32.4	44.1	47.1	38.9	707.8	471.1	461.1
14	7.48	5.00	5.59	28.1	25.9	32.4	46.7	49.4	34.6	761.5	617.0	598.1
15	7.64	5.03	5.28	35.2	29.6	31.1	45.2	46.8	32.7	790.7	523.7	617.0
16	7.29	4.83	5.52	34.1	27.7	27.2	44.9	48.3	37.3	710.7	539.6	624.4
17	6.25	4.10	4.98	28.7	27.2	27.8	49.3	49.8	41.1	679.6	503.0	654.4
18	6.45	4.13	5.62	28.8	28.1	28.9	49.5	49.9	42.5	709.3	480.4	575.6
19	6.29	4.13	4.66	29.8	26.5	33.1	40.2	44.5	33.3	695.6	518.9	599.3
20	6.39	4.19	4.78	31.0	23.7	32.1	42.2	44.4	33.0	685.9	526.7	593.0
21	7.25	5.19	5.96	33.6	30.4	33.8	46.5	44.7	38.1	577.8	486.3	581.5
22	7.12	4.62	5.05	35.4	28.8	32.3	43.1	44.2	36.8	660.7	567.8	593.3
23	7.44	4.93	5.23	37.1	31.0	34.4	45.1	48.0	36.7	720.0	553.3	533.3
24	5.91	4.09	3.90	23.9	17.6	23.4	48.7	49.9	38.0	703.3	593.3	670.0
Mean	6.99 A	4.65 C	5.20 B	33.0 A	29.1B	32.4 A	43.5 B	45.5 A	36.0 C	698.5 A	516.3 C	602.9B
LSD5%	0.695	0.49	0.586	5.43	1.56	6.02	3.15	2.16	3.87	36.90	99.86	112.0

Ginkel *et al.* (1998) who reported a higher grain yield under early drought than late drought stress conditions.

The drought stress intensities were 0.34 and 0.25 under pre-anthesis and post-anthesis drought stress conditions, respectively, i.e. applied drought stress in pre-anthesis was more severe than in post-anthesis.

The reason for lower grain yield under pre-anthesis rather than post-anthesis drought stress conditions was mainly due to a reduction in the number of spikes/m^2 under pre-anthesis drought stress condition. The number of spikes/m^2 in non-stress, pre-anthesis and post-anthesis drought stress conditions were 698.5, 516.3 and 603, respectively (Table 3). The average number of seeds /spike in non-stress, pre-anthesis and post-anthesis drought stress conditions was 33.0, 29.1 and 32.4, respectively (Table 3). Thus, the number of spikes/m^2 and seeds No./spike were significantly reduced in pre-anthesis compared to non-stress and post-anthesis drought stress conditions. Average 1,000 kernel weight under non-stress, pre-anthesis and post-anthesis drought stress conditions was 43.5 g, 45.5 g and 36.0 g, respectively (Table 3). A similar result is evident in the data of Inness *et al.* (1981) with two winter wheat varieties. They reported the results of experiments with winter wheat selections,

Table 4. Mean values of tolerance and susceptibility indices under pre-anthesis drought stress conditions.

