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Full Length Research Paper

Evaluation of physiological screening techniques for drought-resistant breeding of durum wheat genotypes in Iran

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This paper summarizes the results of a project aimed to evaluate the use of physiological traits (such as canopy temperature and chlorophyll content) in determining drought tolerance of durum wheat genotypes under a variety of environmental conditions. Six durum wheat genotypes were planted in rainfed and supplementary irrigation conditions in Gachsaran of Iran for two years (2007 to 2009). Five drought tolerance indices including stress susceptibility index (SSI), stress tolerance index (STI), tolerance index (TOL), mean productivity (MP) and geometric mean productivity (GMP) were calculated. Canopy temperature depression (CTD) and chlorophyll content (CHL) was used to estimate crop yield and to rank genotypes. CTD and CHL were measured at three stages from emergence of 50% of inflorescence (Zadoks Growth Scale54) to watery ripe stage (ZGS71). Genotypes G5 (OUASERL-1) and G6 (Stj//Bcr/LKS41CD94) were superior genotypes for both environments with high PC1 and low PC2 in biplot analysis. The results of genotypes CTD in ZGS69 stage and CHL in grain filling stage had high significant differences. The significant and positive correlation of MP, SSI, STI, CHL and CTD showed that these indices were more effective in identifying high yielding genotypes under both conditions and the result showed that CTD and CHL played important roles to search for the physiological basis of grain yield of wheat and CTD and CHL can successfully be used as a selection criterions in breeding programs.

Key words: Canopy temperature, chlorophyll content, drought stress, durum wheat.

INTRODUCTION

Increasing the genetic potential of yield in water deficit condition is one of the major objectives of durum wheat breeding programs in Iran and other countries. Water deficit is one of the most important factors limiting crop yield and the monitoring of crop water status has prime importance for reasonable irrigation and water saving cultivation. Deviation of temperature of plant canopies in comparison to ambient temperature, also known as CTD (canopy temperature depression = air temperature – canopy temperature), has been recognized as indicators of the overall plant water status (Ehrler, 1972; Blum et al., 1982; Jackson et al., 1981; Idso, 1982) and it is used in such practical applications as evaluation of plant response to environmental stress (Ehrler et al., 1978; Idso et al., 1984; Howell et al., 1986; Jackson et al., 1981), irrigation scheduling (Hatfield, 1982; Pinter and Reginato, 1982; Evett et al., 1996; Wanjura et al., 1995), cultivar comparison for water use (Pinter et al., 1990;

