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Physiological-based Selection Criteria for Terminal Drought in Wheat (*Triticum aestivum* L.)

A. R. Koocheki[1*], A. Yazdansepas[1], U. Mahmadyorov[2], and M. R. Mehrvar[1]

ABSTRACT

Drought is the most restricting factor in agricultural production in arid and semi-arid regions. This research was conducted on 19 facultative and winter wheat genotypes grown under normal irrigation (N), early post-anthesis (S_1), and late post-anthesis (S_2) drought stress conditions. The experiments were conducted at Karadj, Arak, and Jolgehrokh Agricultural Research Stations in Iran, during 2008-11 cropping seasons. Stress reduced grain number per spike, thousand grain weight, grain weight per spike, harvest index, biological weight, and grain yield. Effect of environment, irrigation, and genotype on most of the traits, including grain yield, was significant. Remobilization, efficiency of remobilization, and pre-anthesis photo-assimilate contribution to grain filling increased under drought stress condition. Correlation coefficients between those traits and grain yield were significantly positive under N, S_1, and S_2 conditions. Based on different drought tolerance indices, the improved line Alvd//Aldan/Ias58*2/3/Gaspard was identified as the most tolerant genotype under anthesis and post-anthesis drought stress conditions. It also had the highest remobilization, efficiency of remobilization, and pre-anthesis photo-assimilate contribution to grain filling under drought stress conditions.

Keywords: Bread wheat, Grain yield, Remobilization, Late drought.

INTRODUCTION

Drought stress adversely affects yield performance of cereals (Rang *et al.,* 2011). Iran, with an annual average precipitation of 240 mm, is located in the semi-arid and arid areas of the world (Kardavani, 1988). Drought stress occurs frequently in irrigated wheat (Jalal Kamali *et al.*, 2009) due to inadequate access to underground water resources (Mohammadi and Karimpour Reihan, 2008). In fact, substantial portions of the 2.4 million ha of irrigated wheat in Iran suffer from irrigation water shortage, especially during post-anthesis i.e. through grain filling period (Jalal Kamali *et al.*, 2009).The best option to attain stable production under drought stress conditions would be to develop drought tolerant genotypes through physiological approaches, which needs a deeper understanding of the yield determining traits and processes. Drought tolerance can be improved through describing drought characteristics of the target environment, identifying associated drought tolerance traits, and developing the corresponding selection criteria to propose appropriate genotypes. Since drought prone environments may have heterogenic soils, Finding favorable selection criteria for drought tolerance of wheat would be a difficult task (Manavalan *et al.*, 2004).

Drought stress, if occurring in vegetative stages of crop development, decreases plant height, leaf area, number of tillers and biomass (Nouri *et al.,* 2011), but the effects are even more drastic when it occurs during the reproductive stages of development

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[1] Department of Cereals Research, Seed and Plant Improvement Institute, Karaj, Islamic Republic of Iran.

[*] Corresponding author; email: arkoocheki@yahoo.com

[2] Department of Agronomy, Faculty of plant science, Tajik Agrarian University, Dushanbe, Tajikistan.

(Shpiler and Blum, 1986). Drought at anytime of crop development decreases leaf chlorophyll and photosynthesis, and hastens senescence (Dulai *et al.,* 2006). Drought during grain filling decreases individual grain weight, due to decrease in grain filling duration rather than decrease in grain filling rate (Wardlaw and Willenbrink, 2000). Blum (1998) reported that drought stress during grain filling decreased current photosynthesis and, consequently, increased the contribution of remobilization.

Drought tolerance or susceptibility indices, as functions of yield reduction determined through comparison of genotypes performance in drought and normal conditions, have been proposed to screen drought tolerant or susceptible genotypes (Mitra, 2001; Fernandez, 1992; Blum, 1996).

The objective of this study was to appraise the effects of post-anthesis drought stress on grain yield and some morpho-physiological based selection traits and indices in wheat genotypes.

MATERIALS AND METHODS

The research was conducted on 19 wheat genotypes (Table 1) at Karadj, Arak and Jolgehrokh Agricultural Research Stations in Iran, during 2008-2011 cropping seasons. The experimental design was split-plot based on randomized complete blocks (RCB) with three replications, in which irrigation treatments were in the main-plots and the 19 winter and facultative wheat genotypes in the sub-plots. Irrigation treatments were normal irrigation (N), irrigation cut-off during early post-anthesis (S_1), and irrigation cut-off during late i.e. 20 days after, anthesis (S_2).The plot size for each genotype was 7 m^2 (1.2×6 m). Sowing was done with an experimental seed planter (Wintersteiger^{TM}), using 450 seeds m^{-2}. An area of 6 m^2 (1.2×5 m) was harvested with by an experimental plot combine harvester (Wintersteiger^{TM}). Soil samples taken from 0-30 cm for all locations showed that: At Karaj, soil texture: loam, *EC*= 1.7 dS m^{-1}, pH= 7.6, available N, P, and K and organic carbon: 0.06%, 9.7 and 176 mg kg^{-1} and

Table 1. Name or pedigree and some other characteristics of the studied genotypes.