Genotypes	Yp[a] (t/ha)	Ys_1[b] (t/ha)	(TOL)[c]	(MP)[d]	(GMP)[e]	(SSI)[f]	(STI)[g]
1	7.22 ad	4.80 ae	2.42 eg	6.01 gh	5.89 e	1.02 be	0.71 d
2	7.21 ae	5.02 ac	2.19 hj	6.12 ef	6.02 c	0.92 gi	0.74 c
3	6.92 bg	4.42 dh	2.50 cf	5.67 k	5.53 h	1.09 b	0.63 g
4	7.83 a	5.08 ac	2.75 a	6.46 ac	6.31 ab	1.06 bc	0.81 a
5	6.51 di	3.91 h	2.60 ad	5.21 pq	5.05 k	1.21 a	0.52 l
6	6.66 ci	5.32 a	1.34 m	5.99 hi	5.95 de	0.61 j	0.73 d
7	7.25 ad	4.75 af	2.50 cf	6.00 gh	5.87 e	1.04 bd	0.70 d
8	7.59 ab	4.91 ad	2.68 ac	6.25 ce	6.10 c	1.07 bc	0.76 c
9	6.03 hi	4.23 eh	1.80 l	5.13 qe	5.05 k	0.90 hi	0.52 l
10	7.15 af	4.42 dh	2.73 a	5.79 j	5.62 g	1.16 a	0.65 f
11	7.25 ad	4.74 af	2.51 cf	6.00 gh	5.86 e	1.05 bd	0.70 d
12	6.81 bh	4.55 cg	2.26 gi	5.68 k	5.57 h	1.01 be	0.63 g
13	7.82 a	5.27 a	2.55 be	6.55 a	6.42 a	0.99 c	0.84 a
14	7.48 ac	5.00 ad	2.48 df	6.24 ce	6.12 c	1.00 c	0.77 b
15	7.64 ab	5.03 ac	2.61 ad	6.34 bc	6.20 b	1.04 bd	0.79 b
16	7.29 ad	4.83 ad	2.46 df	6.06 fg	5.93 de	1.02 be	0.72 d
17	6.25 fi	4.10 gh	2.15 hj	5.18 q	5.06 k	1.04 bd	0.52 l
18	6.45di	4.13 gh	2.32 fh	5.29 op	5.16 jk	1.09 b	0.55 k
19	6.29 fi	4.13 gh	2.16 hj	5.21 pq	5.10 k	1.04 bd	0.53 k
20	6.39 ei	4.19 fh	2.20 hj	5.29 op	5.17 jk	1.04 bd	0.55 k
21	7.25 ad	5.19 ab	2.06 jk	6.22 de	6.13 c	0.86 i	0.77 b
22	7.12 af	4.62 bg	2.50 cf	5.87 j	5.74 f	1.06 bc	0.67 f
23	7.44 ac	4.93 ad	2.51 cf	6.19 de	6.06 c	1.02 be	0.75 c
24	5.91i	4.09 gh	1.82 i	5.00 r	4.92 i	0.93 gi	0.49 i
Mean	6.99 a	4.65 c	2.34	5.82	5.70	1.01	0.67
S[h]	1.121	0.771	1.061	0.803	0.790	0.380	0.127
LSD 5%	0.152	0.100	0.175	0.094	0.092	0.061	0.022

Means with similar letters in each column are not significantly different.
[a]Yield in non-stress conditions, [b]Yield in pre-anthesis drought stress, [c]Tolerance, [d] Mean productivity, [e] Geometric mean productivity, [f] Stress susceptibility index, [g] Stress tolerance index, [h] Standard deviation.
For TOL and SSI, lower values are desirable.

For MP, GMP and STI, higher values are desirable.

Table 5. Mean values of tolerance and susceptibility indices under post-anthesis drought stress conditions.