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Hatfield et al., 1987), and tolerance to heat (Amani et al., 1996; Reynolds et al., 1998) and drought (Blum et al., 1989; Royo et al., 2002; Rashid et al., 1999). High CTD has been used as a selection criterion to improve tolerance to drought and heat (Amani et al., 1996; Ayeneh et al., 2002; Blum, 1996; Blum et al., 1989; Pinter et al., 1990; Rashid et al., 1999; Reynolds et al., 1994, 2001; Fischer et al., 1998) and has been associated with yield increase among wheat (*Triticum aestivum* L.) cultivars at CIMMYT (Fischer et al., 1998). The suitability of CTD as an indicator of yield and stress tolerance, however, must be determined for individual environments. For example, it can be a poor indicator where yield is highly dependent on limited amounts of soil-stored water (Idso et al., 1984; Winter et al., 1988; Royo et al., 2002; Sojka et al., 1981; Balota et al., 2007, 2008). Vapour pressure deficit has a large effect on CTD, while net radiation, air temperature and wind speed have slight effects (Smith et al., 1986). CTD affected by biological and environmental factors like water status of soil, wind, evapotranspiration, cloudiness, conduction systems, plant metabolism, air temperature, relative humidity and continuous radiation (Reynolds et al., 2001), has preferably been measured in high air temperature and low relative humidity because of high vapour pressure deficit conditions (Amani et al., 1996). At the end of 1980s, Cimmyt began CTD measurements on different irrigated experiments in Northwest Mexico and it was found that phenotypic correlations of CTD with grain yield were occasionally positive (Reynolds et al., 1994; Fischer et al., 1998). It was also observed that CTD has been used as a selection criterion for tolerance to drought and high temperature stress in wheat breeding and the used breeding method generally comes by mass selection in early generations like F3. According to this method, firstly, bulks which show high CTD value (have cool canopy) were selected in F3 generation. Later, single plants which show high stomata conductance (g) among bulks which show cool canopy at the same selection generation; thus, both of these traits were used at the same breeding program (Reynolds et al., 2001). Munjal and Rena (2003) reported that cool canopy during grain filling period in wheat is an important physiological principle for high temperature stress tolerance. Wheat production in Mediterranean region is often limited by sub-optimal moisture conditions. Visible syndromes of plant exposure to drought in the vegetative drought stress at the grain filling period dramatically reduces grain yield (Ehdaie and Shakiba, 1996). Breeding for drought tolerance is complicated by the lack of fast, reproducible screening techniques and the inability to routinely create defined and repeatable water stress conditions when a large amount of genotypes can be evaluated efficiently (Ramirez and Kelly, 1998). Achieving a genetic increase in yield under these environments has been recognized to be a difficult challenge for plant breeders, while progress in yield grain has been much higher in favourable environments (Richards et al., 2002). Thus, drought indices which provide a measure of drought based on yield loss under drought conditions in comparison to normal conditions have been used for screening drought-tolerant genotypes (Mitra, 2001). These indices are either based on drought tolerance or susceptibility (Fernandez, 1992). Drought tolerance is defined by Hall (1993) as the relative yield of a genotype compared to other genotypes subjected to the same drought stress. Drought susceptibility of a genotype is often measured as a function of the reduction in yield under drought stress (Blum, 1996), whilst the values are confounded with differential yield potential of genotypes (Ramirez and Kelly, 1998). Rosielle and Hamblin (1981) defined stress tolerance (TOL) as the differences in yield between the stress (YS) and supplementary irrigation (YP) environments and mean productivity (MP) as the average yield of YS and YP. Fischer and Maurer (1978) proposed a stress susceptibility index (SSI) of the cultivar. 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 supplementary irrigation conditions. Other yield based estimates of drought tolerance are geometric mean productivity (GMP), 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 (Ramirez and Kelly, 1998). Clarke et al. (1992) used SSI for evaluation of drought tolerance in wheat genotypes and found year-to-year variation in SSI for genotypes and their ranking pattern. In spring wheat cultivars, Guttieri et al. (2001) using SSI criterion suggested that SSI more than 1 indicated above-average susceptibility to drought stress. Golabadi et al. (2006) and Sio-Se Mardeh et al. (2006) suggested that selection for drought tolerance in wheat could be conducted for high MP, GMP and STI under rainfed and supplementary irrigation environments. Selection of different genotypes under environmental stress conditions is one of the main tasks of plant breeders for exploiting the genetic variations to improve the stress-tolerant cultivars (Clarke et al., 1984). Ragab Moussa and Abdel-Aziz (2008) in their investigation examined the relative significance of anti-oxidative enzymes, photosynthetic activity and membrane permeability at seedling stage in drought-tolerant and susceptible maize genotypes. Mostafa Kamal etal. (2010) determined specific proteins induced by each abiotic stress, with particular emphasis placed on the heat shock, drought, cold, salt and others environmental stress by proteomic approaches. The physiological basis of drought tolerance among durum wheat genotypes was associated with improved chlorophyll content from heading onwards, as well as more leaf chlorophyll retention during grain filling (Delgado et al., 1994),

Table 1. Name and pedigree of genotypes used in this research.

Genotype code	Name and pedigree
G1	Bcr/3/Ch1//Gta/Stk/4/Bcr/Lks4ICD92-01 50-Cabl -11AP-0AP-8AP-0TR-4AP-0AP
G2	Gsb1-1/4/D68/1/93A-1A//Ruff/Fg/3/Mtl-5I CD95-1174-C-2AP-0AP-2AP-0AP
G3	Altar84/Stn/Wdz-2ICD92-MABL-0238-4AP- 0AP-5AP-0TR-15AP-0AP
G4	DON-Md 81-36
G5	OUASERL-1 ICD96-0758-C-2AP-0AP-5AP-0AP
G6	Stj//Bcr/LKS41CD94

Table 2. Regional climatic data including average temperature and rainfall for both growth seasons of 2007 to 2008 and 2008 to 2009.