Genotypes codes	Name/Parentage	Year of release	Growth type	Ploidy
G1	Shahriyar	2001	Winter	Hexaploid
G2	Alvand	1995	Facultative	Hexaploid
G3	C-80-4	Promising line	Facultative	Hexaploid
G4	Gascogne//Rsh*2/10120/3/Alvd//Aldan/Ias58	Promising line	Facultative	Hexaploid
G5	Alvd//Aldan/Ias58/3/MV17/4/Evwyt2/Azd//Rsh*2/10120	Promising line	Facultative	Hexaploid
G6	Alvd//Aldan/Ias58*2/3/Gaspard	Promising line	Winter	Hexaploid
G7	Mhdv/Soissons/4/Bloudan/3/Bb/7C*2//Y50E/Kal*3	Promising line	Facultative	Hexaploid
G8	F4141-W-1-1/Pastor//Pyn/Bau	Promising line	Winter	Hexaploid
G9	Au//YT542/N10B/3/II8260/4/Ji/Hys/5/Yunnat Odesskiy/6/Ks82W409/Spn	Promising line	Winter	Hexaploid
G10	Id800994.W/Vee/3/Ures/Jun//Kauz/4/Bul5052.1	Promising line	Winter	Hexaploid
G11	Basswood/MV17	Promising line	Winter	Hexaploid
G12	Basswood/MV17	Promising line	Winter	Hexaploid
G13	Bhr*5/Aga//Sni/3/Trk13/4/Gaspard	Promising line	Winter	Hexaploid
G14	Qds/4/Anza/3/Pi/Nar//Hys/5/Vee/Nac/6/Gascogne (PR-14)	Promising line	Winter	Hexaploid
G15	Qds/4/Anza/3/Pi/Nar//Hys/5/Vee/Nac/6/Gascogne (PR-15)	Promising line	Winter	
G16	Omid//H7/4P839/3/Omid/Tdo/4/ICWHA81-1473/5/90Zhong87/6/Owl	Promising line	Winter	Hexaploid
G17	Soissons/M-73-4//Owl 852524-*3H-*O-*HOH	Promising line	Winter	Hexaploid
G18	Bilinmeyen-6	Promising line	Winter	Hexaploid
G19	Sn64//Ske/2*Ane/3/Sx/4/Bez/5/Seri/6/Chervona/7/Kleiber/2 *FL80//Donskpoluk	Promising line	Winter	Hexaploid

0.53%, respectively. At Jolgeh Rokh, soil texture: clay loam, *EC*= 2.8 dS m^{-1}, pH= 8.0, available N, P, and K and organic carbon: 0.05%, 14.0, and 250 mg kg^{-1} and 0.50%, respectively. At Arak, soil texture: clay loam, *EC*= 1.2 dS m^{-1}, pH= 7.8, available N, P and K and organic carbon: .08%, 18.0 and 230 mg kg^{-1}, and 0.50%, respectively.

The experimental field was under two years cereal-fallow rotation and land preparations included stubble mulch fall tillage and next spring tillage with moldboard plow, disking, two times perpendicular land leveling, fertilizer application, and Making raised beds.

Application of basal and top-dress fertilizers were according to the soil test recommendations. Normal (N), S1 and S2 treatments received 6, 2 and 4 irrigations, respectively during the whole season. At physiological maturity, plant samples were randomly taken from the non-marginal plot area including 20 complete stems. Peduncle unit length weight and grain number per spike were determined. The samples were dried in a forced air oven for 72 hours at 70°C, then, total dry matter weight, spike weight, thousand grain weight (TGW), grain weight per spike, and harvest index were measured. The traits of stem assimilates remobilized to grain (SaGR), stem to grain reserve remobilization efficiency (SGRE) and pre-anthesis photoassimilate contribution to grain (PAPCG) were estimated as follows (Ehdaie, 1998; Kobata *et al.*, 1992):

$$SaGR = SdWA - SdWM \qquad (1)$$

where, *SaGR*: Stem assimilates remobilized to grain; *SdWA*: Stem dry weight at early post-anthesis, *SdWM*: Stem dry weight at maturity.

Also, *SGRE* was calculated as follows (Palta *et al.*, 1994):

$$SGRE = \frac{SaGR}{SWA} * 100 \qquad (2)$$

Where, *SGRE:* Stem to grain reserve remobilization efficiency; *SaGR*: Stem assimilates remobilized to grain, *SWA*: Stem dry weight in early post-anthesis

To calculate *PAPCG*, Equation (3) was used (Niu *et al.*, 1998):

$$PAPCG = \frac{SaGR}{GWM} * 100 \qquad (3)$$

Where, *PAPCG:* Pre-anthesis photoassimilate contribution to grain; *SaGR:* Stem assimilates remobilized to grain, *GWM:* Grain weight at maturity.

The combined ANOVA for the three treatments i.e. N, S_1, and S_2, was carried out to determine the main effects of irrigation, genotypes, and their interaction on the studied traits. To evaluate drought tolerance of the genotypes, the indices of tolerance (TOL), mean productivity (MP) (Rossielle and Hamblin, 1981), stress susceptibility index (SSI) (Fischer and Maurer, 1978), stress tolerance index (STI) and geometric mean productivity (GMP) (Fernandez, 1992) were used. Pearson's correlation coefficients between the traits in normal (N) and drought stress conditions (S_1 and S_2) were also calculated.

