International Journal of Farming and Allied Sciences
Available online at www.ijfas.com
©2013 IJFAS Journal-2013-2-24/1185-1191
ISSN 2322-4134 ©2013 IJFAS

Study on tolerance to terminal drought stress of bread wheat genotype using indices for susceptibility and tolerance to stress

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ABSTRACT: In order to study the response of bread wheat (Triticum aestivum L.) to drought stress, two experiments were conducted in Research Station of Islamic Azad University, Ardabil Branch, in 2007-08 and 2008-09 cropping years. 6 wheat genotypes were evaluated during two experiments conducted under normal irrigation or non-stressed and terminal drought stressed conditions, based on randomized complete blocks design, with three replications. Results from combined analysis of variance based on grain yield trait showed that year proved significantly effective both under normal irrigation and drought stress conditions. Interaction of "genotype × year" was insignificant under both normal irrigation and drought stress conditions. Genotypes also proved significantly effective under normal irrigation, at 1% probability level, which put it in contrast with drought stress condition. Indices such as Stress tolerance index (STI), stress susceptibility index (SSI), tolerance index (TOL), mean productivity (MP) and geometric mean productivity (GMP) were calculated for various genotypes based on grain yield under both non-stressed and stressed conditions. Genotype 4057 was the most desirable among all 6 genotypes being studied. Grain yield of this genotype was 4.087 ton/ha under non-stressed condition, whereas its grain yield under stressed condition was 2.83 ton/ha. Mean productivity and geometric mean productivity were estimated to be 3.465 and 3.41 ton/ha, respectively, whereas values for drought tolerance index and drought susceptibility index of the genotypes were estimated to be 1.16 and 1.42, respectively. Pearson correlation coefficients used to identify the relation between grain yield and indices, revealed that indices such as MP, GMP and STI were significantly and positively correlated with grain yield under both conditions, which can be used to identify productive and drought tolerant genotypes for both environmental conditions. In general, 4057 was identified as tolerant genotype, whereas Saratovskaya-29 was identified as the most susceptible to terminal drought stress.

***Keywords*:** wheat, drought stress, indices of susceptibility and tolerance to stress

INTRODUCTION

Wheat farming is practiced under a vast expanse of climatic condition and geographical areas and due to its high adaptability to diverse climatic conditions, it dominates more arable land than any other plant species and is considered as staple food for a great part of world's ever-increasing population (Jalal-Kamali, 2008). Apart from being important commercially, it is also an increasingly functional tool in political and international relations all around the world. Although Iran boasts nearly 1% of world population, it consumes roughly 2.5% of wheat produced worldwide. Wheat is a strategic good like energy and considered one of the most important indices for agriculture (Akbari et al., 2010). Unfortunately, drought stress, as one of the most important and dominant environmental stresses, has been challenging its production and decreasing its yield in semiarid and drought stress areas. According to Ambrejeh, a region with an annual precipitation of 20 to 450mm should be referred to as semiarid (Rajaram and Vanginkel, 1996). Almost 32% of arable lands under wheat cultivation in developing countries experience one or more types of drought stress during growth season (Rajaram and Vanginkel, 1996). Blum (1988) believes that environmental stresses occur on the field mainly as the result of limitation of such factors as water, nutrients and heat. Stress can range from very low to very high in intensity while its level of intensity associates with the amount of energy involved in changing processes within biological system.

According to Fischer and Maurer (1978) production of drought tolerant cultivars involves two stages. In first stage, cultivars are screened intensively and quickly based on grain yield under water stress, while in the second stage the remaining samples are screened based on important morpho-physiological traits associated with yield and traits effective on tolerance to drought.

Ehdaei et al. (1988) argued that old wheat cultivars that are characteristically drought tolerant produce more yield than new short cultivars, though they have lower yield potential. Results from studies conducted by Slafer and Araus (1998) indicated that wherever crop production is in danger of terminal drought, the best strategy to increase harvest index and grain yield is to select cultivars and lines with high growth potential, which are capable of proceeding to reproductive stage from vegetative growth stage under higher availability of moisture in the soil. These cultivars or lines have more time opportunity to use moisture reserve in the soil before the terminal drought can occur.