Month	2007- 2008 season		2008- 2009 season	
	Average temperature	Rainfall (mm)	Average temperature	Rainfall (mm)
November	17.3	63.8	17.6	43.6
December	9.5	112.2	9.6	96.3
January	9.9	66.8	8.4	24.9
February	13.1	23.4	12.3	12.8
March	15.2	6.3	15.6	1.6
April	27.1	24.1	30.1	41.2
May	26.3	37.8	26.9	11.3
June	32.6	1.2	30.6	0.0
Total	-	334.4	-	231.7

greater thermo stability of membranes indicated by electrolyte leakage (Fokar et al., 1997; Balota et al., 1993), chlorophyll fluorescence (Balota et al., 1996) and cooler canopies, which were associated with increased stomatal conductance (Amani et al., 1996).

The objectives of this study were (1) to evaluate the ability of several selection indices to identify drought tolerance cultivars under a variety of environmental conditions; and (2) to determine the relationships of CTD and chlorophyll content with drought indices, grain yield and yield components in six durum wheat genotypes in Gachsaran semi-warm condition of Iran.

MATERIALS AND METHODS

Plant material

The trial was conducted in 2007 to 2008 and 2008 to 2009 growing seasons at Gachsaran agricultural research station situated at 710 m altitude above sea level with longitude 50°50' east and latitude 30°20' north located in south-western of Iran. Soil texture of the experimental site was silty clay loam and 20 years average of rainfall was 460 mm. In this study, six durum wheat genotypes (Table 1) were planted in two set (each set 4 replicates) by using a randomized complete block design in four replicates under two supplementary irrigation and rainfed conditions (twice irrigation supplied for supplemental irrigated). Plots were planted at a seeding rate of 300 seed per m^2 by WINTERSTEIGER AG trial drilling machine on the 25th November 2008 and 28th November 2009. Plot size contained six rows (7.03 m long) with row differences of 17.5 cm. Fertilizers were applied; 80 kg ha^{-1} of nitrogen and 80 kg ha^{-1} of phosphorus as 40.40.0 compose fertilizer at planting time, 80 kg ha^{-1} of nitrogen as ammonium nitrate (half of the top dressed fertilizer) was given at tillering and the other half of the top dressed fertilizer was given at swollen stage. No disease was shown during growth period and weed control was made by chemical method (Topic and Granstar). After physiological maturity, plots were harvested by WINTERSTEIGER AG trial thrasher/ harvester machine. Regional climatic data during growth seasons (mean of November 2007 to June 2008 and November 2008 to June 2009) were relatively alike: average monthly temperature and rainfall according to months (November to June) is shown in Table 2. Total rain amount were 334.4 and 231.7 in 2007 to 2008 and 2008 to 2009 growing seasons, respectively, although, from emergence of eighty percent of inflorescence to completion of 50% anthesis, rain amount were zero for 18 and 29 days, respectively. Maximum air temperature at measurement dates (14, 16 and 23 March and 6 to 8 April), was respectively 26.4, 28.3, 25.2, 29.4 and 33.6°C. Average temperature was respectively 15.3, 17.4, 18.8, 23.9 and 25.1°C and relative humidity was respectively 57.6, 51.9, 51.3, 44.8 and 41.3% on the same dates (Annual report, 2008, 2009). Twice irrigation for trial under supplementary irrigation condition at 18 March and 10 April in 2008 and 20 March and 15

Table 3. Combined analysis of variance for grain yield inthe two years for both rainfed and supplementary irrigation conditions (four environments).

Source	Degree of freedom	Mean square	F. value
Environment (year×condition)	3	34955347	35.583**
Error 1	12	982357.9	-
Genotype	5	1659378	6.956**
Genotype×environment	15	930014.7	3.898**
Error 2	60	238549.5	-
Total	95	-	-

*P < 0.05 and ** P < 0.01.

April 2009 were conducted.

