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Morpho-physiological traits associated with terminal drought-stress tolerance in triticale and wheat

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Abstract. The objectives of this study were to evaluate the genotypic effects on tolerance to terminal drought stress in triticale and to compare it with that of durum and bread wheat under drought stress and normal field conditions using morpho-physiological traits. Five triticale ('Zoro', 'Moreno', 'Lasko', 'Prego' and 'Alamos 83'), one bread wheat ('Roshan') and one durum wheat ('Osta-Gata') cultivars were used. A randomized complete block design with three replications was used in each of the drought stress and well-watered (non-stress) experiments. Morpho-physiological traits including chlorophyll content, relative water content (RWC), excised leaf water retention (ELWR), rate of water loss (RWL), initial water content (IWC), leaf area, leaf angle, number of stomata, pollen viability, dry weight of awn and awn length were evaluated. Results of combined analyses of variances indicated the highly significant differences among genotypes for all traits and significant genotype × environmental interaction for all traits with the exception of leaf width, number of stomata and awn length. Overall performance of triticale cultivars was superior to wheat cultivars under both environmental conditions. Among triticale genotypes, 'Lasko' and 'Moreno' cultivars were the most drought tolerant and 'Prego' cultivar was the most sensitive genotype to water stress. Under drought stress conditions ELWR showed significant and negative correlation with grain yield, while their correlation was significant and positive under non-stress conditions. This relationship indicates that ELWR had an important impact on grain yield under both water stress and non-stress conditions.

Keywords: morpho-physiological traits, drought stress, triticale, pollen viability, tolerance.

INTRODUCTION

Water stress is the major limiting factor in crop production worldwide. In developing a breeding program to improve the drought resistance of a crop plant it is necessary to gain knowledge concerning the genetics and physiology of tolerance mechanisms (Clarke & Townley-Smith, 1984; Inoue et al., 2004). Yield is the principle selection index used under drought stress conditions. If we had known how to select for high yield potential using criteria other than grain yield, perhaps results could have been achieved by way of enhanced total plant productivity rather than just by changing the production ratio (Blum, 2005). The identification of physiological traits responsible for drought tolerance should be considered in the breeding program, because grain yield and drought resistance are controlled at independent genetic loci (Morgan, 1984). Therefore, the use of physiological traits as an indirect selection would be important in augmenting yield-based selection procedures. Selection efficiency could be improved if particular physiological and/or morphological attributes related to yield under a stress environment could be identified and employed as selection criteria for complementing traditional plant breeding (Acevedo, 1991). These morpho-physiological traits should be highly heritable, greatly correlated with stress tolerance and can be easily assessed. A range of traits has been suggested that could be utilized to increase selection efficiency and used as indirect selection for improving yield under stress conditions. Wheat has gained special attention in respect to morphological and physiological characters affecting drought tolerance, including stomata (size, number, aperture); leaf (area, shape, expansion, orientation, senescence, pubescence, waxiness, cuticular resistance); root (length, density, dry weight); water-use efficiency; relative water content; evapo-transpiration efficiency; abscisic acid levels; cell membrane stability; heat-shock proteins and carbon isotope discrimination (Dencic et al., 2000). Traits related to drought resistance, such as small plant size, reduced leaf area, and early maturity, lead to reduced total seasonal evapo-transpiration (Rizza et al., 2004). Water potential (WP) was used for measurement of the water status in the plant; leaf relative water content (RWC) was introduced as a better indicator. Matin (1990), studying barley, reported that drought tolerant cultivars usually maintained higher leaf RWC under the stress. Plants are developmentally and physiologically designed by evolution to reduce water use (WU) under drought stress (Blum, 2005). The rate of photosynthesis often limits plant growth when soil water availability is reduced (Liu & Li, 2005). Reduced leaf chlorophyll content expressed in yellowish coloration is indicative of a reduction at the photosystem II reaction centre. This reduces photosynthetically active radiation (PAR) absorption and subsequently water use (Blum, 2005). Water balance has a strong influence on the viability of mature pollen grains when they are exposed to the environment, but also during the development of pollen inside the anther. Especially in cereals, short periods of drought stress specifically affect male reproductive performance and can greatly reduce grain yield (Bots & Mariani, 2005). Water deficit during meiosis in pollen mother cells of wheat (*Triticum aestivum* L.) induces male sterility, which can reduce grain set by 40 to 50%. Female fertility is not affected by water deficit during this period (Saini & Aspinall, 1981).

