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Moisture stress tolerance in reproductive growth stages in triticale (X *Triticosecale* Wittmack) cultivars under field conditions

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Abstract

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To evaluate moisture-stress tolerance in reproductive growth stages in five triticale (Alamos83, Lasko, Moreno, Prego, and Zorro), one bread wheat (Roshan) and one durum wheat (Osta-Gata) cultivars, two field experiments were conducted in 2005-06 cropping season at Research Farm, Isfahan University of Technology, Lavarak, Njafabad, Iran. The genotypes were sown in two normal and moisture stress after mid-booting growth stage, conditions-using randomized complete block design with three replications in each moisture regimes. Agro-morphological traits including plant height, spike no. m^{-2}, grain $spike^{-1}$, grain weight $spike^{-1}$, 1000 grain weight, grain yield, biological yield and harvest index were measured and recorded. A significant and positive correlation was observed between grain yield and grain weight $spike^{-1}$ under both conditions. Triticale cultivars performed superior than wheat cultivars under both moisture conditions. Considering the grain yield potential, Alamos 83, Lasko, Moreno, and Zorro cultivars were ranked as the superior group of drought tolerant genotypes. Nevertheless, Moreno was identified as a triticale cultivar that could be grown under both normal and moisture stress conditions with high grain yield.

Key words: Triticale, Agronomic traits, Drought tolerance, Wheat, Grain yield.

Introduction

Drought is a serious problem for agriculture that reduces crop productivity. Therefore, improvement of drought tolerance in crop is a major objective of most crop breeding programs, particularly in arid and semi-arid areas of the world (Moustafa *et al.*, 1996). Dencic *et al.* (2000) reported that many morphological and physiological characteristics were affected by drought stress. Agronomic traits such as grain yield and its components are the major selection criteria for evaluating drought tolerance under field conditions. The number of grains per spike, grain weight per spike, 1000 grain weight and especially grain yield were more drought sensitive than plant height and number of spikelets per spike in wheat cultivars (Dencic *et al*., 2000). Guttieri *et al*. (2001) observed that moisture-deficit induced reduction in grain yield due primarily to reduction in grain weight, while the differential effect of moisture deficit on specific cultivars could be due to reduction in number of grains per spike.

Genetically, triticale (X *Triticosecale* Wittmack) is an amphiploid hybrid between the female parent wheat (*Triticum* ssp.) and the male parent rye (*Secale* ssp.) (Ammar *et al*., 2004). The objective in the synthesis of this new cereal crop was to combine the desirable characteristics of the two species, i.e. the quality, adaptation, plant type and grain characteristics of wheat with the high sink capacity, stress tolerance, disease resistance and superior nutritional quality of rye. Therefore, triticale is a widely adapted and robust cereal and is more productive than other cereals under abiotic stress conditions (Oettler, 2005). Pfeiffer (1993) suggested that under drought stress conditions and problematic soil regions, complete triticales show distinct yield superiority and appear to have adaptive advantages over wheat. Giunta *et al*. (1993) evaluated durum wheat and triticale genotypes under different moisture regimes in a typical Mediterranean climatic region and observed that grain yield of durum wheat reduced significantly under drought stress, while triticale had a slight and non-significant reduction in grain yield as compared to the irrigated control.

The objectives of this study were to evaluate moisture-stress tolerance in reproductive stage in triticale, bread wheat and durum wheat cultivars, and to determine the relationships among grain yield and yield components under normal and moisture stress field conditions.

Materials and Methods

Field experiments were carried out during 2005-06 cropping season at Research Farm of Isfahan University of Technology, Lavark, Najaf-Abad, Iran (32° 32′ N and 51° 23′ E, 1630m asl) with soil type of silty clay loam, pH=7.3-7.8, mean annual precipitation and temperature of 140 mm and 14.5°C, respectively. The plant materials consisted of five triticale cultivars: Alamos83 with the origin of CIMMYT; Lasko, Moreno, Prego and Zorro originated from Poland;

Roshan, a bread wheat cultivar, from Iran; and Osta-Gata, a durum wheat cultivar, from ICARDA. Based on a preliminarily laboratory experiment-using 80 CIMMYT and Poland originated triticale cultivars exposed to PEG at germination stage four tolerant and one sensitive (Alamos83) triticale cultivars were selected and used in this study (data not shown). Roshan is known as a drought-tolerant bread wheat cultivar in Iran. Osta-Gata was used as a drought-tolerant durum wheat cultivar based on a two-year field experiment conducted at four sites in central and western regions of Iran (Arzani, 2002).