Genotypes may fall into four groups based on their response to stressed and non-stressed environmental conditions (Fernandez, 1992):

Group A: genotypes producing good yield in both stressed and non-stressed environments.
Group B: genotypes producing good yield only in non-stressed environment.
Group C: genotypes producing good yield in stressed environment.
Group D: genotypes producing low yield in both stressed and non-stressed environments.

Various indices have been proposed for evaluating response of genotypes under various environmental conditions and determining the tolerance and susceptibility of the genotypes. The best selection criterion is one that can distinguish group A from other three groups. Rosielle and Hamblin (1981) introduced Tolerance (TOL) and Mean Productivity (MP) indices. High values for TOL give an indication of genotype's susceptibility to stress, curiously the selection of genotypes is done based on lower values of TOL and higher values of MP. It is possible to distinguish genotypes of group B from those of C by using MP and TOL indices and Fernandez (1992) classification. Fischer and Maurer (1978) proposed Stress Susceptibility Index (SSI). Low SSI value indicates that yield variations of a given genotype is less under stressed condition than under non-stressed condition and is a result of higher stability of that genotype. It is possible to distinguish genotypes of groups B and C from those of other groups by using SSI index and Fernandez (1992) classification.

Fernandez (1992) introduced Stress Tolerance Index (STI). Genotypes with higher stability based on this index, have higher STI values. Thus, it is expectedly possible to distinguish genotypes of group A from those of other groups by using this index. Narayan and Misra (1989) after conducting an experiment to investigate drought tolerance of wheat varieties in both stressed and non-stressed conditions found that SSI had a positively significant correlation with yield under non-stressed condition ($r = 0.71^{**}$). Ehdaei et al. (1988) in a study on some landraces and advanced vernal wheat varieties under stressed environment aiming to investigate responses to these stresses concluded that landraces had no difference with advanced varieties in terms of mean susceptibility index. They also reported a negative correlation as much as $r = -0.84^{**}$ between SSI and grain yield under stressed condition. In this experiment, SSI and Yp (grain yield under non-stressed condition) did not produce a significant correlation. Nourmand Moayyed (1997) in a study conducted to investigate the variation of qualitative traits and to determine the best drought tolerance indices for bread wheat, reported that the correlation between SSI and Yp (grain yield under non-stressed condition) was positively significant ($r = 0.43^{**}$), whereas the correlation between SSI and Ys (yield under stressed condition) was negatively significant ($r = -0.56^{**}$). Study on correlations between indices of drought tolerance and yield under both stressed and non-stressed conditions showed that Geometric Mean Productivity (GMP) and STI are efficient indices.

This aim of this study is three folded: 1– Response of bread wheat genotypes to terminal drought stress; 2– Identifying the best evaluation index or indices; and 3– Identifying stress tolerant genotypes.

MATERIALS AND METHODS

This study was conducted in order to investigate terminal drought tolerance in bread wheat genotypes at research station of Islamic Azad University, Ardabil Branch, located at Hasan-barough (5km west of Ardabil) in 2007-08 and 2008-09 cropping years. Six bread wheat genotypes including three genotypes namely Gascogene, Sabalan, 4057 provided from natural resource and agricultural research center of Ardabil Province and three others namely Ruzi-84, Gobustan and Saratovskaya-29 provided by agricultural institute of Azerbaijan Republic were evaluated under non-stressed and terminal drought stress conditions based on randomized complete blocks design with three replications. Each experimental plot included 3, 3 meters long rows recurring 20cm from each other. Amount of seed usage was based on 450 seeds per 1m2 and weight of 1000 grains for each variety, which were sown in late October. Irrigation was done traditionally, which included two autumnal and three vernal irrigations. In treatments under drought stress, two times of irrigations were deleted after anthesis. No chemical or toxic fertilizer was applied during the experiment to deal with weeds, whereas throughout growth stages from tillering to grain-filling, weed control was done either mechanically or manually. The field was under a wheat-fallow rotation. Cultivation on the field before plantation included plowing after harvest of preceding crop, two times disking, two times cultivation with leveler and furrowing. It should be mentioned that after applying stress, there was no effective rainfall in either of years. After maturity and harvest of the crop, grain yield of the varieties was measured under both conditions (non-stressed and stressed) and combined analysis of variance for data was run based on statistical standards of the design for both experimental conditions in order to identify the effects of year and genotypes and interaction of “genotype × year”.
Evaluation of the genotypes, in terms of their tolerance to drought, by using the indices, was done as follow:

$$MP = (Y_{Pi} + Y_{Si}) / 2 \qquad GMP = \sqrt{Y_{Pi} \times Y_{si}} \qquad STI = (Y_{Pi} \times Y_{Si}) / Y_p^2$$

$$TOL = (Y_{Pi} - Y_{Si}) \qquad SSI = (1-(Y_{si}/Y_{pi})) / SI \qquad SI = 1- (Y_s/Y_p)$$

Where, Ypi is grain yield of each genotype under non-stressed condition; Ysi is grain yield under stressed condition; Ys is mean yield of genotypes under stressed condition and Yp is mean yield of genotypes under non-stressed condition.

Simple correlation coefficients between grain yield (under both conditions) and the indices were estimated. SPSS-16, Minitab-15 and MSTAT-C software were used to do statistical calculations.

RESULTS AND DISCUSSION

Table 1 shows the results of combined analysis of variance on grain yield under normal and drought stress conditions for 2007-08 and 2008-09 cropping years. Year proved significantly effective under both normal irrigation and drought stress conditions. Interaction of “genotype × year” was insignificant under both normal irrigation and drought stress. Effect of genotypes was significant under normal irrigation condition at 1% probability level, and this suggests that there was a significant difference between the genotypes and that they have varied in their genetic potential of responding to increased grain yield. However, this was not the case under drought stress condition. In fact, there was a significant difference between the genotypes under normal irrigation.

Table1. Combined analysis of variance for grain yield in normal and drought stress condition in different Year in 2008-2009 & 2009-2010 seasons

S.O.V	d.f	MS	
		Normal	Drought stress
Year	1	15.748**	4.403**
Rep / Year	4	0.657	1.113
Genotype	5	2.135**	0.456ns
Genotype × Year	20	0.357ns	0.131ns
Error	36	0.296	0.396
C.V.%			

ns and *, ** : Not significant and significant 5 , 1% probability levels, respectively

Ahmadi et al. (2000), Parvizi Almani et al. (1997), Aflatouni and Daneshvar (1993), Abdemishani and Jafari Shabestari (1988) and Ehdaei (1995) in their study have reported the effect of genotype as significant under drought stress condition.

Interaction of "genotype × year" was not found significant either under normal irrigation or drought stress and this suggests that the genotypes did not produce different responses during the years of study and mean grain yield did not vary by year. Mean yield of the genotypes was 3.15ton/ha under normal irrigation in both years, whereas it was 2.47ton/ha under stressed condition, i.e. stress has decreased grain yield by 21.59% (Figure 1). Under non-stressed conditions, genotypes such as 4057 (4.087ton/ha) and Ruzi-84 (3.225ton/ha) had the highest and lowest yields, respectively, whereas under terminal drought stress condition, 4057 (2.83ton/ha) and Sabalan (2.71ton/ha) had the highest and lowest yields, respectively (Table 2).

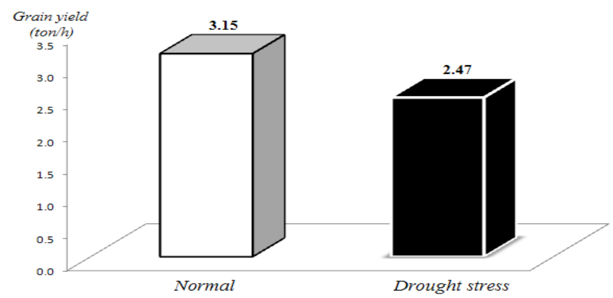

Figure 1 . mean yield of the genotypes under normal irrigation and drought stress conditions in 2007-08 and 2008-09 cropping years