RESULTS AND DISCUSSION

Main effects of environment, genotype, and irrigation were significant on grain yield and most of the traits. The irrigation×environment, irrigation×genotype, environment×genotype, and genotype x environment x irrigation interactions on grain yield and most of the studied traits were found significant (Table 2). Drought stress intensities were 0.30 and 0.13 under S_1 and S_2 conditions, respectively, i.e. the applied drought stress at early post-anthesis was more severe than in late post-anthesis. The mean grain yields of the 19 genotypes under N, and S_1 and S_2 drought stress conditions were 5,936, 4,139, and 5,162 kg

Table 2. Combined Anova results for measured characteristics in normal and drought conditions (N, S_2, S_1).

	df[a]	YLD[b]	BWA[c]	BWM[d]	BWPM[e]	GNM[f]	GWM[g]	HI[h]	TGWM[i]	SaGR[j]	SGRE[k]	PAPCG[l]
Env	7	318801036**	32.10**	52.6*	94.62**	6995.67**	11.24**	2620.66**	1572.96**	2.95**	5205.2**	18891.94**
Rep(Env)	16	1418927	0.142	0.86	0.24	106.39	0.27	51.85	36.16	0.11	252.3	1039.95
Irr	2	370501235**	1.24*	35.43**	9.42**	1136.96**	19.54**	4420.23**	7445.02**	0.34^{ns}	731.13^{ns}	13083.12**
En×Irr	14	5457234**	0.55**	0.57**	1.19**	191.1**	0.17**	255.18**	102.77**	0.15**	285.09**	1374.51**
Rep(Env×Irr)	32	969097	0.24	0.66	0.56	44.63	0.08	27.04	15.93	0.11	279.45	1058.16
Gen	18	2915274**	0.35**	1.26**	1.19**	262.15**	0.24**	96.53**	68.52**	0.15**	409.06**	967.69**
Irr×Gen	36	390394^{ns}	0.09^{ns}	0.16^{ns}	0.24**	25.27^{ns}	0..03**	13.83^{ns}	6.86^{ns}	0.03^{ns}	56.17^{ns}	221.98^{ns}
Env×Gen	126	1078184**	0.15*	0.35**	0.54**	67.55**	0.08ns	31.83**	24.16**	0.04*	89.56**	348.81^{ns}
Env×Irr×Gen	252	319440^{ns}	0.77*	0.18ns	0.20**	25.77^{ns}	0.04ns	15.16^{ns}	6.64^{ns}	0.03^{ns}	68.14^{ns}	291.96^{ns}
Error	864	316582	0.063	0.175	0.119	23.74	0.038	13.8	8.25	0.030	66.24	277.64
Total	1367											
CV%[m]		11.07	12.26	13.26	12.5	12.45	14.53	8.77	8.43	74.88	73.95	85.64

*,** Significant at the 5 and 1% probability level, respectively, and ns as not significant. [a] Degree of Freedom, [b] Grain Yield; [c] Biomass Weight at Anthesis; [d] Biomass Weight at Maturity; ; [e] Biomass Weight 20 days after anthesis; [f] Grain Number per spike; [g] Grains Weight per spike; [h] Harvest Index; [i] Thousand Grain Weight at Maturity; [j] Stem assimilates to Grain Remobilization; [k] Stem to Grain Reserve remobilization Efficiency; [l] Pre-Anthesis Photo assimilate Contribution to Grain, [m] Coefficient of Variation.

ha^{-1}, respectively (Table 3). Grain yield reduction due to post-anthesis drought stress has been previously reported (Gooding *et al,* 2003; Ozturk and Aydin, 2004; Sanjari Pireivatlou and Yazdansepas, 2008). These findings are not in accordance with Calhoun *et al.* (1994) and Van Ginkel *et al.* (1998) who reported a higher grain yield under early drought than late drought stress conditions. The reason for lower grain yield observed in early post-anthesis rather than late post-anthesis drought stress conditions may mainly be due to a reduction in TGW, which is determined in early post-anthesis while grain number per spike is determined pre- and post- anthesis.

All traits were reduced in stressed conditions (S_1 and S_2) compared to normal irrigation (Table 3). The reduction was higher in S_1 than S_2 for all traits, except BWA. Thousand grain weight under N, S_1 and S_2 drought stress conditions was 37.8, 29.8 and 34.5 g; and the number of grains per spike was 40.8, 37.7, and 38.9, respectively. These results were consistent with those of Inness *et al.* (1981) and Plaut *et al.* (2004) who reported that the rate of dry matter accumulation by kernels was considerably decreased by water deficit. Hatim and Majidian (2012) reported that grain yield was mainly influenced by TGW under both normal irrigation and water stress conditions, while in the present study, harvest indices of the studied genotypes were significantly different in all conditions.

There was a significant difference among genotypes in grain yield (Table 3). In this experiment, genotype no.6 had significantly the highest grain yield in both stress conditions with 4,737 and 5,713 kg ha^{-1}, respectively, probably due to its highest scores in harvest index (46.3%), remobilization (0.38 g), remobilization efficiency (19.65%) and *PAPCG* (31.14%). The genotype no. 15 produced the highest grain yield (6,265 kg ha^{-1}) in normal irrigation condition. Drought stress generally reduced harvest index (Ehdaei, 1993), which was 42.35, 38.8, and 44.8% in late post anthesis, early post-anthesis, and normal

Table 3. DMRT for measured characteristics in normal (N), moderate (S_2) and severe (S_1) drought conditions.[a]