Triticale (X. *Triticosecale* Wittmack) is one of the most successful man-made cereals and was syntheticized to obtain a cereal that combines the unique grain quality of its wheat (*Triticum* ssp.) parent with tolerance to abiotic and biotic stresses of the rye (*Secale* spp.) parent. It was found to have superior tolerance to low nutrient availability, drought, frost, soil acidity, aluminum and other element toxicities and salinity (Lelley, 2006). Wherever intensive breeding efforts have been sustained, modern triticale cultivars are on a par with the best common wheats in terms of their yield potential under favorable conditions and are often more productive than most wheats when planted in different types of marginal soils (Ammar et al., 2004).

The objectives of the present study were to investigate the genotypic effects for tolerance to terminal drought stress in triticale and to compare them with those of a drought-tolerant bread and a drought-tolerant durum wheat cultivar under drought stress and normal field conditions using morpho-physiological traits.

MATERIALS AND METHODS

Plant materials

Based on our preliminary field experiment using 41 triticale genotypes (data not shown), 4 drought tolerant ('Zoro', 'Moreno', 'Lasko', 'Prego') and one drought sensitive ('Alamos 83') triticale cultivars were used. A bread wheat cultivar ('Roshan') and a durum wheat cultivar ('Osta-Gata') were also included as the drought tolerant cultivars.

Field experiments

Plant materials were grown in two separate experiments under stress and non-stress regimes in 2005/06 at the research farm of Isfahan University of Technology located at Lavark-Isfahan, Iran (40 km southwest of Isfahan, 32˚ 32´N, 51˚ 23´ E, 1630 m asl). The soil at this site is silty clay loam, typic Haplargids of the arid tropic with pH = 7.3–7.8. Mean annual precipitation and mean annual temperature were 140 mm and 14.5°C, respectively. Each experiment was conducted using a randomized complete block design with three replications. Each plot consisted of six 4m long rows spaced 25 cm apart. The plant materials were grown under two moisture regimes of irrigation after 70 mm evaporation from class-A Pan corresponded to soil water potential of -0.5 MPa (non-stress) and irrigation after 130 mm evaporation from class-A Pan corresponded to soil water potential of -1.2 MPa (water-stress). The moisture treatments were applied from the booting stage (Zadoks 45) till physiological maturity (Zadoks 92).

Morpho-physiological traits

Data for length and width of the flag leaf were measured using 10 samples from each plot; leaf area was then calculated based on a formula suggested by Muller (1991). These traits were measured at the physiological maturity stage (Zadoks 92). For measuring stomata frequency the above surface of 10 flag leaves from each plot were covered by a thin layer of polish and after polish drying the number of stomata per microscopic field at 20 × magnification was counted. Leaf angle was measured as the angle between flag leaf and stem using 10 leaves per plot. Awn length and awn dry weight were collected from randomly 20 awns per plot.

Water-related variables and the chlorophyll content were measured at anthesis stage (Zadoks 64). Ten plants were randomly selected from each plot and the water-related parameters were described.

Relative water content (RWC): The flag leaves were cut into 2 cm pieces and weighed (fresh weight = FW). The leaf pieces were then placed in distilled water for 4 hours and re-weighed to obtain turgor weight (TW). The leaf pieces were oven dried, weighed and used as dried weight (DW). RWC was calculated using the formula proposed by Ritchie et al. (1990):

$$\%RWC = \frac{FW - DW}{TW - DW} \times 100$$

Excised leaf water retention (ELWR): The flag leaves were collected and weighed, kept at 30ºC for 5 hours and reweighed. ELWR was then calculated using the following formula:

ELWR = [1-(weight of fresh leaves – weight of leaves after 5 hours)/ weight of fresh leaves]×100

Rate of water loss (RWL): The flag leaves were collected and weighed (W_1). The leaves were wilted at 30ºC and re-weighed (W_2) transferred to an oven for 24 h and weighed (W_3). Then RWL was calculated by the formula suggested by Yang et al. (1991):

$$RWL = \left(\frac{W_1 - W_2}{W_3}\right)\left(\frac{t_1 - t_2}{60}\right)$$

Where t_1 and t_2 are the time of measurement for initial and wilted weight (in minutes).

Initial water content (IWC): IWC was calculated as:

$$IWC = \frac{W_0 - W_d}{W_d}$$

W_0= fresh weight, W_d= leaves placed in an oven at 50º C for 24 h and re-weighed.