In Table 2, in addition to mean grain yield (under two conditions), 5 indices have been calculated to estimate drought tolerance of the genotypes. Figure 2 shows the classification of genotypes based on grain yield under both non-stressed and terminal drought stress conditions. In addition, Figures 3-6 show grain yield variation by indices (under both experimental conditions). Based on values of MP, GMP and STI for genotypes, selection based on this criterion leads to selection of high yielding genotypes under both conditions. Other authors also reported this characteristic for the mentioned indices (Rosielle and Hamblin, 1981; Nourmand, 1997). Genotype 4057 was designated as the best genotype in terms of indices such as MP, GMP and STI (Table 2 and Figs. 3, 4 and 7). This genotype produced the highest yields both under non-stressed (4.10 ton/ha) and stressed (2.83 ton/ha) conditions. Genotypes such as Sardari and Ruzi-84, which had higher yield under non-stressed and stressed conditions, produced higher values for MP, GMP and STI than others (Table 2 and Figs. 3, 4 and 7).

Table 2. Estimates of stress tolerance of wheat genotypes based on mean yield of two years under non-stress and post anthesis drought stress conditions

Genotypes	Yp	R	Ys	R	MP	R	GMP	R	TOL	R	SSI	R	STI	R
1	2.92	5	2.29	5	2.61	5	2.59	5	0.63	3	0.99	4	0.67	5
2	3.32	2	2.71	2	3.02	2	2.99	2	0.61	2	0.84	2	0.90	2
3	4.10	1	2.83	1	3.47	1	3.41	1	1.27	6	1.42	6	1.17	1
4	3.26	3	2.48	3	2.87	3	2.84	3	0.78	5	1.10	5	0.81	3
5	3.07	4	2.43	4	2.75	4	2.73	4	0.64	4	0.96	3	0.75	4
6	2.26	6	2.07	6	2.17	6	2.16	6	0.19	1	0.39	1	0.47	6
Mean	3.15	-	2.47	-	2.81	-	2.79	-	0.69	-	0.95	-	0.8	-

Yp: Yield in normal condition
Ys: Yield in stress condition
SSI : Stress Susceptibility Index
STI :Stress Tolerance Index
TOL : Tolerance
MP : Mean Productivity
GMP : Geometric Mean Productivity
R : Rank

Study on TOL suggests that genotypes with high yield did not exhibit an optimal tolerance against humidity stress, for instance genotypes such as Saratovskaya-29 had the highest tolerance to drought (minimum TOL) followed by Ruzi-84, however they didn't produce an efficient yield under non-stressed condition. Saratovskaya-29 also was the best genotype in terms of SSI (Figure 5). In contrast, genotypes such as 4057 and Ruzi-84, which produced optimal yield under both conditions, did not produce efficient TOL and SSI (Table 2 and Figs. 2, 5 and 6).

Correlation coefficients of indices with grain yield under terminal drought stress and non-stressed conditions have been given in Table 3. Correlation coefficient between grain yield under stressed condition (Ys) and grain yield under non-stressed condition (Yp) was positively significant (r = 0.948**). Yield under stressed condition (Ys) was positively and significantly correlated with indices such as MP, GMP, TOL and STI, at 5 and 1% probability levels; however it produced a positively insignificant correlation with SSI. Grain yield under non-stressed condition (Yp) produced a positively significant correlation with all the indices (Table 3).

Table 3. Correlation coefficient between tolerance and susceptibility indices, Yp and Ys in 6 genotypes in two years under non-stress and post anthesis drought stress conditions

	Yp	Ys	MP	GMP	TOL	SSI
Ys	0.948**	1				
MP	0.995**	0.976**	1			
GMP	0.994**	0.977**	1**	1		
TOL	0.968**	0.838*	0.938**	0.935**	1	
SSI	0.923**	0.776	0.887*	0.885**	0.972**	1
STI	0.992**	0.974**	0.997**	0.997**	0.935**	0.868*

ns and *, ** : Not significant and significant 5 , 1% probability levels, respectively

MP index tends to increase yield potential and in most of the yield tests the correlation between MP and Ys was positive (Rosielle and Hamblin, 1981). MP index produced the highest correlation coefficient with grain yield under non-stressed condition, followed by STI and then GMP indices, however under stressed condition GMP produced the highest correlation coefficient with grain yield, followed by MP and then STI indices. Results from this study are consistent with those reported by other authors (Fernandez, 1992, Nourmand, 1997; Ahmadi, 1999).