Drought indices

Drought tolerance/susceptibility indices were calculated for each genotype using the following relationships:

Stress susceptibility index (SSI = (1- (Ys / Yp)) / SI

Stress intensity (SI) = 1 – ($\bar{Y}s$ / $\bar{Y}p$)

Mean productivity (MP) = (Ys + Yp) / 2

Tolerance (TOL) = Yp – Ys

Geometric mean productivity (GMP) = $(Yp.Ys)^{1/2}$

Stress tolerance index (STI) = (Yp) (Ys) / $(\bar{Y}p)^2$

Where, Ys, is the grain yield of genotype under stress; Yp, the grain yield of cultivar under irrigated condition; Ys and Yp are the mean yields of all genotypes under stress and non- stress conditions, respectively. Among the stress tolerance indices, a larger value of TOL and SSI represent relatively more sensitivity to stress, thus, a smaller value of TOL and SSI are favorable. Selection based on these two criteria favors genotypes with low yield potential under non-stress conditions and high yield under stress conditions. On the other hand, selection based on STI and GMP will result in genotypes with higher stress tolerance, and yield potential will be selected (Fernandez, 1992).

Measurement of canopy temperature and chlorophyll content

CTD measurements were made by infrared thermometer (Model 8866, JQA Instrument, Inc., Tokyo, Japan) which was focused on 10:1 m and at late morning to early afternoon cloudless periods (10:00 to 14:00 h). As similar to the method of Fischer et al. (1998), the data for each plot were the mean of four readings, taken from the same side of each plot at an angle of approximately 45° to the horizontal in a range of directions such that they covered different regions of the plot and integrated many leaves. Also, measurements were at different three periods; on 24th March (ZGS 54, emergence of fifty percent of inflorescence), 12th April (ZGS 69, completing of anthesis) and 28 April (ZGS 71 watery ripe, clear liquid) by using ZGS defined Zadoks Growth Scale (Zadoks et al., 1974). Variance analysis of all agronomical traits and CTD measurements on each growth stage were carried out and the significance of cultivar mean square was determined by testing against the error mean square. Flag leaf chlorophyll content was measured at pre-heading, heading and grain filling stages by using of a Minolta SPAD meter on 5 to 8 flag leaves per plot. All calculations for this article were set up by Genstat 12 statistical packed program. Correlations between two traits were evaluated by MINITAB 14.

RESULTS AND DISCUSSION

The result of the combined analyses of variance for grain yield, in supplementary irrigation and rainfed conditions for two years is shown in Table 3. In this table, the environment that was defined as combination of year × condition and the genotypes showed high significant difference at 0.01 probability level for grain yield; suggesting that high potential yield under optimal conditions does not necessarily result in improved yield under rainfed conditions. Thus, indirect selection for a drought prone environment based on the results of optimum conditions will not be efficient. These results are in agreement with those of Sio-Se Mardeh et al. (2006) and Bruckner and Frohberg (1987) that wheat with low yield potential was more productive under rainfed conditions. Genotype × environment (GE) interaction showed significant difference at 0.01 probability level, also this GE interaction can be used for determining genotypic stability. Drought tolerant indices were calculated on the basis of grain yield of genotypes (Table 5). As shown in Table 5, the greater the TOL value, the larger the yield production under supplementary irrigation conditions and the smaller the TOL value, the larger the yield production under rainfed conditions. The significant and positive correlation was between TOL and YP, but the significant and negative correlation between TOL and YS indicated this relation very well (Table 7) suggesting that selection based on TOL will result in reduced yield under well-watered conditions. Similar results were reported by Clark et al. (1992), Sio-Se Mardeh et al. (2006) and Talebi et al. (2009). In this study, yield under irrigation was about 74% higher than yield under rainfed. Since MP is a mean production under both rainfed and supplementary irrigation conditions, it will be correlated with YS, YP and TOL indices. This result is similar to that of Talebi et al. (2009). There was a positive significant correlation between STI with YS, YP and MP indices (Table 7). It was concluded that MP and STI were able to discriminate tolerant genotypes under rainfed conditions. The results indicated that there was a positive and significant correlation among YP and MP, STI and TOL indices. Also, there was a positive and significant correlation among YS and MP and STI. The observed relations were consistent with those reported by Fernandez (1992) in mungbean, Farshadfar and Sutka (2002) in maize, and Talebi et al. (2009) and Golabadi et al. (2006) in durum wheat. The correlation coefficient for rainfed tolerance (TOL) and YS was -0.719, thus, selection for tolerance should decrease yield in the moisture rainfed environment and increase grain yield under supplementary irrigation, as indicated by r= 0.943. Therefore, selection for rainfed tolerance should give a negative yield response under rainfed environment. The correlation coefficients for the mean productivity (MP) and yield in supplementary irrigation and rainfed environments were 0.771 and 0.943, respectively. Fernandez et al. (1992) proposed that STI index discriminates genotypes with high yield and rainfed tolerance potentials. The correlation coefficients between STI and YP and YS were similar to the correlation coefficients of MP index.