To measure the chlorophyll content**,** 50 to 100 mg of tissue from 10 leaves was obtained randomly from each plot. The tissues were then placed into a mortar, 10 mL of 80% acetone (v/v) was added, and the tissue was ground with a pestle. The leaf homogenate was vacuum-filtered using a vacuum pump. The filtrate volume was then brought up to 30 mL with 80% acetone (v/v). Absorbance was measured at 663 nm and 645 nm using a UV/VIS spectrophotometer (Beckman DU-530). The amount of chlorophyll a, chlorophyll b and total chlorophyll were calculated according to Arnon's equation (1949).

$$\text{Chl a (mg/g)} = \frac{((12.7 \times \text{Abs663}) - (2.6 \times \text{Abs645}) \times \text{ml Aseton})}{\text{mg leaf tissue}}$$

$$\text{Chl b (mg/g)} = \frac{((22.9 \times \text{Abs645}) - (4.68 \times \text{Abs663}) \times \text{ml Aseton})}{\text{mg leaf tissue}}$$

$$\text{Chl a + b (mg/g)} = \frac{((22.9 \times \text{Abs645}) - (4.68 \times \text{Abs663}) \times \text{ml Aseton})}{\text{mg leaf tissue}}$$

To assess the pollen viability in the studied genotypes, pollen grains were treated with 1% 2.35-triphenlytetrazolium chloride (TTC) and studied under microscope after two hours (Khatun & Flowers, 1995). The viable pollen had a yellow color and circle shape but the dead pollen was wrinkled and black in color.

Statistical analysis

The data were subjected to both separate and combined analyses of variances (ANOVA) using SAS computer package (SAS Institute, 2003). Means comparisons were conducted using Fisher's (protected) least significant differences (LSD).

RESULTS AND DISCUSSION

The results of combined analyses of variances indicated the highly significant differences among genotypes for all traits and significant genotype × environmental interaction for all traits with the exception of leaf width, number of stomata and awn length (Tables 1–4).

Table 1. Combined analysis of variances for chlorophyll content of triticale and wheat genotypes.

Source of variation	df	Mean square			
		Chlorophyll a	Chlorophyll b	Chlorophyll a+b	Chlorophyll a/b
Environment	1	1.66**	22.02**	35.77**	0.27*
Genotype	6	2.61**	12.20**	24.43**	0.15**
Genotype × environments	6	3.07**	12.75**	29.33**	0.23**
Residual	24	0.09	1.42	1.21	0.01

*: $P < 0.05$ and **: $P < 0.01$

Chlorophyll content

Analysis of variance showed that genotypes significantly differed for chlorophyll a, chlorophyll b, chlorophyll a+b and chlorophyll a/b ratio (Table 1) Means of chlorophyll a, chlorophyll b and chlorophyll a+b increased and the mean of chlorophyll a/b ratio decreased due to drought in the 'Lasko' cultivar, while the trend was notconsistently observed for other genotypes (Table 5). Decrease in the chlorophyll content under drought stress was also observed by Sayar et al. (2008) in wheat.

Table 2. Combined analysis of variances for RWC, IWC, RWL and ELWR of triticale and wheat genotypes grown under non-stress and drought stress conditions.

Source of variation	df	Mean square			
		RWC	IWC	RWL	ELWR
Environment	1	0.01*	0.19^{ns}	9.35*	0.008**
Genotype	6	0.001**	0.14**	2.75**	0.01**
Genotype × environments	6	0.0008**	0.13*	1.32*	0.002**
Residual	24	0.001	0.04	0.48	0.0004

ns: non significant, *: P < 0.05 and **: P < 0.01

Table 3. Combined analysis of variances for leaf length, leaf width, leaf area and number of stomata of triticale and wheat genotypes grown under non-stress and drought stress conditions.

Source of variation	Df	Mean square			
		leaf length	leaf width	leaf area	number of stomata
Environment	1	7.27**	0.005^{ns}	16.19**	2.21^{ns}
Genotype	6	15..85**	0.14**	72.4**	353.64**
Genotype × environments	6	6.46**	0.19^{ns}	7.81*	5.68^{ns}
Residual	24	0.74	0.02	3.33	4.24

ns: non significant, *: P < 0.05 and **: P < 0.01.

Table 4. Combined analysis of variances for awn length, awn dry weight, leaf angle and grain yield of triticale and wheat genotypes.

Source of variation	Df	Mean square			
		awn length	awn dry weight	leaf angle	grain yield
Environment	1	0.0001^{n}s	0.001**	0.21^{ns}	151.62**
Genotype	6	49.15**	0.005**	12.62**	3.93**
Genotype × environments	6	0.36^{ns}	0.0007**	8.32**	2.55**
Residual	24	0.17	0.00003	0.09	0.13

ns: non significant, *: P < 0.05 and **: P < 0.01.

Combined ANOVA indicated a significant difference between drought stress and non-stress conditions for the chlorophyll contents (Table 1). Triticale genotypes only differed from wheat genotypes under non-stress conditions for chlorophyll a, chlorophyll b, chlorophyll a+b and chlorophyll a/b ratio (Table 5).

Table 5. Means of chlorophyll content of triticale and wheat genotypes grown under drought stress and non-stress conditions as well as pairwise mean comparison of triticale vs. wheat using orthogonal contrast.