The plant materials were grown in two separate experiments under two irrigation regimes including: 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 (moisture-stress). No precipitation was recorded during application of moisture-stress treatment. Each experiment was sown in a randomized complete block design with three replications. The moisture treatments were applied from mid-booting stage till physiological maturity. Each plot consisted of six rows of four meter length and 25 cm apart. Agro-morphological characteristics including: plant height, spike no. m^{-2}, grain no. $spike^{-1}$, grain weight $spike^{-1}$, 1000 grain weight, grain yield, biological yield and harvest index were measured and recorded. Plant height was measured using 20 randomly selected plants in each plot from ground to the tip of main spike at maturity. A sample of 20 plants was harvested from each plot to measure the yield components. Grain yield and biological yield (total above ground dry weight) were estimated by harvesting four middle rows of each plot. Harvest index (HI) was calculated as grain yield divided by biological yield.

Statistical analysis

Simple and combined analysis variances were performed for data using SAS software (SAS Institute, 2003). Each experiment was analyzed using randomized complete block design model. Mean comparisons were conducted using Fisher's (protected) least significant difference (LSD). Percentage of reduction in traits due to drought stress was calculated as followings:

$$C = \frac{\overline{X}ns - \overline{X}ds}{\overline{X}ns} \times 100 \quad \text{(Eq. 1)}$$

where $\overline{Xns}$ is the mean of trait in given cultivar under non-stress conditions and $\overline{Xds}$ is the mean of trait in given cultivar under drought stress conditions.

Analysis of correlation coefficient between grain yield and other characteristics was used to determine the principal components influencing final grain yield.

Stress susceptibility index (SSI) was calculated for each cultivar following Fischer and Maurer (1978):

$$S = (1\text{-}Yds/Yns)/(1\text{-}\overline{Yds}/\overline{Yns}) \quad \text{(Eq. 2)}$$

where Yds is the grain yield under stress, Yns is the grain yield under non-stress conditions, $\overline{Yds}$ is the average yield of all cultivars under stress and $\overline{Yns}$ is the average yield of all cultivars under non-stress conditions.

Results

Analysis of variance showed highly significant effects of moisture regimes on all the studied traits (Table 1). Irrigation regime × genotype interactions effect was also highly significant for all traits, suggesting different response of genotypes to each moisture environment conditions. Means of agro-morphological traits under normal and moisture stress conditions as well as reduction (%) in the concerned traits due to moisture stress are shown in Table 2.

Plant height ranged from 110.4 cm for Alamos83 to 138.5 cm for Roshan under non-stress conditions; however, plant heights were shorted under moisture stress conditions and ranged from 86.5 cm for Prego to 114.4 cm for Roshan (Table 2). The highest reduction (22%) in plant height due to moisture stress was observed in Prego cultivar (Table 2).

Roshan bread wheat cultivar produced the highest spike no. m^{-2} which was significantly higher than all cultivars under both conditions. On the other hand, Prego cultivar had the least spike no. m^{-2} under moisture stress conditions.

Grain no. $spike^{-1}$ ranged from 28.4 for Roshan to 52.7 for Moreno under non-stress conditions and ranged from 22.7 for Roshan to 35.6 for Lasko under moisture stress conditions.

Table 1. Combined analysis of variance for agro-morphological traits in triticale and wheat genotypes grown under two moisture regimes conditions.

S. O. V.	d.f.	MS							
		Plant height	**Spike no. m^{-2}**	**Grain no. spike^{-1}**	**Grain weight spike^{-1}**	**1000 grain weight**	**Biological yield**	**Grain yield**	**Harvest index**
Moisture regime (M)	1	2619**	347259**	1302.4**	6.58**	1104.9**	370.9**	151.62**	996.5**
Genotype (G)	6	598.7**	65829**	248.16**	0.19**	170.4**	5.74**	3.93**	76.8**
M × G	6	94.3**	21162**	43.73**	0.10**	10.01**	8.22**	2.55**	22.1**
Residual	24	1.99	412.1	0.61	0.01	1.49	0.45	0.13	3.59

* and**: Significant at the 0.05 and 0.01 probability level, respectively.

The decline (9.8%) in grain no. spike^{-1} in Alamos83 due to the moisture stress was significantly less than all other cultivars (Table 2).

