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Evaluation of drought Tolerance Indices in Dryland Bread wheat Genotypes under Post-Anthesis drought Stress

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***Abstract*—**Post-anthesis drought stress is the most important problem affecting wheat production in dryland fields, specially in Mediterranean regions. The main objective of this research was to evaluate drought tolerance indices in dryland wheat genotypes under post-anthesis drought stress. The research was including two different experiments. In each experiment, twenty dryland bread wheat genotypes were sown in a randomized complete blocks design (RCBD) with three replications. One of experiments belonged to rain-fed conditions (post-anthesis drought stress) and other experiment was under non-stress conditions (with supplemental irrigation). Different drought tolerance indices include Stress Tolerance (Tol), Mean Productivity (MP), Geometric Mean Productivity (GMP), Stress Susceptibility Index (SSI), Stress Tolerance Index (STI), Harmonic Mean (HAM), Yield Index (YI) and Yield Stability Index (YSI) were evaluate based on grain yield under rain-fed (Ys) and supplemental irrigation (Yp) environments. G10 and G12 were the most tolerant genotypes based on TOL and SSI. But, based on MP, GMP, STI, HAM and YI indices, G1 and G2 were selected. STI, GMP and MP indices had high correlation with grain yield under rain-fed and supplementary irrigation conditions and were recognized as appropriate indices to identify genotypes with high grain yield and low sensitivity to drought stress environments.

***Keywords*—**Dryland wheat, Supplemental irrigation, Tolerance indices

I. INTRODUCTION

WHEAT (*Triticum aestivum* L.) is the most important cereal crop in the world. World's wheat production was about 650 million tones in 2010 [1]. Iran is ranked 12th in world wheat production [1 , 2]. According to recent statistics, wheat was cultivated more than seven million ha and total wheat production was about 15 million tones in Iran, during 2009-2010 [3].

In Iran, wheat crop is usually sown as mono-crop and area under rain-fed conditions is more than 60% of total area under wheat cultivation. In west provinces of Iran such as Kermanshah province, more than 80% of the wheat cultivating area is under rain-fed [3].

Rain-fed regions locally called as 'Daim' areas, which are characterized by low yields and severe water shortage conditions. In these areas, rainfall decreases and soil evaporation increases in spring when winter cereal crops enter to the grain filling period. So, these crops usually experience water deficit and heat stress during grain filling growth and development [4]. To improve the livelihoods of the farmers of the rain-fed areas, it is necessary to introduce new high yielding wheat varieties which are resistant to post-anthesis drought stress.

Drought stress is the most significant environmental factor to impact on growth and yield of crops and it affects 40 to 60% of the world's agricultural lands [5].

To evaluate response of plant genotypes to drought stress, some selection indices has been proposed based on a mathematical relation between stress and optimum conditions [6, 7, 8].

Drought indices which provide a measure of drought based on loss of yield under drought conditions in comparison to normal conditions have been used for screening drought tolerant genotypes [9]. These indices are either based on drought resistance or susceptibility of genotypes [8].

Drought resistance is defined by Hall (1993) as the relative yield of genotype compared to other genotypes subjected to the same drought stress [10]. Drought susceptibility of a genotype is often measured as a function of the reduction in yield under drought stress [11]. Rosielle and Hamblin (1981) defined stress tolerance (TOL) as the differences in yield between the stress and non-stress environments and mean productivity (MP) as the average yield under stress and non-stress environments [6]. Fischer and Maurer (1978) proposed a stress susceptibility index (SSI) of the cultivar [12]. Fernandez (1992) defined a new advanced index (STI = Stress tolerance index), which can be used to identify genotypes that produce high yield under both stress and non-stress conditions [8]. Other yield based estimates of drought resistance are geometric mean (GM), Mean productivity (MP) and TOL. The Geometric mean is often used by breeders interested in relative performance since drought stress can vary in severity in field environment over years [13].