Genotype	Chlorophyll a (mg/g)		Chlorophyll b (mg/g)		Chlorophyll a+b (mg/g)		Chlorophyll a/b (mg/g)	
	Non stress	Stress	Non stress	Stress	Non stress	Stress	Non tress	Stress
'Zoro'	8.6	8.28	9.55	11.48	18.6	19.92	0.91	0.75
'Moreno'	8.5	8.51	11.28	7.64	19.79	16.5	0.75	1.11
'Lasko'	5.04	8.65	2.89	9.39	7.94	18.05	1.73	0.94
'Prego'	8.67	8.67	8.79	8.8	17.46	17.47	0.97	0.98
'Alamos 83'	8.8	8.28	8.03	11.27	16.84	19.56	1.14	0.77
'Osta-Gata' (wheat)	8.61	8.72	9.48	7.77	18.09	16.5	0.91	1.12
'Roshan' (wheat)	8.75	8.48	8.04	11.87	16.8	20.35	1.08	1.12
$LSD_{0.05}$	0.69	0.32	1.74	2.44	1.66	2.22	0.25	0.21
Reduction (%)[a]	4.91		17.35		11.25		-14.95	
Orthogonal contrast [b]								
Triticale vs. wheat	-0.75**	-0.12[ns]	-0.65**	-0.1[ns]	-1.31**	-0.12[ns]	0.1**	-0.21[ns]

ns: non significant, *: $P < 0.05$ and **: $P < 0.01$.
[a] Reduction percentage: [100 - (non stress - stress)/non stress)].
[b] means of two groups being contrasted.

Water-related traits

Drought significantly influenced RWC, RWL and ELWR traits (Table 2) and caused a decrease in RWC and RWL and an increase in ELWR (Table 6). But drought stress did not significantly affect the IWC. Orthogonal contrast of triticale versus wheat genotypes was significant for IWC under drought stress condition, RWL under non-stress condition and for ELWR under both conditions (Table 6).

Table 6. Means of water related traits (RWC, IWC, RWL, ELWR) of triticale and wheat genotypes grown under drought stress and non-stress conditions as well as pairwise mean comparison of triticale vs. wheat using orthogonal contrast.

Genotype	RWC		IWC		RWL		ELWR	
	Non stress	Stress	Non stress	Stress	Non stress	Stress	Non stress	Stress
'Zoro'	87	86	2.18	2.55	4.69	4.29	81	87
'Moreno'	91	89	2.59	5.6	5.22	5.42	88	79
'Lasko'	90	86	2.73	2.52	5.97	5.92	79	78
'Prego'	91	86	2.61	2.17	5.71	4.42	80	85
'Alamos 83'	89	83	2.3	2.12	6.5	5.69	73	73
'Osta-Gata' (wheat)	90	83	2.58	2.06	7.43	5.29	72	80
'Roshan' (wheat)	87	81	2.29	2.29	7.12	5.01	72	77
$LSD_{0.05}$	3	7	0.39	0.32	0.99	1.44	5	1
Reduction (%)[a]	-4.49		-5.67		-15.43		3.89	
Orthogonal contrast [b]								
Triticale vs. wheat	-10.00^{ns}	-6.88^{ns}	-0.23^{ns}	0.28**	-1.82**	-0.47^{ns}	-3.25**	-8.50**

ns: non significant, *: $P < 0.05$ and **: $P < 0.01$.
[a] Reduction percentage: [100 - (non stress - stress)/non stress)].
[b] means of two groups being contrasted.

'Moreno' and 'Prego' triticale cultivars possessed the highest and 'Roshan' (wheat) and 'Zoro' (triticale) cultivars had the lowest RWC under both conditions (Table 6). Schonfeld *et al*. (1988) observed a decline in the amount of RWC in wheat due to drought stress and reported the highest RWC in the tolerant genotype. Accordingly 'Moreno' triticale cultivar was ranked as drought tolerant while 'Roshan' wheat cultivar ranked as a drought sensitive genotype. Drought stress caused an average of 15.4% decline in rate of water loss (RWL) in this study that may indicate some inhibiting mechanisms of water loss under drought stress. This result is consistent with that of Golestani Araghi and Asad (1998) who observed decrease in the RWL under stress condition in wheat. Triticale genotype had lower RWL than wheat genotypes. This may indicate the more efficient use of water by triticale genotypes than wheat genotypes under drought stress conditions. 'Prego', 'Roshan' and 'Osta-Gata' cultivars significantly ($P < 0.05$) decreased their RWL under water stress conditions (Table 6). Occasionally drought stress caused excised leaf water retention (ELWR) increase; this phenomenon shows that the probable mechanisms for water retention in the leaf under stress condition may be by leaf rolling or decrease in leaf area. 'Zoro', 'Prego', 'Roshan' and 'Osta-Gata' cultivars significantly ($P < 0.01$) increased their ELWR under drought stress conditions (Table 6). RWC and ELWR negatively and significantly ($P < 0.01$) correlated under stress ($r = -0.57$) and under non-stress ($r = -0.91$) conditions. Although, ELWR had positive and significant ($P < 0.01$) correlation with grain yield ($r = 0.73$) under non-stress conditions, they had a negative and significant ($P < 0.01$) correlation ($r = -0.59$) under stress conditions. Based on the above results, among the plant water relation parameters, ELWR could be a superior indirect selection criterion for grain yield.