Génotypes	Yp[a] (t/ha)	Ys_2[b] (t/ha)	(TOL)[c]	(MP)[d]	(GMP)[e]	(SSI)[f]	(STI)[g]
1	7.22 ad	5.58 ad	1.64 fh	6.40 cd	6.35 d	0.87 ik	0.82 c
2	7.21 ae	5.02 dg	2.19 bc	6.12 f	6.02 h	1.17 bd	0.74 f
3	6.92 bg	5.03 dg	1.89 df	5.98 h	5.90 i	1.05 dg	0.71 g
4	7.83 a	5.90 ab	1.93 de	6.87 a	6.80 a	0.95 gi	0.95 a
5	6.51 di	5.07 dg	1.44 i	5.79 h	5.75 ij	0.85 ik	0.68 h
6	6.66 ci	4.43 gh	2.23 bc	5.55 j	5.43 kl	1.29 a	0.60 j
7	7.25 ad	5.27 af	1.98 de	6.26 e	6.18 f	1.05 dg	0.78 e
8	7.59 ab	5.58 ad	2.01 d	6.59 b	6.51 ab	1.02 f	0.87 b
9	6.03 hi	4.94 dg	1.09 k	5.49 j	5.46 kl	0.70 m	0.61 j
10	7.15 af	5.41 ae	1.74 fg	6.28 e	6.22 f	0.94 gi	0.79 e
11	7.25 ad	5.17 cf	2.08 cd	6.21 f	6.12 g	1.10 df	0.77 e
12	6.81 bh	5.37 ae	1.44 i	6.09 g	6.05 g	0.81 k	0.75 f
13	7.82 a	5.53 ad	2.29 ab	6.68 b	6.58 ab	1.13 c	0.89 b
14	7.48 ac	5.59 ad	1.89 df	6.54 c	6.47 bc	0.97 gi	0.86 b
15	7.64 ab	5.28 af	2.36 a	6.46 cd	6.35 d	1.19 b	0.83 c
16	7.29 ad	5.52 ad	1.77 eg	6.41 cd	6.34 d	0.93 gi	0.82 c
17	6.25 fi	4.98 dg	1.27 jk	5.62 ij	5.58 k	0.78 kl	0.64 i
18	6.45di	5.62 ad	0.83 l	6.04 g	6.02 h	0.49 p	0.74 f
19	6.29 fi	4.66 fg	1.63 gh	5.48 j	5.41 l	1.00 fg	0.60 j
20	6.39 ei	4.78 eg	1.61 gh	5.59 j	5.53 k	0.97 gi	0.63 i
21	7.25 ad	5.96 a	1.29 jk	6.61 b	6.57 ab	0.68 n	0.88 b
22	7.12 af	5.05 dg	2.07 cd	6.09 g	6.00 h	1.12 d	0.74 f
23	7.44 ac	5.23 bf	2.21 bc	6.34 de	6.24 f	1.14 c	0.80 d
24	5.91 I	3.90 h	2.01 d	4.91 k	4.80 m	1.31 a	0.47 k
Mean	6.99 a	5.20 bf	1.79	6.10	6.03	0.98	0.74
S[h]	1.121	1.076	1.342	0.870	0.877	0.702	0.180
LSD 5%	0.152	0.120	0.200	0.093	0.092	0.103	0.022

Means with similar letters in each column are not significantly different.
[a]Yield in non-stress conditions, [b]Yield in post-anthesis drought stress, [c]Tolerance, [d] Mean productivity, [e] Geometric mean productivity, [f] Stress susceptibility index, [g] Stress tolerance index, [h] Standard deviation.
For TOL and SSI, lower values are desirable.
For MP, GMP and STI, higher values are desirable.

which differed in the final number of spikes brought about by genetic differences in tiller production. When water was withheld post-anthesis, grain yields of the studied genotypes were not significantly different from their values under full irrigation because, by the time the drought treatment began, the plants were able to extract water from a considerable depth in the soil profile. A pre-anthesis drought treatment reduced the number of grains per spike of both winter wheat lines almost equally, and also reduced the final number of spikes and grain yields. They also reported that in pre-anthesis drought the period of tiller and spikelet death caused a reduction in number of spikes, but a proportionally greater reduction in the number of grains per spike compared with the values for these genotypes in the fully irrigated plots (Inness *et al.* 1981).

The 1,000 kernel weight of wheat genotypes was significantly reduced under post-anthesis drought stress conditions, which is consistent with results of Plaut *et al.* (2004). Plaut *et al.* (2004) also reported that 1,000 kernel weight and weight of kernels per spike were more severely decreased by water deficit than by heat stress in wheat varieties, i.e. the rate of dry matter accumulation by kernels was considerably decreased by water deficit. The increase of an average of 1,000 kernel weight of genotypes in pre-

[DOR: 20.1001.1.16807073.2008.10.2.1.5]

Table 6. Correlation coefficients between tolerance and susceptibility indices of wheat genotypes under pre- anthesis drought stress conditions (n=24).