Grain weight spike^{-1} ranged from 1.4 g for Roshan to 2.1 g for Moreno under non-stress conditions, and ranged from 0.9 g for Prego to 1.4 g for Alamos83 under moisture stress conditions. Alamos83 cultivar had greater grain weight spike^{-1} under moisture stress conditions and showed the least reduction in this trait. 1000 grain weight varied from 28.9 g to 45.6 g for Prego and Alamos83 cultivars under non-stress conditions, respectively. Under moisture stress conditions 1000 grain weight ranged from 22.3 g for Prego to 35.4 g for Alamos83 (Table 2).

Moreno, Zorro, Lasko and Prego triticale cultivars ranked as superior group for biological yield under non-moisture-stress conditions; however, Lasko and Alamos83 triticale cultivars included in the superior group under moisture stress conditions. The reduction (6.4%) in biological yield due to moisture-stress in reproductive stage in Alamos83 was significantly less than all other cultivars (Table 2).

Relative yield performance of genotypes in moisture stressed and more favorable environments seems to be a common starting point in identification of traits related to moisture tolerance and selection of parents for breeding for dry environments (Clarke *et al*., 1992).

Table 2. Mean of agro-morphological characteristics in triticale and wheat cultivars under non-moisture stress (NON) and moisture stress (MS) conditions and % reduction (R%).

Cultivars		Plant height (cm)	Spike no. m^{-2}	Grain no. spike^{-1}	Grain weight spike^{-1} (g)	1000 grain weight (g)	Biological yield (t ha^{-1})	Grain yield (t ha^{-1})	Harvest index (%)
Alamos83	NON	110.35d	506.67d	36.57f	1.8c	45.56a	19.7e	7.51c	38.13a
	MS	106.72c	378dc	32.97cb	1.36a	35.37a	18.45ab	5.71a	30.98a
	%R	3.29	25.4	9.84	24.44	22.37	6.35	23.97	18.75
Lasko	NON	122.13c	618.33c	50.9b	2.06ab	34.81c	24.71abc	8.62b	34.88c
	MS	110.08b	464b	35.57a	1.09bc	26.75c	18.89a	5.28a	28ab
	%R	9.87	24.96	30.12	47.09	23.15	23.55	38.75	19.72
Moreno	NON	111.82d	627.33c	52.7a	2.14a	35.44c	25.61a	9.53a	37.18ab
	MS	101.87d	467.33b	35.47a	1.10b	25.65c	17.9bc	5.27a	29.44ab
	%R	8.90	25.5	32.69	48.60	27.62	30.11	44.7	20.82
Prego	NON	110.83d	688.67b	45.03d	1.76c	28.93d	23.83bcd	8.44b	35.42c
	MS	86.47e	274e	34.33ab	0.89d	22.33d	16.28e	2.92d	18.06c
	%R	21.98	60.21	23.76	49.43	22.81	31.68	65.4	49
Zorro	NON	110.78d	624.00c	49.07c	2.08ab	39.39b	24.83ab	9.38a	37.72a
	MS	88.82e	410.00c	32.57c	1.02bcd	25.28c	16.78de	4.25bc	25.54b
	%R	19.82	34.29	33.63	50.96	35.82	32.42	54.69	32.29
Osta-Gata	NON	124.22b	516.67d	39.57e	1.89bc	43.98a	23.34cd	8.3b	35.55bc
	MS	109.7bc	338.00d	30.70d	1.15b	33.77a	17.42cd	4.54b	26.09b
	%R	11.71	34.58	22.42	39.15	23.22	25.36	45.3	26.61
Roshan	NON	138.45a	752.67a	28.40g	1.35d	43.64a	22.74d	6.41d	28.19d
	MS	114.4a	730a	22.67e	0.91cd	30.79b	17.47cd	3.63c	20.78c
	%R	17.37	3.01	20.18	32.59	29.45	23.18	43.37	26.29

Means, in each column for each moisture environment, followed by at least one letter in common are not significantly different at the 5% probability level- using Fisher's (protected) least significant difference (LSD).

Table 3. Correlation coefficients between grain yield and its components under non-stress (above diameter) and moisture stress conditions (below diameter).

	Grain no. spike^{-1}	Grain weight spike^{-1} (g)	Biological yield (t ha^{-1})	Grain yield (t ha^{-1})	Harvest index (%)
Grain no. spike^{-1}	1	0.92**	0.73^{ns}	0.95**	0.65^{ns}
Grain weight spike^{-1} (g)	0.34^{ns}	1	0.54^{ns}	0.94**	0.81*
Biological yield (t ha^{-1})	0.18^{ns}	0.65^{ns}	1	0.70^{ns}	0.04^{ns}
Grain yield (t ha^{-1})	0.40^{ns}	0.87**	0.86**	1	0.73^{ns}
Harvest index (%)	0.43^{ns}	0.88**	0.77*	0.98**	1

*and **: Significant at the 0.05 and 0.01 probability levels, respectively.
ns = Non-significant.