Based on Table 2 and Figs. 3, 4 and 7 all the genotypes were classified in one group with respect to mean productivity (MP), geometric mean productivity (GMP) and stress tolerance index (STI). Furthermore, these indices produced a positively significant correlation with grain yield under both non-stressed and drought stress conditions. Thus, the abovementioned three indices are efficient for evaluation of drought tolerance of genotypes.

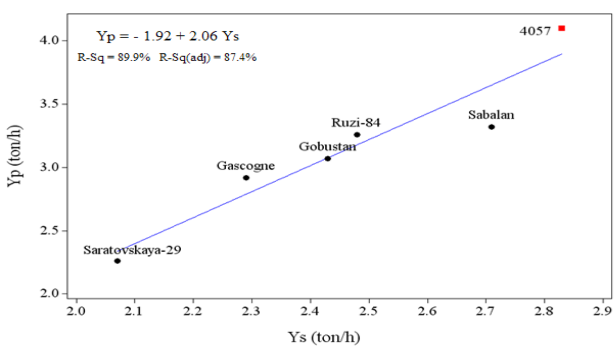

Figure 2 . classification of genotypes based on grain yield under non-stressed (Yp) and terminal drought stress (Y_s) conditions

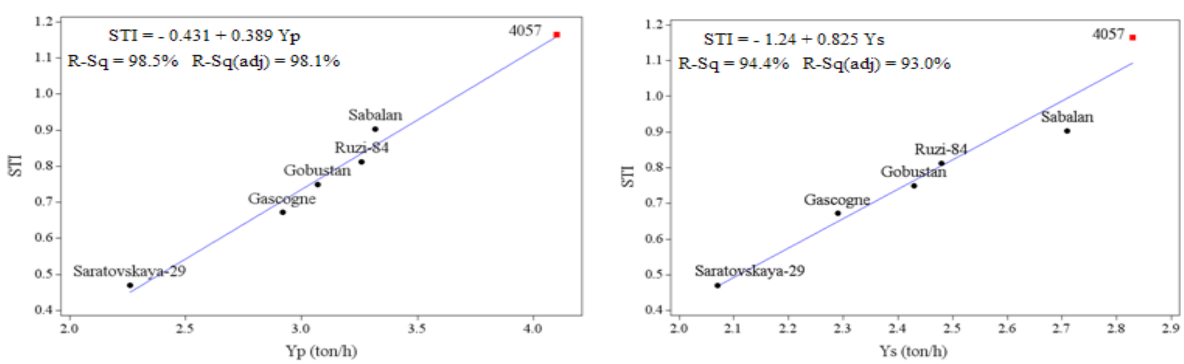

Figure 3 . Variations of STI and grain yield under non-stressed and terminal drought stress conditions in various wheat genotypes

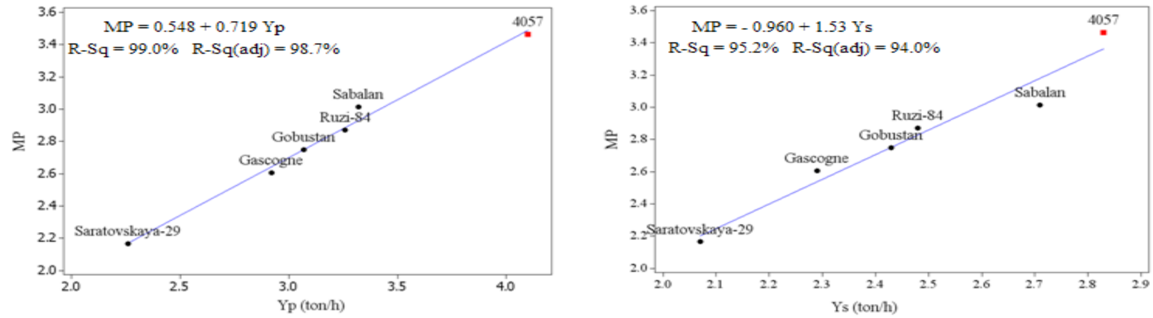

Figure 4 . Variations of MP index and grain yield under non-stressed and terminal drought stress conditions in various wheat genotypes