Gen	YLD			BWA			BWM		
	N	S_2	S_1	N	S_2	S_1	N	S_2	S_1
1	5621f	4710e	3352d	2.0def	1.88d	1.85e	3.29bcd	2.98bcde	2.88ef
2	5820bcdef	4988cde	3942bc	2.10abcde	2.07abc	1.98cde	3.37bcd	3.14abcd	2.80cdef
3	6074abcde	5071bcd	4151bc	2.15abcde	2.06abcd	2.15ab	3.47bc	3.27ab	3.04ab
4	5845bcdef	5166bcd	4206bc	2.06bcdef	2.05abcd	2.07abcd	3.27cd	3.10abcde	2.88abcdef
5	5758cdef	5047bcd	3953bc	2.19abc	2.09abc	2.17a	3.56bc	3.16abcd	3.11a
6	6102abcd	5713a	4737a	1.90f	1.93cd	2.04abcd	3.10d	2.87de	2.75def
7	6156abc	5356b	4300bc	2.02cdef	1.99abcd	2.07abcd	3.46bc	3.19abc	2.90abcd
8	5960abcdef	5178bcd	4262bc	1.97ef	1.89d	1.93de	3.11d	2.82e	2.66f
9	6077abcde	5182bcd	4053bc	2.23ab	2.12ab	1.98cde	3.60ab	3.27ab	2.89abcdef
10	6111abcd	5317bc	4302bc	2.27a	2.05abcd	2.02bcd	3.86a	3.25abc	3.02abc
11	5975abcdef	5267bcd	4353b	2.08bcdef	1.94bcd	1.98cde	3.41bcd	3.08abcd	2.84bcdef
12	6229ab	5108bcd	4162bc	2.08bcdef	2.05abcd	2.09abc	3.39bcd	3.14abcd	3.02abc
13	5792cdef	4948de	3914c	2.08bcdef	2.05abcd	2.02bcd	3.46bc	3.12abcd	2.97abcd
14	6045abcde	5196bcd	4273bc	2.14abcde	1.91cd	1.93d	3.51bc	2.96cde	2.79cdef
15	6265a	5313bc	4180bc	2.13abcde	2.05abcd	1.94de	3.47bc	3.25abc	2.8cdef
16	5815bcdef	5076bcd	4181bc	2.16abcd	2.16a	2.07abcd	3.59abc	3.35a	2.96abcd
17	5779cdef	5198bcd	4092bc	2.09abcde	1.93cd	1.98cde	3.40bcd	3.08abcde	2.85bcdef
18	5701def	5223bcd	4328b	2.21ab	2.09abc	2.10abc	3.59abc	3.19abc	3.03abc
19	5670ef	5025bcd	3904c	2.14abcde	1.93cd	2.00cd	3.54bc	3.06abcde	2.88abcdef
Mean	5936	5162	4139	2.11	2.01	2.02	3.44	3.12	2.89

Gen	BWPM			GNM			GWM		
	N	S_2	S_1	N	S_2	S_1	N	S_2	S_1
1	2.82cdef	2.52fg	2.41d	40.8abc	36.5g	36.1cde	1.47bc	1.21ef	1.04cd
2	2.85cdef	2.68cdefg	2.52bcd	37.0de	38.8bcdefg	35.9de	1.46bc	1.32bcd	1.07bcd
3	2.95bcde	2.79bcd	2.80a	39.7cd	40.4abcde	38.0abcde	1.53b	1.41abc	1.17ab
4	2.86bcdef	2.61defg	2.76a	37.0de	37.4efg	35.1ef	1.45bc	1.33abcd	1.10abcd
5	3.33a	2.92ab	2.80a	41.8abc	38.5bcdefg	39.5ab	1.59ab	1.35abcd	1.16ab
6	2.69fg	2.62defg	2.52bcd	40.8abc	39.9abcdef	38.5abcd	1.49b	1.33abcd	1.18ab
7	2.81cdef	2.41g	2.44cd	41.7abc	40.1abcdef	37.3bcde	1.60ab	1.42abc	1.17ab
8	2.57g	2.77bcde	2.45cd	34.5e	33.1h	32.9f	1.34c	1.18f	1.02d
9	3.10b	2.91ab	2.53bcd	41.3abc	40.5abcd	38.1abcde	1.54b	1.38abcd	1.11abcd
10	2.98bcd	2.62defg	2.66abc	43.5a	40.9abc	37.9abcde	1.71a	1.45a	1.20a
11	2.90bcde	2.62defg	2.69ab	40.5abc	38.3cdfg	37.6abcde	1.53b	1.31cde	1.15ab
12	3.03bc	2.78bcdef	2.64abc	39.8bcd	38.4cdefg	38.1abcde	1.51b	1.31cde	1.4abc
13	3.05bc	2.83abcd	2.65abc	41.7abc	37.4fg	38.5abcd	1.57ab	1.30cde	1.16ab
14	2.76defg	2.54efg	2.54bcd	41.4abc	37.8defg	36.5bcde	1.55ab	1.29de	1.10abcd
15	2.69fg	2.66cdefg	2.59abcd	41.6abc	40.00abcdef	38.3abcde	1.52b	1.37abcd	1.10abcd
16	3.01bc	2.87abc	2.70ab	43.2abc	42.2a	39.4abc	1.61ab	1.43ab	1.11abcd
17	2.73efg	2.67cdefg	2.51bcd	43.4ab	41.4ab	40.95a	1.52b	1.36abcd	1.13abcd
18	2.95bcde	3.02a	2.78a	42.4abc	39.5abcdef	38.8abcd	1.60ab	1.34abcd	1.16ab
19	2.97bcde	2.87abc	2.67ab	42.9abc	38.9bcdefg	37.8abcde	1.60ab	1.34abcd	1.11abcd
Mean	2.9	2.73	2.61	40.8	38.9	37.7	1.54	1.34	1.13

[a] DMRT means followed by similar letters in each column are not significantly different at 5% level of probability.

Table3. Continued

Table 3. Continued.