In present study, drought tolerance in twenty genotypes of dryland bread wheat was investigated under post-anthesis drought stress conditions based on drought tolerance indices.

II. MATERIALS AND METHODS

This research carried out at campus of Agriculture and Natural Resources, Razi University, Kermanshah, Iran. The Campus of Agriculture and Natural Resources Located in the west of Iran (34º20' N latitude, 47º20' E longitude, elevation 1351 m above see level) in the moderate-cold and semiarid zone.

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TABLE I
DROUGHT TOLERANCE INDICES

Index	Formula	Reference
Stress Tolerance	$TOL = Yp - Ys$	Rosielle and Hamblin [6]
Mean Productivity	$MP = (Yp + Ys) / 2$	Rosielle and Hamblin [6]
Geometric Mean Productivity	$GMP = (Yp * Ys)^{0.5}$	Fernandez [8]
Stress Susceptibility Index (Stress Index)	$SSI = [(1 - (Ys / Yp)] / SI$ $SI = 1 - (\tilde{Y}s / \tilde{Y}p)$	Fischer and Maurer [12]
Stress Tolerance Index	$STI = (Yp * Ys) / (\tilde{Y}p)^2$	Fernandez [8]
Harmonic Mean	$HAM = [2 * (Yp * Ys)] / (yp + Ys)$	Kristin *et al.*, [14]
Yield Index	$YI = Ys / \tilde{Y}s$	Lin *et al.*, [15]
	$YSI = Ys / Yp$	Bouslama and Schapaugh [16]

Yp and Ys: Grain yield of each genotype under non-stress and stress conditions, respectively.
$\tilde{Y}p$ and $\tilde{Y}s$: Mean grain yield of all genotypes under non-stress and stress conditions, respectively

TABLE II
ANALYSIS OF VARIANCE FOR GRAIN YIELD UNDER NON-STRESS (YP) AND STRESS (YS) CONDITIONS AND DIFFERENT DROUGHT TOLERANCE INDICES IN TWENTY GENOTYPES OF DRYLAND BREAD WHEAT (MEAN SQUARES)

Source of variations	Degree of freedom	Yp	Ys	TOL	MP	GMP
Replication	2	2978.951	44.180	2383.466	915.699	837.863
Genotype	19	11901.131 *	6004.071 **	11451.124 *	6089.820 **	5874.964 **
Error	38	5353.894	2107.709	6106.812	2204.099	2015.889
Total	59					

THE CONTINUATION OF TABLE II

Source of variations	Degree of freedom	SSI	STI	HAM	YI	YSI
Replication	2	0.275	0.011	764.501	0.0001	0.016
Genotype	19	0.831 *	0.094 **	5776.386 **	0.055 **	0.048 *
Error	38	0.432	0.033	1906.39	0.019	0.025
Total	59					

Ns, * and **: Non-significant, significant at 5 and 1 % probability levels, respectively.

TABLE III
MEAN COMPARISONS OF GRAIN YIELD UNDER NON-STRESS (YP) AND STRESS (YS) CONDITIONS AND DIFFERENT DROUGHT TOLERANCE INDICES IN TWENTY GENOTYPES OF DRYLAND BREAD WHEAT