Drought tolerance and susceptibility indices		(YP)[a]	(Ys)[b]	(TOL)[c]	(MP)[d]	(GMP)[f]	(SSI)[g]
Ys	Pre-anthesis	0.80**					
	Post-anthesis	0.71**					
TOL	Pre-anthesis	0.65**	0.08 ns				
	Post-anthesis	0.58**	-0.17 ns				
MP	Pre-anthesis	0.96**	0.94**	0.41*			
	Post-anthesis	0.94**	0.91**	0.26 ns			
GMP [e]	Pre-anthesis	0.95**	0.95**	0.37 ns	1.00**		
	Post-anthesis	0.79**	0.88**	0.08ns	0.90**		
SSI [f]	Pre-anthesis	0.14 ns	-0.46*	0.84**	-0.14 ns	-0.20 ns	
	Post-anthesis	0.24 ns	-0.51*	0.93**	-0.11 ns	-0.26 ns	
STI [g]	Pre-anthesis	0.94**	0.95**	0.37 ns	1.00**	1.00**	-0.20 ns
	Post-anthesis	0.92**	0.92**	0.22 ns	1.00**	0.91**	-0.15 ns

* and **, Significant at 5% and 1% probability level, respectively.
ns: Non significant.
[a] yield in non-stress conditions, [b] yield under drought stress condition, [c] Tolerance, [d] Mean Productivity,
[e] Geometric Mean Productivity, [f] Stress Susceptibility Index, [g] Stress Tolerance Index.

anthesis drought stress compared to non-stress and post–anthesis drought stress conditions could be due to a lower number of seeds/spike in pre-anthesis drought stress conditions (Table 3), i.e. under pre-anthesis drought stress conditions, assimilates were partitioned to a lower number of seeds/spike, and thus resulted heavier grains. These results are in agreement with the results of Van Ginkel *et al.* (1998) who reported lower grain No./m^2 under early rather than late drought stress conditions, although the 1,000 kernel weight in an early drought was higher than in a late drought.

The TOL index selected genotypes with low yield but tolerant to drought stress. These were genotypes No. 18, 9, 17, 21, 12 and 19 under post-anthesis drought stress condition (Table 5) and genotypes No. 6, 9 and 24 under pre-anthesis drought stress (Table 4). These findings are in accordance with results of Rosielle and Hamblin (1981). An important component for the success of a plant breeding program in stressed environments is good performance of genotypes under severe stress conditions and maximum yield under optimum conditions.

The grain yield of genotypes under pre-and post-anthesis drought stress conditions showed positive and highly significant correlations with MP, GMP and STI, and a significantly negative correlation with SSI (Table 6). Also, the grain yield of genotypes under non-stress condition (Y_P) showed positive and highly significant correlations with TOL, MP, GMP and STI under pre- and post-anthesis drought stress conditions but was not correlated with SSI (Table 6). Tables 6 indicate that MP, GMP and STI were better predictors of Yp and Ys than other indices under both water deficit conditions. Overall, STI was a better predictor of Yp and Ys under both stress conditions. This result is in agreement with the results of Fernandez (1992). Shafazadeh *et al.* (2004) reported positive and highly significant correlation coefficients between STI and grain yield under normal and terminal drought stress conditions.