Gen	TGW			HI		
	N	S_2	S_1	N	S_2	S_1
1	36.1de	33.1ef	28.5ef	44.8bc	41.0e	37.9bc
2	39.6a	33.9cdef	29.6ced	43.4c	42.5cde	38.0bc
3	38.4abc	35.1abcd	30.4abcd	44.2bc	43.6bcd	37.8bc
4	39.4ab	35.9ab	31.68a	44.3bc	43.4bcde	38.6bc
5	38.4abc	35.2abcd	29.5de	45.5bc	43.4bcde	37.5c
6	36.8cde	33.4def	30.9abcd	48.7a	46.8a	43.3a
7	38.5abc	35.3abc	30.9abcd	46.4b	45.23ab	40.1b
8	39.6a	36.10a	31.3abc	43.5c	41.9de	38.2bc
9	37.6abcd	34.5abcdef	29.2de	43.0c	42.8bcde	38.6bc
10	39.2ab	35.3abc	31.4ab	44.3bc	44.8abc	39.7bc
11	37.9abcd	34.2bcdef	30.3abcd	44.8bc	42.6cde	40.1b
12	38.2abcd	34.5abcdef	29.9abcde	45.9bc	42.1de	37.8bc
13	37.8abcd	35.00abcde	30.1abcde	45.7bc	42.1de	39.0bc
14	37.6abcd	34.30bcdef	29.8bcde	44.5bc	43.7bcd	39.2bc
15	36.7cde	34.1bcdef	28.6ef	44.3bc	43.52bcd	39.8bc
16	37.2bcd	33.97bcdef	28.4ef	44.6bc	43.5bcd	37.7bc
17	35.1e	33.00f	27.4f	44.9bc	44.3bcd	38.9bc
18	37.9abcd	34.2cdef	29.8bcde	44.6bc	42.3cde	37.9bc
19	37.2bcd	34.1bcdef	29.2d	45.1bc	44.0bcd	38.2bc
Mean	37.8	34.5	29.8	44.8	42.4	38.8

Gen	SaGR			SGRE			PAPCG		
	N	S_2	S_1	N	S_2	S_1	N	S_2	S_1
1	0.18bc	0.11c	0.20c	8.26bc	6.2c	10.bc	12.59bc	11.30c	22.bc
2	0.20abc	0.25b	0.25bc	9.85b	12.2bc	11.6bc	16.30ab	24.9ab	28.7bc
3	0.22ab	0.20bc	0.27bc	10.10b	9.2bc	12.9bc	16.06ab	14.9bc	28.3bc
4	0.23ab	0.28ab	0.29bc	11.11b	13.0b	13.8bc	17.92ab	23.1abc	27.0c
5	0.23ab	0.28ab	0.23bc	10.9b	12.7b	9.4c	14.92ab	21.4abc	19.9bc
6	0.30a	0.38a	0.48a	15.91a	19.9a	23.1a	21.00a	30.1a	42.4a
7	0.17bc	0.22bc	0.33b	8.08bc	11.5bc	15.5b	11.49bc	18.4abc	30.9abc
8	0.20abc	0.25b	0.30bc	10.34b	12.8b	14.8bc	15.74ab	21.1cab	32.8ab
9	0.18bc	0.23bc	0.19c	8.59bc	10.5bc	9.8bc	14.80abc	17.9bc	21.9bc
10	0.11c	0.22bc	0.20c	5.03c	11.1bc	9.9bc	7.38c	17.7bc	19.9bc
11	0.20abc	0.17bc	0.28bc	9.56bc	8.6bc	12.9bc	13.88abc	14.8bc	26.3bc
12	0.20abc	0.22bc	0.20c	9.95b	10.3bc	9.2c	15.17abc	18.5abc	20.5bc
13	0.20abc	0.22bc	0.20c	9.15bc	10.2bc	9.5c	12.60bc	17.3bc	18.2c
14	0.18bc	0.24b	0.24bc	8.38bc	11.9bc	11.5bc	12.53bc	20.6abc	23.2bc
15	0.19bc	0.22bc	0.25bc	8.93bc	10.9bc	12.3bc	12.35bc	17.6bc	22.2bc
16	0.18bc	0.24bc	0.22bc	7.83bc	10.8bc	10.5bc	11.00bc	17.4bc	22.4bc
17	0.21abc	0.21bc	0.26bc	10.15b	10.6bc	11.5bc	15.16abc	16.9bc	24.4bc
18	0.22ab	0.25b	0.22bc	9.81b	11.4bc	9.9c	15.61ab	19.6abc	20.0bc
19	0.20abc	0.21bc	0.22bc	9.95b	11.1bc	10.4bc	15.10abc	15.1abc	22.8bc
Mean	0.20	0.24	0.26	9.58	11.34	12.03	14.29	19.07	24.99

[a] DMRT means followed by similar letters in each column are not significantly different at 5% level of probability.

conditions, respectively (Table 3). The results of reduction in grain yield due to drought stresses compared to normal condition (Gooding *et al.*, 2003; Ozturk and Aydin, 2004) was attributable to a reduction of thousand grain weight (TGW); total plant weight (BWM); number of seeds per spike (GNM), and seeds weight per spike (GWM) in S_2 and S_1 compared to treatment N (Table 3).