Genotype	Yp ($g.m^{-2}$)	Ys ($g.m^{-2}$)	TOL	MP	GMP
1	479.9 a-d	427.6 a	52.2 abc	453.7 a	452.7 a
2	515.3 ab	383.8 abc	131.4 abc	449.5 a	442.7 ab
3	384.6 b-e	300.1 cde	84.5 abc	342.4 cde	339.6 def
4	369.1 cde	251.9 e	117.2 ab	310.5 de	304.6 ef
5	487.1 a-d	310.9 cde	176.1 ab	399.0 a-d	389.0 a-e
6	432.7 a	358.0 a-d	174.6 ab	445.3 ab	434.9 abc
7	455.5 a-d	282.5 de	173.0 ab	369.0 a-e	357.7 b-f
8	364.4 cde	293.7 cde	70.7 abc	329.0 cde	327.0 def
9	311.7 e	283.2 de	28.4 bc	297.5 e	294.8 f
10	355.6 de	354.4 a-d	1.1 c	355.0 b-e	351.4 c-f
11	366.3 cde	319.3 b-e	47.0 bc	342.8 cde	341.6 def
12	411.8 a-e	401.2 ab	10.6 c	406.5 abc	406.4 a-d
13	474.9 a-d	338.1 b-e	136.7 abc	406.5 abc	400.0 a-d
14	487.4 a-d	276.2 de	211.1 a	381.8 a-e	365.9 a-f
15	410.0 a-e	332.4 b-e	77.6 abc	371.2 a-e	368.8 a-f
16	435.4 a-e	362.4 a-d	72.9 abc	398.9 a-d	396.8 a-d
17	441.6 a-e	359.0 a-d	82.5 abc	400.3 a-d	397.4 a-d
18	503.2 abc	337.2 b-e	166.0 ab	420.2 abc	409.2 a-d
19	384.8 b-e	300.7 cde	84.1 abc	342.8 cde	355.3 def
20	494.3 a-d	317.6 b-e	176.7 ab	405.9 abc	396.1 a-d

Mean followed by the same letter(s) in each column are not significantly different according to Duncan’s Multiple Range Test ($p < 0.05$).

THE CONTINUATION OF TABLE III

Genotype	SSI	STI	HAM	YI	YSI
1	0.445 bcd	1.09 a	451.6 a	1.29 a	0.89 abc
2	1.003 a-d	1.04 ab	436.0 ab	1.16 abc	0.75 a-d
3	0.889 a-d	0.62 def	336.8 def	0.91 cde	0.78 a-d
4	1.323 abc	0.50 ef	298.8 ef	0.76 e	0.68 bcd
5	1.500 ab	0.81 a-f	379.2 a-e	0.94 cde	0.64 cd
6	1.289 abc	1.01 abc	424.9 abc	1.08 a-d	0.69 bcd
7	1.527 ab	0.69 c-f	346.8 c-f	0.85 de	0.63 cd
8	0.793 a-d	0.57 def	325.0 def	0.89 de	0.81 a-d
9	0.248 bcd	0.46 f	292.1 f	0.86 de	0.94 abc
10	0.104 d	0.65 def	347.9 c-f	1.07 a-d	1.04 a
11	0.471 bcd	0.63 def	340.5 c-f	0.96 b-e	0.88 abc
12	0.111 cd	0.88 a-d	406.3 a-d	1.21 ab	0.97 ab
13	1.168 abc	0.85 a-e	393.6 a-d	1.02 b-e	0.72 bcd
14	1.784 a	0.71 b-f	350.8 b-f	0.83 de	0.57 d
15	0.772 a-d	0.72 b-f	366.4 b-f	1.00 b-e	0.81 a-d
16	0.707 a-d	0.84 a-e	394.7 a-d	1.10 a-d	0.83 a-d
17	0.762 a-d	0.84 a-e	394.6 a-d	1.09 a-d	0.81 a-d
18	1.327 abc	0.91 a-d	398.6 a-d	1.02 b-e	0.68 bcd
19	0.582 a-d	0.61 def	328.3 def	0.91 cde	0.86 a-d
20	1.499 ab	0.84 a-e	386.5 a-d	0.96 b-e	0.64 cd

Mean followed by the same letter(s) in each column are not significantly different according to Duncan's Multiple Range Test ($p < 0.05$)