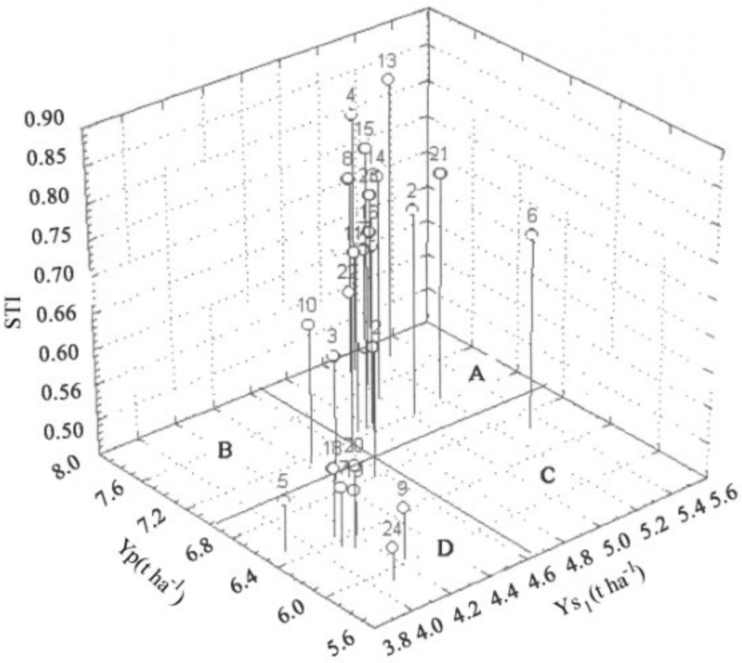

Figure 1. Three dimensional plot of Yp, Ys_1 and STI under pre-anthesis drought stress conditions.

Three-D-plots among Ys, Yp and STI are presented in Figures 1 and 2 and they shows the interrelationships among these three variables, illustrating the advantage of STI as a selection criterion for identifying high-yielding and drought tolerant genotypes. In a three-D plot (Figures 1 and 2) the X-Y axes is divided into four sections and marked as groups A to D. According to the 3-D plot classification of Fernandez (1992), the group A genotypes have high yield in both non-stressed and stressed environments, genotypes in group B favored a non-stressed environment, group C genotypes favored stressed environments and the group D genotypes have low yield in both stressed and non-stressed environments. On the basis of a 3-D plot (Figure 2) in post-anthesis drought stress most of the genotypes in group A showed high STI (genotypes No. 1, 4, 8, 13, 14, 15, 16, 21 and 23). Two other genotypes (No. 7 and 10), also expressed a moderate STI (0.78 and 0.79, respectively). However, genotypes No. 12 and 18 were more suitable for stress conditions (Group C) and genotypes No. 2, 3, 11 and 22 were more suitable for non-stressed environments (Group B). In pre-anthesis drought stress experiments, genotypes No. 2, 4, 7, 8, 11, 13, 14, 15, 16, 21 and 23 were identified as group A genotypes which also showed high STI values (Figure 1). Overall, genotypes No. 4, 8, 13 and 14 with high yield and high drought stress tolerance were more suitable in both water deficit conditions. Selection based on the SSI (Stress Susceptibility Index) favored genotypes No. 9, 18 and 21 under post-anthesis drought stress (Table 5) and genotypes No. 6, 9 and 21 under pre-anthesis drought stress (Table 4) conditions. Nevertheless, SSI failed to identify the high yielding and stress tolerant genotypes under both water deficits and non-stress conditions. These findings are in accordance with the results of Fernandez (1992). Thus, a 3-D plot of Ys, Yp and STI separated the group

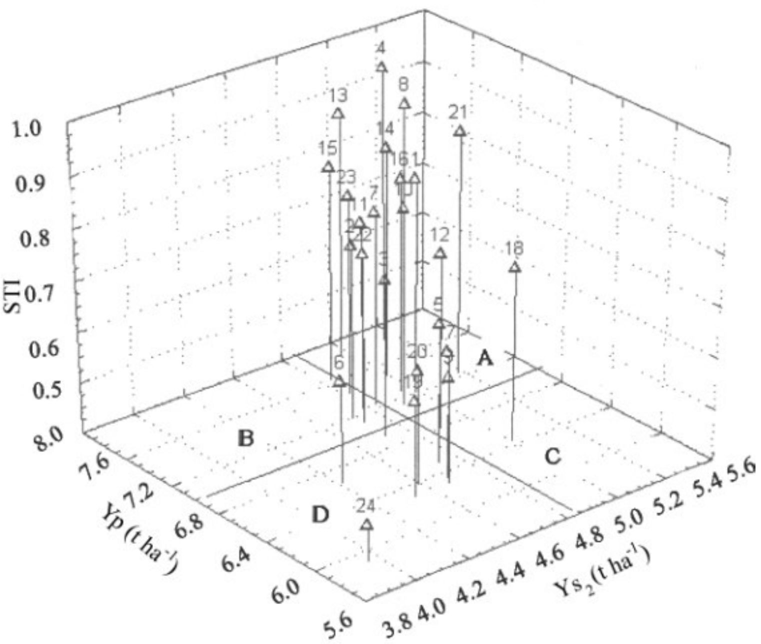

Figure 2. Three dimensional plot of Yp, Ys_2 and STI under post-anthesis drought stress conditions.