Leaf area

The length and area of the flag leaf increased significantly ($P < 0.01$) due to drought stress while the width of the flag leaf did not significantly change (Table 3). Wheat and triticale cultivars varied significantly for length and area of flag leaf under water stress conditions where wheat genotypes had higher leaf area than the triticale genotypes (Table 7). 'Zoro' genotype lowered its leaf area under drought stress conditions and it may use this mechanism to tolerate those conditions. Considering the genotype × environmental interaction, leaf length seems to have profound impact on leaf area under both environmental conditions (Table 3). Leaf extension can be limited under water stress conditions in order to get a balance between the water status of plant tissues and the water absorbed by plant roots (Passioura, 1996). Length of flag leaf had negative and significant ($P < 0.01$) correlation with RWC ($r = -0.66$) under water stress conditions. This relationship indicates that increase in length of flag leaf causes the decline in relative water content. Under non-stress conditions, the width and area of the flag leaf had negative and significant correlation with ELWR. Blum (2005) suggested that a small leaf area is beneficial under drought stress due to being dehydration-avoidant.

Number of stomata in flag leaf

Drought stress did not significantly affect the number of stomata in the flag leaves (Table 4). 'Osta-Gata' had the highest and 'Lasko' had the lowest number of stomata on flag leaf under both stress and non-stress conditions (Table 7). This result is in agreement with that of Golestani Araghi and Asad (2007), who observed the non-significant effect of drought on the number of stomata in wheat.

Length and dry weight of awn

Analysis of combined variances showed a significant effect of drought on awn dry weight and a non-significant effect of drought on awn length (Table 4). Drought stress decreased awn dry weight. 'Moreno' possessed the lowest awn dry weight and awn length while their highest values belonged to 'Osta-Gata', under both conditions (Table 8).

Table 7. Means of flag leaf (leaf length, leaf width, leaf area and number of stomata) of triticale and wheat genotypes grown under drought stress and non-stress conditions as well as pairwise mean comparison of triticale vs. wheat using orthogonal contrast.

Genotype	Leaf length (cm)		Leaf width (cm)		Leaf area (cm^2)		Number of stomata	
	Non stress	Stress	Non stress	Stress	Non stress	Stress	Non stress	Stress
'Zoro'	14.31	12.29	1.25	1.24	13.24	11.32	66.33	65.03
'Moreno'	14.85	13.55	1.2	1.34	13.25	13.5	56.03	58.26
'Lasko'	13.89	14.79	1.27	1.23	13.03	13.55	51.24	51.63
'Prego'	12.57	14.17	1.22	1.17	11.26	12.32	57.29	60.8
'Alamos 83'	13.08	16.25	1.31	1.16	12.67	13.92	53.7	54.76
'Osta-Gata' (wheat)	14.84	18.25	1.45	1.6	16.03	21.68	73.36	72.56
'Roshan' (wheat)	17.48	17.75	1.52	1.64	19.69	21.57	67.62	65.78
$LSD_{0.05}$	1.46	1.6	0.24	0.28	2.58	3.79	3.92	3.38
Reduction (%)[a]	5.96		-2.23		8.75		0.75	
Orthogonal contrast [b]								
Triticale vs. wheat	-3.35^{ns}	-4.41**	-0.3^{ns}	-0.41^{ns}	-5.14^{ns}	-7.66**	-16.8^{ns}	-15.1^{ns}

ns: non significant, *: $P < 0.05$ and **: $P < 0.01$.
[a] Reduction percentage: [100 - (non stress - stress)/non stress)].
[b] means of two groups being contrasted.

Leaf angle

Analysis of combined variances showed that drought stress did not have significant effect on flag leaf angle (Table 4). The leaf angle was decreased in 'Osta-Gata', 'Roshan', 'Lasko' and 'Moreno' cultivars while it was increased in 'Zoro' and 'Alamos 83' by drought stress (Table 8).

Araus and Slafer (2002) stated that stress during plant development causes changes in canopy features and produces horizontal leaves. Orthogonal analysis showed that wheat and triticale cultivars varied significantly for flag leaf angle under drought stress conditions, with triticale having lower leaf angle than wheat (Table 8). Change in flag leaf angle can influence the plant water status (Clarke & Townley-Smith, 1984).