Grain yield ranged from 6.4 t ha^{-1} for Roshan to 9.5 t ha^{-1} for Moreno under non-stress conditions and varied from 2.9 t ha^{-1} to 5.7 t ha^{-1} for Prego and Alamos83 cultivars under moisture stress conditions. The lowest and highest reduction in grain yield due to moisture stress were also observed in Alamos83 (24%) and Prego (65.4%) cultivars, respectively (Table 2).

HI varied from 28.2% for Roshan to 38.1% for Alamos83 in normal conditions. However, HI varied from 18% for Prego to 31% for Alamos83, under moisture stress conditions (Table 2). Moisture stress had the least effect on HI in Alamos83 and Lasko.

Calculated correlation coefficients among the traits for both non-stress and moisture stress conditions are presented in Table 3. Significant and positive correlation coefficient ($r = 0.95^{**}$) was found between grain no. spike^{-1} and grain yield under non-stress conditions (Table 3). Grain yield also had significant and positive correlation ($r = 0.94^{**}$) with grain weight spike^{-1} under both moisture environment conditions. HI had the highest significant positive correlation coefficient ($r = 0.98^{**}$) with grain yield under moisture stress conditions (Table 3). The biological yield under moisture stress conditions had a significant positive correlation with harvest index ($r = 0.77^{*}$) and grain yield ($r = 0.86^{**}$). Grain no. spike^{-1} had a high, positive and significant correlation ($r = 0.92^{**}$) with grain weight spike^{-1} under non-stress conditions. Grain weight spike^{-1} had also positive and significant correlation with HI under both conditions (Table 3).

Results showed that Alamos83 was the most tolerant and Prego was the most sensitive cultivars to moisture stress considering the studied agro-morphological traits (Table 2). Stress susceptibility index (SSI) was used as a selection criterion of moisture tolerance in terms of minimization of yield reduction caused by moisture stress as compared with non-stress conditions. Calculated SSI varied in from 0.5 to 1.4 for Alamos83 and Prego, respectively (Table 4). Alamos83 and Prego triticale cultivars that had the lowest and highest SSI values were found to be the most tolerant and the most susceptible cultivars, respectively. This was in agreement with conclusions made based on agro-morphological characteristics.

Discussion

Moisture stress had the profound negative effects on agro-morphological traits. Reduction in plant height in wheat under drought stress was reported by Guttieri *et al*. (2001) and Dencic *et al*. (2000). The decrease in plant height under drought stress could be due to decrease in relative turgidity and dehydration of protoplasm which is associated with loss of turgor and reduced cell division and cell expansion (Bayoumi *et al*., 2008).

Table 4. Grain yield and stress susceptibility index (SSI) of triticale and wheat cultivars under normal (GY_{non}) and moisture stress (GY_{ms}) conditions.

Cultivars	GY_{non} (t ha^{-1})	GY_{ms} (t ha^{-1})	SSI
Alamos83	7.51c	5.71a	0.52
Lasko	8.62b	5.28a	0.85
Moreno	9.53a	5.27a	0.98
Prego	8.44b	2.92d	1.43
Zorro	9.38a	4.25bc	1.20
Osta-Gata	8.30b	4.54b	0.99
Roshan	6.41d	3.63c	0.95

Means, in each column, followed by at least one letter in common are not significantly different at the 5% probability level- using Fisher's (protected) least significant difference (LSD).

Drought susceptibility of a genotype is often measured as a function of the reduction in grain yield under drought stress (Blum, 1988); however, it could be confounded with differential yield potential of genotypes (Ramirez and Kelly, 1998).

Roshan bread wheat cultivar had the highest spike no. m^{-2} under both moisture conditions. On the other hand, Prego cultivar had the lowest spike no. m^{-2} under drought stress conditions. This finding is in agreement with report by Sweeny *et al*. (1992) who showed that triticale was superior to wheat for yield components except for spike no. m^{-2}.