TABLE IV
RANKING OF TWENTY WHEAT GENOTYPES IN RESPECT TO DIFFERENT DROUGHT TOLERANCE INDICES

Genotype	TOL	MP	GMP	SSI	STI	HAM	YI	YSI	MEAN RANK
1	5	1	1	4	1	1	1	4	1
2	13	2	2	12	2	2	3	12	3
3	11	17	16	11	16	16	15	11	16
4	12	19	19	15	19	19	20	15	19
5	18	9	10	18	10	10	5	18	12
6	17	3	3	14	3	3	6	14	6
7	16	13	13	19	13	14	18	19	20
8	6	18	18	10	18	18	16	10	17
9	3	20	20	3	20	20	17	3	15
10	1	14	14	1	14	13	7	1	7
11	4	15	15	5	15	15	11	5	11
12	2	6	5	2	5	4	2	2	2
13	14	5	6	13	6	8	8	13	8
14	20	11	12	20	12	12	19	20	18
15	8	12	11	9	11	11	10	9	10
16	7	10	8	7	9	6	4	7	4
17	9	8	7	8	8	7	5	8	5
18	15	4	4	16	4	5	9	16	9
19	10	6	17	6	17	17	14	6	14
20	19	7	9	17	7	9	12	17	13

TABLE V
CORRELATION COEFFICIENT AMONG GRAIN YIELD UNDER NON-STRESS (YP) AND STRESS (YS) CONDITIONS AND DIFFERENT DROUGHT TOLERANCE INDICES IN TWENTY GENOTYPES OF DRYLAND BREAD WHEAT

	1	2	3	4	5	6	7	8	9	10
1. Yp	1.00									
2. Ys	0.30 *	1.00								
3. TOL	0.78 **	- 0.35 **	1.00							
4. MP	0.88 **	0.71 **	0.39 **	1.00						
5. GMP	0.83 **	0.77 **	0.30 *	0.99 **	1.00					
6. SSI	0.66 **	- 0.47 **	0.96 **	0.25 *	0.17 ns	1.00				
7. STI	0.82 **	0.78 **	0.29 *	0.99 **	0.99 **	0.16 ^{ns}	1.00			
8. HAM	0.77 **	0.83 **	0.21 ^{ns}	0.97 **	0.99 **	0.08 ^{ns}	0.99 **	1.00		
9. YI	0.30 *	1.00 **	- 0.35 **	0.71 **	0.77 **	- 0.47 **	0.78 **	0.83 **	1.00	
10. YSI	- 0.66 **	0.47 **	- 0.96 **	- 0.25 *	- 0.17 ^{ns}	- 1.00 **	- 0.16 ^{ns}	- 0.08 ^{ns}	0.47 **	1.00

Ns, * and **: Non-significant, significant at 5 and 1 % probability levels, respectively.

Field experiment was conducted on a clay soil with pH 7.6, N 0.122%, P2O5, K2O, Mn, Fe, Zn and Cu were equal 10.8, 380, 2.6, 6.2, 1.03 and 2.1 mg.kg-1, respectively.

The research was including two different experiments. In each experiment, twenty dryland bread wheat genotypes were sown in a randomized complete blocks design (RCBD) with three replications. One of experiments belonged to rain-fed conditions (post-anthesis drought stress) and other experiment was under non-stress conditions (with supplemental irrigation). N, P2O5 and K2O fertilizers were applied as much as 100, 50 and 25 kg.ha-1, respectively.

The sources of N, P and K were urea, triple superphosphate and potassium sulphate, respectively. Triple superphosphate and potassium sulphate and half of urea fertilizers were applied before planting. Another half of urea fertilizer applied at the beginning of stem elongation growth stage.

After physiological ripening, grain yield was obtained. Drought tolerance indices were calculated by the following formula (Table I).

Data were analyzed by ANOVA and means were testes by Duncan's multiple range test using MSTAT-C and SAS statistical analysis packages.

III. RESULTS AND DISCUSSION

The results showed that there were significant differences among genotypes in respect to grain yield under non-stress conditions ($p < 0.05$) (Table II). Significant differences ($p < 0.01$) were observed among genotypes under stress conditions, too. These results demonstrate high diversity among genotypes that enable us to select genotypes under non-stress and stress environments.