Table 8. Means of traits related to awn, leaf angle and grain yield of triticale and wheat genotype grown under drought stress and non-stress conditions and means of triticale vs. wheat using orthogonal contrast.

Genotype	Awn length (cm)		Awn dry weight (g)		Leaf angle (degree)		Grain yield (t ha^{-1})	
	Non stress	Stress	Non stress	Stress	Non stress	Stress	Non stress	Stress
'Zoro'	6.04	6.57	0.06	0.05	25.3	77.5	9.38	4.24
'Moreno'	5.6	5.49	0.03	0.03	99	80.5	9.52	5.26
'Lasko'	6.58	6.99	0.05	0.04	105	84	8.61	5.28
'Prego'	6.64	6.54	0.05	0.05	53	55	8.44	2.91
'Alamos 83'	7.28	7.38	0.07	0.06	60.22	87.8	7.51	5.71
'Osta-Gata' (wheat)	13.8	12.95	0.15	0.09	100	39.5	8.3	4.54
'Roshan' (wheat)	-	-	-	-	131.19	115	6.41	3.62
$LSD_{0.05}$	0.67	0.67	0.009	0.009	0.48	0.58	0.62	0.66
Reduction (%)[a]	-0.06		-33.33		-1.59		-45.73	
Orthogonal contrast [b]								
Triticale vs. wheat	-43.82**		-9.77^{ns}		-0.01**		-0.05^{ns}	

ns: non significant, **P* < 0.05 and ***P* < 0.01.
[a] Reduction percentage: [100 - (non-stress - stress)/non-stress)].
[b] means of two groups being contrasted.

Chlorophyll b and a+b content had positive and significant correlation ($P < 0.01$) with flag leaf angle under water stress conditions ($r = 0.54$ and $r = 0.53$, respectively). Flag leaf angle had negative and significant correlation ($P < 0.05$) with grain yield under non-stress condition ($r = -0.43$). This result showed that higher flag leaf angle should cause light influence into the canopy and, in turn, increase in grain yield.

Pollen viability

Drought caused a decrease in pollen viability in nearly all the genotypes (Table 9). However, the result of pairwise t-test between pollen viability of genotypes under drought stress and non-stress conditions showed that only 'Zoro' cultivar was affected negatively and significantly by drought stress. Pollen sterility ranged from 1.1 to 9.1% under normal conditions and 5.7 to 11.7% under drought stress conditions. The results of the present study are in agreement with those of Saini & Aspinall (1981) who observed an increase in the pollen sterility caused by drought stress in wheat.

Table 9. Percentage of pollen sterility in triticale and wheat genotypes grown under non-stress and drought stress field conditions.

Genotype	Non stress	Stress
'Zoro'	3.87	11.7
'Moreno'	4.3	6.6
'Lasko'	10	9.7
'Prego'	2.9	5.7
'Alamos 83'	9.1	7.2
'Osta-Gata' (durum wheat)	4	2.32
'Roshan' (bread wheat)	1.1	4.3

Grain yield

Grain yield of the genotypes was significantly (P < 0.01) affected (Table 4), and reduced in all genotypes by drought stress (Table 8). The means of grain yield ranged from 6.41 t ha^{-1} for 'Roshan' to 9.53 t ha^{-1} for 'Moreno' under non-stress conditions and ranged from 2.91 t ha^{-1} to 5.71 t ha^{-1} for 'Prego' and 'Alamos 83' cultivars under drought stress conditions, respectively (Table 8). Triticale cultivars 'Moreno', 'Zoro', 'Lasko' and 'Prego' produced superior grain yield under non-stress conditions (Table 8). Under water-deficit conditions, 'Alamos 83', 'Lasko' and 'Moreno' triticale cultivars ranked as the superior group for grain yield production (Table 8). Therefore, it could be noticed that, triticale cultivars overall performed superior to wheat cultivars under both conditions. In this study, a general linear model regression of grain yield on excised leaf water retention (ELWR) produced under non-stress and water stress conditions are presented in Fig. 1 and Fig. 2, respectively. Linear regression was used to determine the relationship between ELWR and grain yield emphasizing the locations of the genotypes related to the regression line (the two variables). The results indicated that ELWR could nicely explain the grain yield under both environmental conditions and, in particular, drought stress conditions. It is interesting to note that, at both environmental conditions 'Lasko' genotype located exactly on the regression line, which in turn suggested the profound effect of ELWR on grain yield in this genotype, under both conditions. Under water stress conditions, 'Prego' and 'Osta-Gata' genotypes also located on the regression line which shows the importance of ELWR for these genotypes in justifying grain yield for these conditions.