Selection based on a combination of indices may provide a more useful criterion for improving drought tolerance of wheat, but the study of correlation coefficients are useful in finding the degree of overall linear association between any two attributes. Thus, a better approach than a correlation analysis such as biplot is needed to identify the superior genotypes for both rainfed and supplementary irrigation environments. Principal component analysis (PCA) revealed that the first PCA explained 0.58 of the variation, thus, the first dimension can be named as the yield potential and drought tolerance. Considering the high and positive value of this biplot, genotypes that have high values of these indices will be high yielding under rainfed and supplementary irrigation environments. The second PCA explained 0.34 of the total variability and correlated positively with TOL and SSI. Therefore, the second component can be named as a stress-tolerant dimension and it separates the stress-tolerant genotypes from supplementary irrigation tolerant ones. Thus, selection of genotypes that have high PC1 and low PC2 are suitable for both rainfed and supplementary irrigation environments (Figure 1). Therefore, genotypes G5 (OUASERL-1) and G6 (Stj//Bcr/LKS41CD94) were superior genotypes for both environments with high PC1 and low PC2. Genotypes G4 (Stj//Bcr/LKS41CD94) and G1 (Bcr/3/Ch1//Gta/Stk/4/Bcr/Lks4) with high PC2 were more suitable for supplementary irrigation environment than for rainfed environment. Farshadfar and Sutka (2003), Sio-Se Mardeh et al. (2006) and Golabadi et al. (2006) obtained similar results in multivariate analysis of drought tolerance in different crops.

For these six lines, the crop cycle was reduced from 139 days (emergence to physiological maturity) in TOL group, to an average of 131 days in the SEN group in rainfed condition. A comparison of performance on a per day basis between TOL and SEN groups showed that under drought stress, total yield and yield per day at maturity had 54 and 46% differences, respectively. The crop cycle was reduced from 146 days (emergence to physiological maturity) in TOL group, to an average of 143 days in the SEN group in supplemental irrigation condition. A comparison of performance on a per day basis between TOL and SEN groups showed that total yield and yield per day at maturity had 39 and 36% differences, respectively. Differences in yield and morpho-physiological traits for the TOL versus SEN lines was apparently associated with differing performance during grain filling, as reflected by the difference in grain filling rate, rather than parameters up until anthesis (Table 4). The physiological data indicate similar contrasts between TOL and SEN lines for photosynthetic chlorophyll content and canopy temperature, again, with differences most pronounced from flowering onwards (Table 6). Result showed that chlorophyll content values in heading stage had the highest value ratio than the other stages in both conditions. We observed decrease in the chlorophyll content in the third stage (grain filling) in both condition, but this reduction of chlorophyll content in supplemental irrigation condition was clearer than for the rainfed condition (Figures 2 and 3).

The CTD measurements were taken at the stage of half of spike visible (ZGS 54), all of spikes are flowering (ZGS 69) and watery ripe, clear liquid (ZGS 71). Genotypic differences were detected at the ZGS 69 and ZGS 71 for both supplementary irrigation and rainfed condition on durum wheat genotypes. CTD values changed between 6.5℃ (SEN genotypes) and 7.4℃ (TOL genotypes) and between 6.1℃ (SEN genotypes) and 6.9℃ (TOL genotypes) at ZGS 54 in supplemental irrigation and rainfed conditions, respectively. At ZGS 69, CTD changed between 7.1℃ (SEN genotypes) and 8.6℃ (TOL genotypes) and between 7.3℃ (SEN genotypes) and 9.1℃ (TOL genotypes) in supplemental irrigation and rainfed conditions, respectively. Finally, CTD values changed between 5.5℃ (SEN genotypes) and 5.9℃ (TOL genotypes) and between 4.6℃ (SEN genotypes) and 5.1℃ (TOL genotypes) at ZGS 71 in supplemental irrigation and rainfed conditions, respectively (Table 6; Figures 4 and 5). Differences among genotypes were significant in the 12th April measurements (ZGS 69). Rees et al. (1993) reported that CTD values was changed

Table 4. Performance and morphological/physiological traits for the mean of three drought tolerance (TOL) and three drought sensitive (SEN) durum wheat varieties over four environment.