A genotypes from other genotypes very effectively.

Injury to cell membranes was studied at 2 stages (booting and heading) by measuring the electro-conductivity of an aqueous medium containing leaf discs which were taken from the pre-anthesis drought stressed experiment. The interaction effect of year× genotype and measurment stages (booting and heading)×genotype were found significant ($P<0.05$) and non-significant, respectively. Results show that the stages of development (booting and heading) of wheat under drought stress conditions could not interact with stability of the membrane and membrane damage. There were significantly differences ($P<0.05$) between genotypes in both the membrane stability and membrane damage indices, i.e. genotypes showed different drought tolerance in stability of the membrane and membrane damage. So it will be possible to select the drought tolerant genotypes by evaluating the afore mentioned indices (Table 7). A lot of evidence suggests that cell membranes and organelles are primary sites for desiccation injury. Loss of membrane integrity was reported with the increase of electrolyte leakage under drought stress (Tan and Blake, 1993; Fan and Blake, 1994). On the basis of differences between cell membrane damage and the stability of membrane indices of winter wheat genotypes, genotypes No. 13, 14, and 21 with low membrane damage (Table 7) were also identified as drought tolerant genotypes. It can be concluded that the laboratory test can be a useful tool for integration in a breeding program for improvement of drought tolerance in wheat.

Overall, these results showed that an important component for success in any plant breeding program under stressed environments is good performance of the genotypes under severe stress and maximum yield un-

Table 7. Average values of stability of membrane (SM) and percentages of membrane damage (MD) of winter wheat genotypes at the booting (1) and heading (2) stages under pre-anthesis drought stress conditions from the 1998 to 2000 cropping seasons.

No	Genotypes	Stability of membrane and membrane damage values			
		(SM_1) %	(SM_2) %	(MD_1) %	(MD_2) %
1	MV17	53.08 ce	59.12 cd	0.6046 b	0.6616 de
2	Alamoot	74.67 ac	78.75 ad	0.9518 ab	1.0170 cf
3	F13011.1321.Rom/Fdi	62.33 ae	70.43 bd	0.8651 ab	0.9320 cf
4	ID13/Mlt.S.WM1274.Mex/Tur…	55.72 be	77.38 ad	0.9568 ab	1.2030 ac
5	Au/3/Minn//llK/4/XMh/Era/5/Dhf	58.02 be	81.08 ad	0.7429 ab	0.9270 cf
6	Horis	63.40 ae	76.33 ad	0.8499 ab	0.9424 cf
7	GK-zuyloy	56.50 be	51.00 d	0.9625 ab	0.5040 f
8	Ymh/Tob/Mcd/3/Lira	64.67 ae	86.75 ac	1.3550 ab	1.5100 ab
9	Ayt94-Tjb788-1080/A/dem/3/Resk//Eno/G11Wre86099	81.83 a	93.42 ab	1.5030 a	1.1990 ac
10	Hkng.SXL-7044/Bow//ksa 74681/SXL/cit…	69.67 ae	80.67 ad	1.0330 ab	0.8917 cf
11	Mach//Bez/GGrk/cit89067-ose…	71.17 ae	87.25 ac	1.2570 ab	1.0810 bd
12	Ba/6529.13	70.33 ae	77.82 ad	0.8163 ab	0.8817 cf
13	Jup/4/cllf/3/111.53/odino//ci18431/Waos477w	49.42 e	63.00 bd	0.7138 ab	1.0050 cf
14	Jup/4/cllf/3/111.53/odino//ci18431/Wa…	50.83 de	70.58 bd	0.7244 ab	0.8220 cf
15	OWL184524-3H-OH OH– ND/P101//Bb…	72.77 ad	68.75 bd	0.9950 ab	0.8612 cf
16	Sbn//Sannina/Ald S	61.93 ae	92.00 ab	0.8254 ab	1.0350 be
17	Stepinak/Karvana	82.00 a	103.3 a	1.4450 ab	1.2160 ac
18	Vratza/wisc245	76.20 ab	103.7 a	1.1430 ab	1.6330 a
19	Agri/Nac (ES91-81) Swm6595…	66.50 ae	67.72 bd	0.9201 ab	0.7944 cf
20	Agri/Nac-Swm65-99-20H-1H-3P-0P-8m-MW-owm	65.78 ae	67.05 bd	0.6746 ab	0.8055 cf
21	Gaspard	54.95 be	64.50 bd	0.6380 b	0.7309 cf
22	Toos	51.87 de	53.83 d	0.7162 ab	0.5550 ef
23	Shahriar	58.42 be	81.25 ad	0.8195 ab	0.9519 cf
24	Sabalan	69.45 ae	75.97 ad	1.4960 a	1.2290 ac
LSD 5 %		18.15	25.15	0.694	0.424