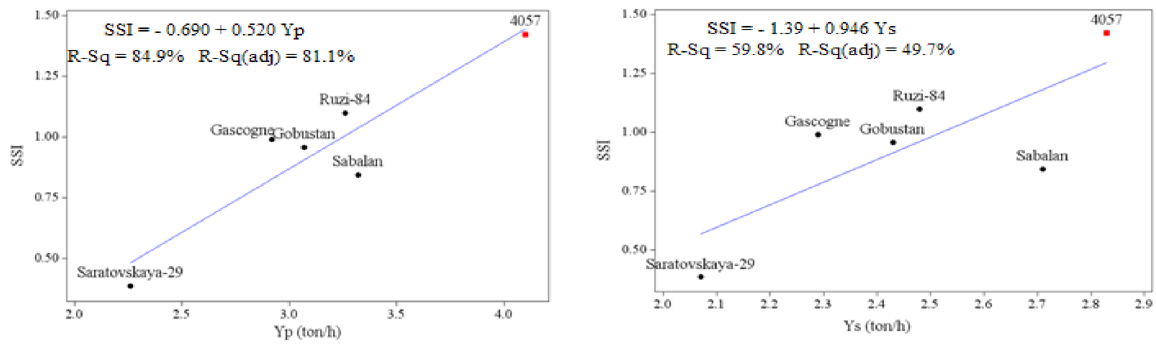

Figure 5 . Variations of SSI and grain yield under non-stressed and terminal drought stress conditions in various wheat genotypes

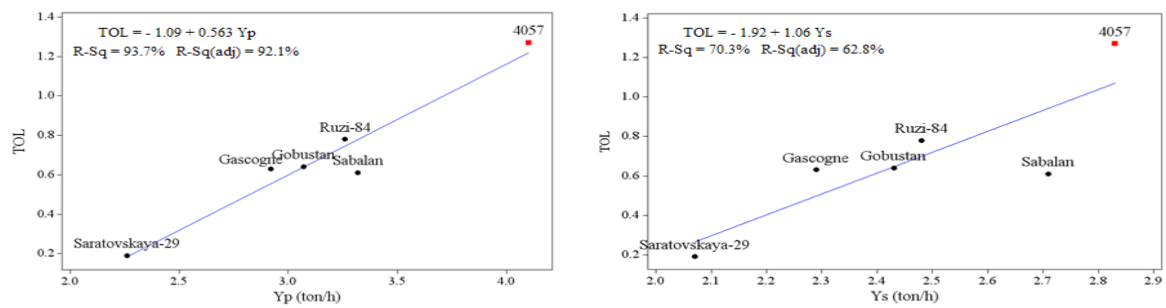

Figure 6 . Variations of TOL and grain yield under non-stressed and terminal drought stress conditions in various wheat genotypes

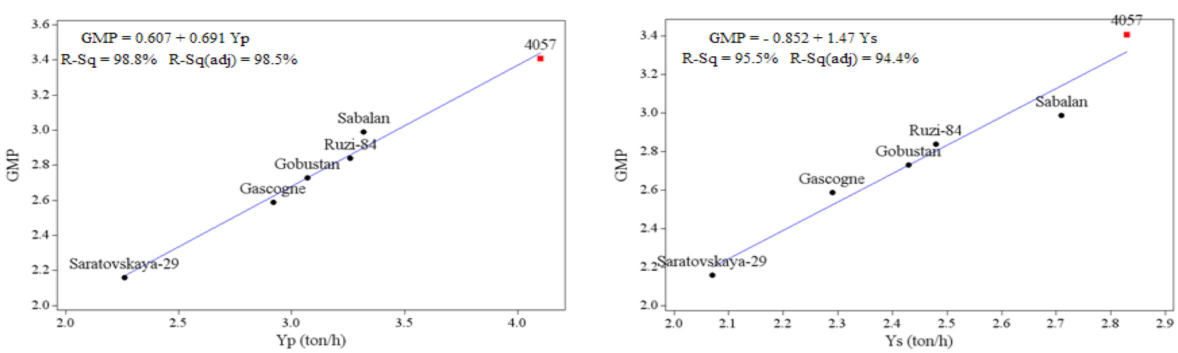

Figure 7 . Variations of GMP index and grain yield under non-stressed and terminal drought stress conditions in various wheat genotypes

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