Mean comparisons showed that G6 with 532.7 g.m-2 and G9 with 311.7 g.m-2, respectively had the highest and the lowest grain yield under non-stress conditions (Table III). Under rain-fed environments G1 with 427.6 g.m-2 and G4 with 251 g.m-2, respectively had the highest and the lowest grain yields, too.

Evaluation of correlation coefficients showed that there was a positive and significant correlation (r2 = 0.30) between grain yield under non-stress (Yp) and stress (Ys) environments, but correlation coefficient was very low (Table V).

Calculation of tolerance indices showed that the highest stress tolerance (TOL) value and Stress Susceptibility Index (SSI) value were related to G14, G7 and G5, indicating that these genotypes had higher grain yield reduction under rain-fed conditions and the highest drought sensitivity (Table III and IV). G10 and G12 were the most tolerant genotypes based on TOL and SSI, which their low quantity is indication tolerance genotypes. It seems TOL had succeeded in selection of genotypes with high yield under drought stress, but had failed to select genotypes with proper yield under both environments. It ,also, seems if a genotype has high grain yield under both non-stress and stress conditions but has high variation in its yields between these two conditions, it is not selected as drought tolerant genotype by SSI.

G1 and G2 were the tolerant genotypes based on Mean Productivity (MP), Geometric Mean Productivity (GMP), Stress Tolerance Index (STI), Harmonic Mean (HAM) and Yield Index (YI), which their high quantity is indicating tolerant genotypes (Table III and IV). Based on these current indices, G9 and G4 were the most sensitive genotypes. G10 and G12 had the highest and G14 and G7 had the lowest Yield Stability Index (YSI), respectively (Table III and IV).

The results showed that, the highest positive and significant correlations with Yp were observed among MP, GMP, and STI (Table V). The same results obtained among Ys and MP, GMP, STI, too. The highest correlation (r2 = 1.00) was observed between Ys and YI. The correlations of TOL (r2 = -0.35) and SSI (r2 = - 45) with Ys was negative and significant ($p < 0.01$). There was a positive and significant correlation between TOL and SSI (r2 = 0.96). There were also, positive and significant correlations among MP, GMP, STI, HAM and YI ($p < 0.01$).

Ranking of genotypes in respect to all drought tolerance indices showed that G1, G12 and G2 had the best mean rank (Table IV).

The results of this experiment demonstrated that the most appropriate index to select drought tolerant genotype is an index which has a high correlation with grain yield under both non-stress and stress conditions. So, STI, GMP, and MP were identified as appropriate indices to select drought tolerance genotypes. Similar results were reported by Zeynali et al., (2004), Sanjari pirevatlou et al., (2008), and Karimizadeh and Mohammadi (2011) [17, 18, 19].

Fernandez (1992) classified genotypes according to their production under non-stress and stress conditions to four groups: genotypes with high production under both conditions (Group A), genotypes with high production only under non-stress conditions (Group B), genotypes with high production only under stress conditions (Group C) and genotypes with weak production under both conditions (Group D) [8].

Moghadam and Hadi-Zadeh (2002) found STI was more useful in order to select favorable cultivars under stress and non-stress conditions [20]. Khalili et al., (2004) showed that based on GMP and STI indices, cultivars with high yield in both stress and non-stress environments can be selected [21]. Sio-Se Mardeh et al., (2006) in a study to evaluate drought tolerance indices in wheat genotypes under different environmental conditions, concluded that under mild drought stress conditions MP, GMP and STI were more effective to recognize genotypes which have similar grain yield in both environments (group A genotypes). Under severe drought stress conditions, none of the applied indices could identify group A genotypes [22]. Golabadi et al., (2006) reported significant and positive correlations of Yp and (MP, GMP and STI) and Ys and (MP, GMP and STI) under both conditions as well as significant negative correlation of SSI and TOL under moisture stress environment, revealed that selection could be conducted for high MP, GMP and STI under both environments and low SSI and TOL under moisture stress environments [23].

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