der optimum conditions. Therefore, three high yielding, and drought tolerant genotypes-genotypes No. 13, 14 and 21- were identified as suitable genotypes for both non-stress and drought stress environments (Tables 3, 4 and 5), with an acceptable stability of membrane and low membrane damage (Table 7).

REFERENCES

1. Bauder, J. 2001. *Irrigating with Limited Water Supplies*. Montana State University Communications Services. Montana Hall. Bozeman, MT 59717. USA.
2. Blum, A. 1985. Breeding Crop Varieties for Stress Environments. *Crit. Rev. Plant Sci*., **2 (3)**:199-238.
3. Calhoun, D. S., Gebeyehu, G., Miranda, A., Rajaram, S., and Van Ginkel, M. 1994. Choosing Evaluation Environments to Increase Wheat Grain Yield under Drought Conditions. *Crop Sci*. **34**: 673-678.
4. Fan, S. and Blake, T. G. 1994. Abscisic Acid Induced Electrolyte Leakage in Woody Species with Contrasting Ecological Requirements. *Plant Physiol*. **89**: 817-823.
5. Fernandez, G. C. J. 1992. *Effective Selection Criteria for Assessing Plant Stress Tolerance*. In: *Proc. Int. Sympos. Adaptation of Vegetative and other Food Crops in Temperature and Water Stress*. Taiwan. **13**: 257-270.
6. Fischer, R. A, and Maurer, R. 1978. Drought Resistance in Spring Wheat Cultivars (Grain Yield Responses). *Aust. J. Agric. Res*. **29**: 897-912

[DOR: 20.1001.1.16807073.2008.10.2.1.5]