According to the results, there were significant ($P< 0.05$) positive coefficients of correlations between grain yield and the studied traits of remobilization; efficiency, and partitioning of the remobilized stem reserves to the grain in all three conditions (N, S_1 and S_2) (Table not shown). Papakosta and Gagianas (1991) also reported the same results in wheat genotypes i.e. positive correlation between remobilized stem reserves and grain yield, which has been also reported in barley genotypes (Abouzar *et al.*, 2012; Przulj and Momcilovic, 2003). The remobilized assimilates (SaGR) were 0.20, 0.24, and 0.26 g in normal, late post-anthesis, and early post-anthesis drought stress conditions, respectively. Drought stress increased remobilization efficiency (SGRE) from 9.58% in normal conditions to 11.34 and 12.03% in late post-anthesis and early post-anthesis drought stress conditions, respectively, which are in accordance with the results reported by Ehdaie *et al.* (2006) and Ghodsi (2004). This increment due to the effect of drought stress was the same for partitioning of remobilized assimilates (PAPCG) (14.29, 19.07, and 24.99%) in normal, late post-anthesis, and early post-anthesis drought conditions, respectively, which has been reported by Yang *et al.* (2000) and Yang and Zhang (2006). Based on the abovementioned findings, the highest values measured in the studied characteristics in wheat line no.6 compared with other genotypes resulted in less grain yield reduction in this genotype. Another advantage for the referred wheat line was more reliance on stem reserves during grain filling period, especially at early post-anthesis and late post-anthesis drought stress conditions. Generally, drought stress causes less photosynthesis and more remobilization during grain filling period. Therefore, efficient varieties in remobilization may have less grain loss in drought affected environments and more drought resistance (Niu *et al.*, 1998; Yang *et. al.,* 2000). The variations seen in studied genotypes for the rate, efficiency, and contribution of remobilization has not been unexpected due to the different genetic structure of the genotypes expressed in terms of their different dry matter accumulation, distribution, and remobilization (Nagarajan *et al.*, 1999).

Drought stress condition resulted in higher *SaGR*, *SGRE*, and *PAPCG* than normal condition in which S_1 (severe stress) had higher values than S_2 (mild stress). Among genotypes, the highest value of *SaGR*, *SGRE*, and *PAPCG* in N, S_1 and S_2 conditions belonged to genotype 6, so that 42.4, 30.1, and 21% of its grain yield resulted from *SaGR*, *SGRE*, and *PAPCG*, respectively. However, Shahryar variety (no.1) was the lowest yielding and the weakest in all susceptibility and tolerance indices at both S_1 and S_2 conditions (Table 3).

Gupta *et al.* (2011) reported that mobilized dry matter and mobilization efficiency in wheat were higher in the internodes of tolerant cultivar, both under control and stress conditions, which boosted translocation of stem reserves to the grains. It is generally accepted that stem reserve mobilization or percentage of stem reserves in grains is affected by sink size, environment, and cultivar (Blum, 1998). In other words, the high amount of stem reserve in a variety does not necessarily mean that the variety has higher remobilization rate in drought environment, therefore, the sink activity and demand for stem reserves are very much important characteristics in drought tolerant varieties. The mentioned parameters are indirectly observed and related to higher TGW, total plant weight (pre-anthesis biomass), and seeds weight per spike, which totally help to decrease grain yield losses in wheat line no.6 or it may also be due to its capability to synthesize and store higher concentration of soluble carbohydrates in the stems prior to anthesis (Conocono, 2002). While, Zhang *et al.* (2013) believe that water deficit increases WSC accumulation and remobilization, remobilization efficiency, and contribution to grain yield in non-leaf organs.

Latest results suggested by Lopes *et al.* (2012) showed that grouped adaptive traits for drought stressed environments in one genotype can increase yields, which is in agreement with the experimental results seen in wheat line no. 6. Also, based on the results of susceptibility and tolerance indices at early post-anthesis and late post-anthesis drought treatments, genotype no.6 had the highest yield under S_1 and S_2 conditions with 4,737 and 5,713 Kg ha^{-1}, respectively. This genotype had the highest rank for all indices in S_1 and S_2 conditions, such that its mean rank ($\overline{R}$) and standard deviation of rank (SDR) for MP, GMP, STI, SSI, and TOL in both stress treatments were 1 and 0, respectively (Results are not shown).

According to the results of drought tolerance and susceptibility indices, wheat line no.6 was the most drought tolerant line, while its remobilization rate, efficiency, and partitioning were the highest among the compared genotypes. It seems the grain yield stability and drought tolerance in line no. 6 can be attributed to its rate, efficiency, and partitioning of remobilization. Mehrpouyan *et al.* (2011) also reported the relationships of wheat grain yield with its remobilization rate, efficiency, and partitioning in drought stressed environments.

According to the calculated indices of MP, GMP, STI, SSI, and TOL in the studied genotypes (results not shown), genotype no. 6 was the most drought tolerant line, because the highest rate of efficiency and partitioning of remobilization belonged to this line. The highest grain yield also belonged to the aforementioned line, in agreement with the report of Sanjari Pireivatlou and Yazdansepas (2008) who found that drought tolerant wheat genotypes with a high yield could be selected by using selection indices of MP, GMP, and STI. Thus, the stability and drought tolerance of line no.6 may be associated to its high rate, efficiency, and partitioning of remobilization. We concluded that wheat line no.6 (Alvd//Aldan/Ias58*2/3/Gaspard) might be the most drought tolerant genotype with higher grain yield under moderate and severe drought stressed conditions and it could be recommended to the farmers for on-farm experiments.

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REFERENCES

1. Abouzar, M., Shahbazi, M., Torabi, S., Nikkhah, H. R. and Nadafi, S. 2012. Post-Anthesis Changes in Internodes Dry Matter, Stem Mobilization, and Their Relation to the Grain Yield of Barley *(Hordeum vulgare* L.*). Iranian J. Plant Physiol.*, **2(4):** 553-557.
2. Blum, A. 1996. Crop Responses to Drought and the Interpretation of Adaptation. *Plant Growth Regul.*, **20:** 135-148.
3. Blum, A. 1998. Improving Wheat Grain Filling under Stress by Stem Reserve Mobilization. *Euphytica,* **100:** 77-83.
4. 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.
5. Conocono, E. A. 2002. Improving Yield of Wheat Experiencing Post-anthesis Water Deficits through the Use of Shoot Carbohydrate Reserves. PhD. Thesis, University of Western Australia, Australia.
6. Dulai, S., Molnar, I., Pronay, J., Csernak, A., Tarnai, R. and Molnár-Láng, M. 2006.