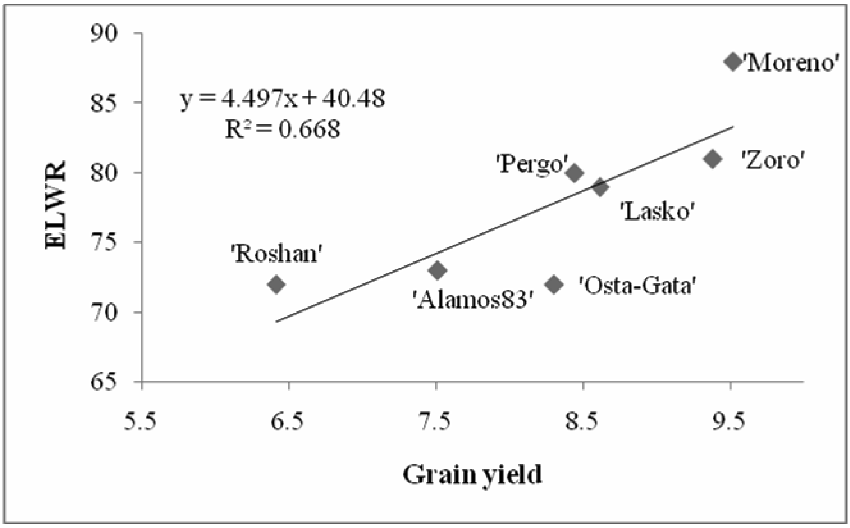

Figure 1. Relationship between grain yield and excised leaf water retention (ELWR) under non-stress condition.

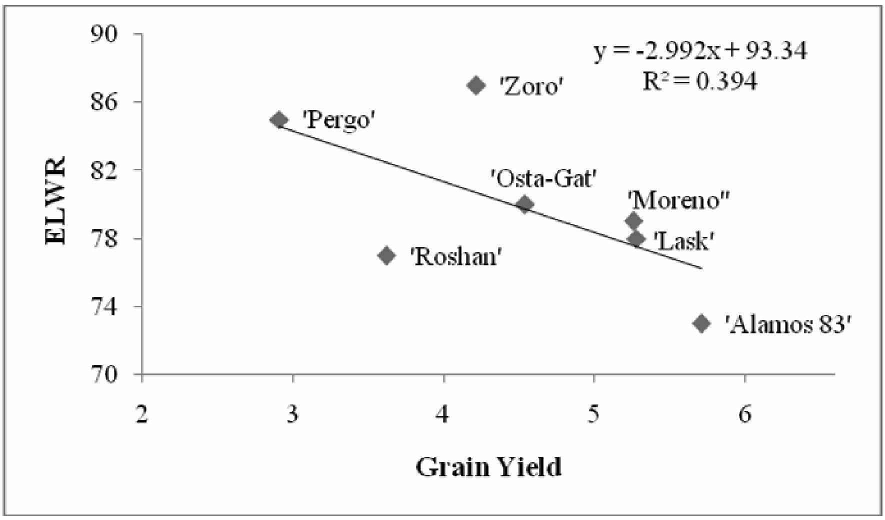

Figure 2. Relationship between grain yield and Excised leaf water retention (ELWR) under stress condition.

CONCLUSIONS

The performance of the triticale cultivars under both normal and drought stress conditions was superior to that of wheat cultivars. The drought tolerance superiority of triticale cultivars under water-restricted conditions could be associated with their lower flag leaf angle, lower leaf area and lower number of stomata. Results of the present study also revealed that triticale cultivars 'Lasko' and 'Moreno' were the most tolerant and wheat cultivars 'Roshan' and 'Osta-Gata' were the most sensitive genotypes to drought stress. It appears that these two drought-tolerant cultivars can exploit physiological mechanisms, such as lower number of stomata, leaf area and RWL and higher RWC, to improve their performance under drought stress conditions.

REFERENCES

Acevedo, E. 1991. Improvement of winter cereal crops in Mediterranean environments. Use of yield, morphological and physiological traits. In Acevedo, E. (ed): *Physiology-Breeding of Winter Cereals for Stressed Mediterranean Environments.* Le Colloque No. 55, pp 273–305, INRA, Paris.

Ammar, K., Mergoum, M. & Rajaram, S. 2004. The history and evolution of triticale. In: Mergoum, M. & Mergoum H. (eds.): *Triticale Improvement and Production*. FAO, 2–9.

Araus, J. L. & Slafer, G. A. 2002. Plant breeding and drought in C3 cereals: what should we breed for? *Ann. Bot.* **89**, 225–240.

Arnon, D. I. 1949. Copper enzymes in isolated chloroplasts. Polyphenoloxidase in *Beta vulgaris*. *Plant Physiol***. 24**, 1–15.

Blum, A. 1989. Breeding methods for drought resistance. In Jones, H. G., Flowers, T. J. and Jones, M. B. (eds.), *Plant Under Stress*. Cambridge Univ Press, UK. pp. 197–216.