7. Gent, M. P. N. 1994. Photosynthate Reserves during Grain Filling in Winter Wheat. *Agron. J.* **86**: 159-167.
8. Innes, P., Blackwell, R. D., Austin, R. B. and Ford, M. A. 1981. Effects of Selection for Number of Ears on the Yield of Winter Wheat Genotypes. *J. Agric. Sci.*, **97**: 523-532.
9. Lewis, C. F. and Christiansen, M. N. 1981. Breeding Plant for Stress Environments. In: "*Plant Breeding II*". (Ed.) Frey, K. J. Proceedings of Plant Breeding Symp. 16 March 1979. Iowa State University Press. Ames, Iowa, pp.151-157.
10. Plaut, Z., Butow, B. J., Blumenthal C. S., and. Wrigley, C. W., 2004. Transport of Dry Matter into Developing Wheat Kernels and its Contribution to Grain Yield under Post-anthesis Water Deficit and Evaluated Temperature. *Field Crop Res.* **86**: 185-198.
11. Rizza, F., Cristina, C., Antonio, M. S. and Lugi, C. 1994. Studies for Assessing the Influence of Hardening on Cold Tolerance of Barley Genotypes. *Euphytica*, **75**: 131-138.
12. Rosielle, A. A. and Hamblin, J. 1981. Theoretical Aspects of Selection for Yield in Stress and Non Stress Environments. *Crop Sci.* **21**: 943- 946
13. SAS. 1988. *SAS/STAT User, Guide. Release* 6.03 SAS Inst. Inc. Cary. USA
14. Shafazadeh, M. K., Yazdansepas, A., Amini, A. and Ghannadha, M. R. 2004. Study of Terminal Drought Tolerance in Promising Winter and Facultative Wheat Genotypes using Stress Susceptibility and Tolerance Indices. *Seed and Plant*, **20(1)**: 57-71.
15. Tan, W. and Blake, T. J. 1993. Drought Tolerance, Abscisic Acid and Electrolyte Leakage in Fast-and-slow-growing Black Spruce Progenies. *Phys. Plant.* **90**: 414-419
16. Van Ginkel, M., Calhoun, D. S., Gebeyheu, G., Miranda, A., Tian-you, C., Pargaz Lara, R., Trethowan, R. M., Sayre, K., Crossa, J. and Rajaram, S. 1998. Plant Traits Related to Yield of Wheat in Early and Late, on Continuous Drought Conditions. *Euphytica*, **100**:109-121.

ارزیابی ژنوتیپ های گندم (*Triticum aestivum* L.) تحت شرایط تنش خشکی قبل و بعد از مرحله گلدهی

ا. ق. سنجری پیرایواتلو و ا. یزدان سپاس

چکیده

در این بررسی عکس العمل عملکرد و اجزای عملکرد ۲۴ ژنوتیپ پیشرفته گندم به شرایط تنش خشکی قبل و بعد از مرحله گلدهی مورد ارزیابی قرار گرفت. این تحقیق در سال های زراعی ۱۳۷۶ تا ۱۳۷۹ در ایستگاه تحقیقات کشاورزی اردبیل انجام پذیرفت. نتایج نشان داد تعداد سنبله در متر مربع ، تعداد دانه در سنبله و عملکرد دانه تحت شرایط تنش قبل از مرحله گلدهی از کاهش بیشتری در مقایسه با شرایط تنش خشکی بعداز مرحله گلدهی برخوردار بود. اما وزن هزار دانه در شرایط تنش خشکی قبل از مرحله گلدهی بیشتر از شرایط بدون تنش و تنش بعد از مرحله گلدهی بود. انتخاب براساس شاخص های TOL و SSI منجر به شناسایی ژنوتیپ های متحمل اما با عملکرد کم شد. اما انتخاب براساس شاخص های MP، GMP، STI شناسایی ژنوتیپ های متحمل با عملکرد بالا را به دنبال داشت. براساس عملکرد دانه در

[DOR: 20.1001.1.16807073.2008.10.2.1.5]

شرایط بدون تنش و تنش های قبل و بعداز مرحله گلدهی ژنوتیپ‌های شماره ۴، ۸، ۱۳، ۱۴ و ۲۱ ژنوتیپ های برتر شناخته شدند. خسارت غشاء سیتوپلاسمی با اندازه گیری هدایت الکتریکی در محیط محلولی که حاوی قطعات برگی که قبلاً در معرض تنش خشکی قرار گرفته بودند برآورد گردید. اثر متقابل ژنوتیپ × سال برای پایداری و خسارت غشاءسیتوپلاسمی معنی دار گردید. اما اثر متقابل ژنوتیپ × مرحله نمو غیر معنی دار شد. براساس نتایج حاصله ژنوتیپ های شماره ۱، ۵، ۱۳، ۱۴، ۲۰، ۲۱و ۲۲ بادارا بودن خسارت غشاء سیتوپلاسمی کم بعنوان ژنوتیپ‌های متحمل به خشکی شناسایی شدند. می توان نتیجه گیری نمود که بررسی‌های آزمایشگاهی در برنامه های اصلاحی می توانند جهت شناسایی ژنوتیپ‌های متحمل به خشکی مورد استفاده قرار گیرند.