Effects of Drought on Photosynthetic Parameters and Heat Stability of PSII in Wheat and in Aegilops Species Originating from Dry Habitats. *Acta Biologica Szegediensis,* **50:** 11–17.

7. Ehdaei, B. 1993. Selection for Drought Resistance in Wheat. *1st Agronomy and Plant Breeding Congress*, University of Tehran. Karadj, Iran. PP.43-62.
8. Ehdaie, B. 1998. Genetic Variation for Stem Reserve and Remobilization to Grain in Spring Wheat under Drought Stress Condition. *Proceedings of the 5th Iranian Crop Science Congress*, Karaj, PP. 1-25.
9. Ehdaie, B., Alloush, G. M., Madore, A. and Waines, J. G. 2006. Genotypic Variation for Stem Reserves and Mobilization in Wheat. I. Post Anthesis Changes in Inter node Dry Matter. *Crop Sci.,* **46:** 735-746.
10. Fernandez, G. C. J. 1992. Effective Selection Criteria for Assessing Plant Stress Tolerance. *Proceedings of the International Symposium "Adaptation of Vegetables and Other Food Crops in Temperature and Water Stress*, AVRDC Publication. Tainan, Taiwan, PP. 257-270.
11. Fischer, R. A. and Maurer, R. 1978. Drought Resistance in Spring Wheat Cultivars Grain Yield Response. *Aus. J. Agri. Res.,* **29L**: 897-912.
12. Ghodsi, M. 2004. The Ecophysiological Effects of the Water Shortage on the Growth of the Wheat Cultivars. PhD Dissertation in Agronomy, University of Tehran, Faculty of Agriculture. Karadj, 250 PP.
13. Gooding, M. J., Ellis, R. H., Shewry, P. R. and Schofield, J. D. 2003. Effect of Restricted Water Availability and Increased Temperature on the Grain Filling, Drying and Quality of Winter Wheat. *J. Cereal Sci.,* **37**: 295-309.
14. Gupta, A. K., Kaur, K. and Kaur, N. 2011. Stem Reserve Mobilization and Sink Activity in Wheat under Drought Conditions. *American J. Plant Sci*., **2:** 70-77.
15. Hatim, M. and Majidian, M. 2012. Effect of Terminal Season Water Stress on Yield, Yield Component and Remobilization in Different Cultivar and Lines of Bread Wheat. *Intl. J. Agri. Crop Sci.*, **4(16):** 1215-1220.
16. Inness, 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.
17. Jalal Kamali, M. R., Asadi, H. and Najafi Mirak, T. 2009. Irrigated and Dry Land Wheat Research Strategic Program. Agricultural Research, Education and Extension Organization, 345 PP. (In Persian)
18. Kardavani, P. 1988. *The Arid Lands*. Tehran University Press, 376p. (In Persian).
19. Kobata, T., Plata, J. A. and Turner, N. C. 1992. Rate of Development of Post-anthesis Water Deficits and Grain Filling of Spring Wheat. *Crop Sci.,* **32:** 1238-1242.
20. Lopes, M. S., Reynolds, M. P., Jalal-Kamali, M. R., Moussa, M. Feltaous, Y. Tahir, I. S. A., Barma, N., Vargas, M., Mannes, Y. And Baum, M. 2012. The Yield Correlations of Selectable Physiological Traits in a Population of Advanced Spring Wheat Lines Grown in Warm and Drought Environments. *Field Crops Res.,* **128**: 129–136.
21. Manavalan, L. P., Guttikonda, S. K., Trans, L. S. and Nguyen, H. T. 2009. Physiological and Molecular Approaches to Improve Drought Resistance in Soybean. *Plant Cell Physiol*., **50(7):** 1260-76.
22. Mehrpouyan, M., Zakavati, B. and Ajali, J. 2011. Effect of Terminal Moisture Stress on Metabolites Remobilization in Different Winter and Intermediate Genotypes of Wheat. *Plant Ecophysiol.,* **3:** 71-77.
23. Mitra, J. 2001 Genetics and Genetic Improvement of Drought Tolerance in Crop Plants. *Crop Sci.*, **80:** 758-762.
24. Mohammadi, H. and Karimpour Reihan, M. 2008. The Effect of 1991-2001 Droughts on Ground Water in Neishabour Plain. *Desert*, **12:** 185-197. (In Persian)
25. Nagarajan, S., Rane, M., Maheswari, M. and Gambhir, P. N. 1999. Effect of Post-anthesis Water Stress on Accumulation of Dry Matter, Carbon, Nitrogen and Their Partitioning in Wheat Varieties Differing in Drought Tolerance. *Crop Sci.,* **183:** 129-136.
26. Niu, J. Y., Gan, Y. T., Zhang, I. W. and Yang, Q. F. 1998. Post-anthesis Dry Matter Accumulation and Redistribution in Spring Wheat Mulched with Plastic Film. *Crop Sci*., **38:** 1562-1568.
27. Nouri, A., Etminan, A. J., Teixeira da Silva, J. A. and Mohammadi, R. 2011. Assessment of Yield, Yield-related Traits and Drought Tolerance of Durum Wheat Genotypes (*Triticum turgidum* var. Durum Desf.). *Aust. J. Crop Sci*., **5:** 8–16.