Blum, A. 2005. Drought resistance, water-use efficiency, and yield potential – are they compatible, dissonant, or mutually exclusive. *Aust. J. Agric. Res.* **56**, 1159–1168.

Bots, M & Mariani, C. 2005. Pollen viability in the field. Research report COGEM 2005–05. University of Nijmegen. The Netherlands.

Clarke, J. M & Townley-Smith, T. F. 1984. Screening and selection techniques for improving drought resistance. In Vose P. B. & Blixt S. G. (eds.) *Crop Breeding: A Contemporary Basis*. Oxford, UK. Pergamon Press, pp. 137–161.

Dencic, S., Kastori, R., Kobiljski, B. & Duggan, B. 2000. Evaluation of grain yield and its components in wheat cultivars and landraces under near optimal and drought conditions. *Euphytica* **113**, 43–52.

Golestani Araghi, S. & Assad, M. T. 1998. Evaluation of four screening techniques for drought resistance and their relationship to yield reduction ratio in wheat. *Euphytica* **103**, 293–299.

Inoue, T., Inanaga, S., Y. Sugimoto, An, P. & Eneji, A. E. 2004. Effect of drought on ear and flag leaf photosynthesis of two wheat cultivars differing in drought resistance. *Photosynthetica* **42**, 559–565.

Khatun, S. & Flowers, T. J. 1995. The estimation of pollen viability in rice. J. Exp. Bot. **46**: 151–154.

Lelley, T. 2006. Triticale: A low-input cereal with untapped potential. In: Singh, R. J. & Jauhar, P. P. (eds.) *Genetic Resources Chromosome Engineering and Crop Improvement*. Vol. 2: Cereals. Boca Raton (FL): CRC Press, Taylor & Francis Group, FL. pp. 395–430.

Liu, H. S &. Li, F. M. 2005. Root respiration, photosynthesis and grain yield of two spring wheat in response to surface soil drying. *Plant Growth Regul*. **45**, 149–154.

Ludlow, M. M. & Muchow, R. C. 1990. A critical evaluation of trait for improving crop yields in water-limited environments. *Adv. Agron.* **43**, 106–153.

Matin, M. A., Jarvis, H. B. & Hayden, F. 1989. Leaf water potential, relative water content, and diffusive resistant as a screening techniques for drought tolerance in barley. *Agron. J.* **81**, 100–105.

Mitchell, J. H., Siamhan, D., Wamala, M. H., Risimeri, J. B., Chinyamakobvu, E., Henderson, S. A. & Fukai, S. 1998. The use of seedling leaf death score for evaluation of drought resistance of rice. *Field Crops Res*. **55**, 129–139.

Morgan, J. M. 1984. Osmoregulation and water stress in higher plants. *Ann. Rev. Plant Physiol*. **35**, 299–319.

Muller, J. 1991. Determining leaf surface area by means of linear measurements in wheat and triticale (brief report). *Archiv Fuchtungsforsch.* **21**, 121–123.

Passioura, J. B. 1996. Drought and drought tolerance. In: Belhassen, E. (ed.) *Drought Tolerance in Higher Plants: Genetical, Physiological and Molecular Biological Analysis.* Kluwer Academic Publishers, Dordrecht. pp: 3–12.

Ritchie, S. W., Nguyen, H.T. & Holaday, A.S. 1990. Leaf water content and gas exchange parameters of two wheat genotypes differing in drought resistance. *Crop Sci.* **30**, 105–111.

Rizza, F., Badeck, F. W., Cattivelli, L., Lidestri, O., Fonzo Di, N., & Stanca, A. M. 2004. Use of a water stress index to identify barley genotypes adapted to rainfed and irrigated conditions. *Crop Sci*. **44**, 2127–2137.

Saini H. S & Aspinall, D. 1981. Effect of water deficit on sporogenesis in wheat (*Triticum aestivum* L.). *Ann. Bot.* **48**, 623-633.

SAS Institute. 2003. SAS/STAT User's Guide, Version 9**.** 1. SAS Institute, Cary. NC.

Sayar, R., Khemira, H., Kameli, A. & Mosbahi, M. 2008.Physiological tests as predictive appreciation for drought tolerance in durum wheat (*Triticum durum* Desf.). Agron. Res.. **6**: 79–90.

Schonfeld, M. A., Johnson, R.C., Carver B.F. & Mornhinweg, D. W. 1988. Water relations in winter wheat as drought resistance indicators. *Crop Sci*. **28**, 526–531.

Yang, R. C., Jana, S. & Clark J. M. 1991. Phenotypic diversity and associations of some potentially drought-responsive characters in durum wheat. *Crop Sci*. **31**, 1484–1491.