Grain no. $spike^{-1}$ decreased under moisture stress conditions. Probably water deficit caused male sterility which may in turn reflected in abortion of terminal and basal florets; hence, reduction in grain no. $spike^{-1}$ (Saini and Aspinall, 1981). In durum wheat Garcia del Moral *et al*. (2005) observed 18.5% of reduction in grain no. $spike^{-1}$ due to the negative effect of moisture stress. In spring wheat, Du *et al*. (2006) observed that reduction in grain yield due to water deficit was mainly attributed to reduction in grain no. $spike^{-1}$. Grain no. $spike^{-1}$ has been proposed as an important selection criterion for drought tolerance (Shpiler and Blum, 1991). Average grain no. $spike^{-1}$ in triticale cultivars was significantly superior to Roshan wheat cultivar under both moisture environmental conditions. Furthermore, triticale cultivars also had significantly higher grain no. spike^{-1} than Osta-Gata durum wheat cultivar under moisture stress conditions.

Grain weight spike^{-1} decreased under moisture stress conditions. Ercoli *et al*. (2008) reported that the reduction of grain yield by severe post-anthesis moisture stress in durum wheat was associated with decrease in grain weight. Guttieri *et al*. (2001) reported that although grain weight spike^{-1} was not reduced in moderate moisture deficit, but it was reduced by 18% in severe moisture deficit conditions. Riaz and Choudhry (2003) also reported that genotypes with high 1000 grain weight under irrigated conditions may not be superior for this trait under moisture stress conditions. This is possible due to the limitation of moisture which forces plant to complete its grain filling in relatively shorter duration.

Triticale cultivars, Moreno, Zoro, Lasko and Prego, had higher grain yield under normal conditions. Alamos83, Lasko and Moreno triticale cultivars also ranked as the superior group for grain yield under water-deficit conditions. Therefore, it could be concluded that overall triticale cultivars performed superior than wheat cultivars under both conditions. This finding was consistent with the report by Sweeney *et al*. (1992) who observed greater (19%) grain yield of triticale than bread wheat. The most single important grain yield component, contributed to superior performance of triticale cultivars, was grain no. spike^{-1}. Reduction in grain yield in barley under moisture stress was reported by Krcek *et al*. (2008). They reported that when moisture stress was applied during shooting or heading stages, grain yield declined by greater than 50% in comparison with optimal moisture conditions.

Significant and positive correlation coefficient was found between grain no. spike^{-1} and grain yield ($r = 0.95^{**}$) under non-stress conditions. Similar finding were reported by other researchers (Okuyama *et al*., 2004; Arzani, 2002). HI also had the highest significant positive correlation coefficient ($r = 0.98^{**}$) with grain yield. This finding is in agreement with report of Abdalla and Trethowan (1990) who found a strong correlation between grain yield and HI under severe moisture stress conditions in triticale. This is expected since the improvement of HI leads to more efficient redistribution of dry matter into grain and in turn increases grain yield (Madic *et al*., 2005). Therefore, HI can be used as an indirect selection criterion for improving grain yield in cereals under moisture stress conditions. The biological yield under moisture stress conditions had a significant positive correlation with harvest index and grain yield. Similar results were reported by Okuyama *et al*. (2004). Significant and positive correlations of grain weight spike^{-1}, biological yield and harvest index with grain yield under moisture stress conditions indicated that these traits are adaptive traits for moisture stress tolerance.

Alamos83 and Prego triticale cultivars that had the lowest and highest SSI values were found to be the most tolerant and susceptible cultivars, respectively. Cultivars with low SSI values are moisture resistant because they have lesser reduction in grain yield under stress compared with non-stress conditions. Nevertheless, this index per se appears to have serious limitations for the quantification of genotype reaction to moisture conditions, because it is based on minimizing yield reduction in stress compared with non-stress conditions. Therefore, selection for low SSI would tend to reduce yield in non-stress conditions (Dencic *et al*., 2000). Ozkan *et al*. (1999) characterized triticale genotypes with the least SSI using twenty genotypes and emphasized that the tolerant genotypes had not necessarily high grain yield. However, triticale genotypes identified as the stress tolerant by SSI may have tolerance mechanisms, and can be used as sources of drought stress resistance in triticale breeding programs for development of secondary triticale germplasm with high grain yield potential.

It is concluded that triticale cultivars performed superior than wheat cultivars under both moisture environment conditions. Considering the grain yield potential, Alamos83, Lasko, Moreno, and Zoro cultivars were ranked as the superior group of drought tolerant triticale genotypes. Nevertheless, Moreno was identified as a triticale cultivar that could be grown under both normal and moisture stress conditions with high grain yield.

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