28. Ozturk, A. and Aydin, F. 2004. Effect of Water Stress at Various Growth Stages on Some Quality Characteristics of Winter Wheat. *J. Agron. Crop Sci*., **190:** 93-99.
29. Papakosta, D. K. and Gagianas, A. A. 1991. Nitrogen and Dry Matter Accumulation, Remobilization, and Losses for Mediterranean Wheat during Grain Filling. *Agron J*., **83:** 864-870.
30. Palta, J. A., Kobata, T., Turner, N. C. and Fillery, I. R. 1994. Remobilization of Carbon and Nitrogen in Wheat as Influenced by Post-anthesis Water Deficits. *Crop Sci*., **34**: 118–124.
31. 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 Crops Res*., **86**: 185-198.
32. Rang, Z. W., Jagadish, S. V. K., Zhou, Q. M., Craufurd, P. Q. and Heuer, S. 2011. Effect of High Temperature and Water Stress on Pollen Germination and Spikelet Fertility in Rice. *Environ. Exp. Bot*., **70:** 58–65.
33. Rossielle, A. A. and Hamblin, J. 1981. Theoretical Aspects of Selection for Yield in Stress and Non-stress Environment. *Crop Sci*., **21:** 943-946.
34. Przulj, N. and Momcilovic, V. 2003. Dry Matter and Nitrogen Accumulation and Use in Spring Barley. *Plant Soil Environ*., **49:** 36-47.
35. Sanjari Pireivatlou, A. and Yazdansepas, A. 2008. Evaluation of Wheat (*Triticum aestivum* L.) Genotypes under Pre and Post-anthesis Drought Stress Conditions. *J. Agric. Sci. Tech*., **10(2)**: 109-121.
36. Shpiler, L. and Blum, A. 1986. Differential Reaction of Wheat Cultivars to Hot Environments. *Euphytica,* **35:** 483–492.
37. Van Ginkel, M., Calhoun, D. S., Gebeyehu, G., Miranda, A., Tian-you, C., Pargas Lara, R., Trethowan, R. M., Sayre, K., Crossa, J. and Rajaram, S. 1998. Plant Traits Related to Yield of Wheat in Early, Late, or Continuous Drought Conditions. *Euphytica,* **100:** 109-121.
38. Wardlaw, I. F. and Willenbrink, J. 2000. Mobilization of Fructan Reserves and Changes in Enzyme Activities in Wheat Stems Correlate with Water Stress during Kernel Filling. *New Phytol*., **148:** 413–422.
39. Yang, J., Zhang, J., Huang, Z., Zhu, Q. and Wang, L. 2000. Remobilization of Carbon Reserves Is Improved by Controlled Soil Drying during Grain filling of Wheat. *Crop Sci*., **40:** 1645-1655.
40. Yang, J. and Zhang, J. 2006. Grain Filling of Cereals under Soil Drying. *New Phytol*., **169(2):** 223-236.
41. Zhang, Y. P., Zhang, Y. H., Xue, Q. W. and Wang, Z. M. 2013. Remobilization of Water Soluble Carbohydrates in Non-leaf Organs and Contribution to Grain Yield in Winter Wheat under Reduced Irrigation. *Intl. J. Plant Prod.,* **7(1):** 97-116.

معیارهای فیزیولوژیکی گزینش گندم در شرایط تنش خشکی آخر فصل

ا. ر. کوچکی، ا. یزدان سپاس، ع. محمد یوروف و م. ر. مهرور

چکیده

خشکی محدود کننده‌ترین عامل تولید محصولات کشاورزی در مناطق خشک و نیمه خشک محسوب می‌شود. تحقیق حاضر به بررسی واکنش ۱۹ ژنوتیپ گندم نیمه‌زمستانه و زمستانه به شرایط آبیاری معمول و قطع آب آبیاری یا خشکی در مراحل گرده‌افشانی و پس از گرده‌افشانی پرداخته که در سه ایستگاه تحقیقاتی کرج، اراک و جلگه رخ در سال های زراعی۹۰-۱۳۸۷ به اجرا در آمد. تنش خشکی تعداد دانه در سنبله، وزن هزاردانه، وزن دانه سنبله، شاخص برداشت، وزن زیست توده و

عملکرد دانه را کاهش داد. اثر عوامل محیط، آبیاری و ژنوتیپ بر اغلب صفات از جمله عملکرد دانه معنی‌دار بود. تنش خشکی باعث افزایش انتقال مجدد، کارایی انتقال مجدد و سهم مواد فتوسنتزی انتقال یافته به دانه قبل از گرده‌افشانی گردید. ضرایب همبستگی بین عملکرد دانه و صفات انتقال مجدد، کارایی انتقال مجدد و سهم مواد فتوسنتزی انتقال‌یافته به دانه قبل از گرده افشانی در هر سه شرایط آبیاری معمول و قطع آب آبیاری یا خشکی در مراحل گرده‌افشانی و پس از گرده‌افشانی مثبت و معنی‌دار بودند. بر پایه نتایج برآمده از شاخص های ارزیابی تحمل و حساسیت به خشکی شامل میانگین بهره‌وری، میانگین هندسی بهره‌وری، شاخص تحمل به خشکی، شاخص حساسیت به خشکی و تحمل، لاین اصلاح شده شماره ۶ متحمل‌ترین ژنوتیپ در شرایط تنش خشکی ملایم و شدید شناخته شد. همچنین از میان ژنوتیپ‌های مورد بررسی در شرایط خشکی، ژنوتیپ شماره ۶ بیشترین مقادیر مربوط به انتقال مجدد، کارایی انتقال مجدد و سهم مواد فتوسنتزی انتقال‌یافته به دانه قبل از گرده‌افشانی را به خود اختصاص داد.