Trait	Rainfed condition		% Difference	Supplementary irrigation		% Difference
	TOL	SEN		TOL	SEN	
Grain yield (kg P ha^{-1})	2380	1538	54	5497	3944	39
Grains / spikes	38	31	22	42	40	5
Number of spikes (m^2)	546	432	26	615	538	14
Days to anthesis	95	91	4	98	96	2
Days to maturity	139	131	6	146	143	2
Height	88	84	4	94	92	5.4
Test weight	73	67	9	75	71	5.6
Yield per day (kg ha^{-1}d^{-1})	17.1	11.7	46	37.7	27.6	36
Thousand kernel weight (g)	43	41	5	47	44	6.8

Table 5. Drought tolerance indices of six durum wheat genotypes under supplementary and rainfed conditions on mean of two year.

Genotype code	YS	YP	TOL	MP	GMP	SSI	STI
G1	2283.4	3751.3	1467.9	3017.4	2921.2	1.96	0.32
G2	2142.4	4197.8	2055.4	3170.1	2993.3	2.49	0.34
G3	2447.7	3883.6	1435.9	3165.6	3080.3	1.88	0.36
G4	3242.4	5491.8	2249.4	4367.1	4218.4	2.10	0.66
G5	3089.7	5335.8	2246.0	4212.7	4058.3	2.16	0.61
G6	3060.2	5662.9	2602.6	4361.6	4162.2	2.36	0.65

Table 6. Physiological parameters for the mean of three drought tolerant (TOL) and three drought sensitive (SEN) durum wheat varieties measured on flag leaves at three phenological stages; pre-heading, heading and grain filling in Gachsaran, 2007 to 2009.

Condition	Pre-heading	Heading	Grain filling
Rainfed condition			
Canopy temperature depression			
TOL	6.9	9.1	5.1
SEN	6.1	7.3	4.6
Chlorophyll content (SPAD)			
TOL	59.9	68.1	61.1
SEN	61.9	64.0	49.0
Supplemental irrigation condition			
Canopy temperature depression			
TOL	7.4	8.6	5.9
SEN	6.5	7.1	5.5
Chlorophyll content (SPAD)			
TOL	65.4	74.4	66.2
SEN	67.4	71.5	42.3

between 3.54 and 5.10°C before anthesis, and 3.16 to 4.61°C after anthesis in bread wheat. Reynolds et al. (1997) reported that CTD average values of heat stress tolerant genotypes in bread wheat were respectively 7.4,

Table 7. Correlation coefficients among CTD values, chlorophyll content and drought indices in durum wheat genotypes.

Genotype	CTD1†	CTD2	CTD3	CHL1††	CHL2	CHL3	YS	YP	TOL	MP	STI
CTD1	1										
CTD2	0.771*	1									
CTD3	0.841*	0.841*	1								
CHL1	-0.232	-0.406	-0.338	1							
CHL2	0.429	0.543	0.116	-0.348	1						
CHL3	0.771*	0.886**	0.812*	-0.638	0.429	1					
YS	0.657	0.771*	0.580	-0.754*	0.771*	0.771*	1				
YP	0.657	0.771*	0.928**	-0.580	0.086	0.771*	0.657	1			
TOL	0.771*	0.657	0.928**	-0.493	0.029	0.714*	-0.719*	0.943**	1		
MP	0.600	0.714*	0.812*	-0.638	0.257	0.657	0.771*	0.943**	0.886**	1	
STI	0.543	0.771*	0.725*	-0.812*	0.429	0.771*	0.886**	0.886**	0.771*	0.943**	1

*P < 0.05, ** P < 0.01; † canopy temperature depression in ZGS 54, ZGS 69 and ZGS 71, respectively; †† chlorophyll content in pre-heading, heading and grain filling stages, respectively.

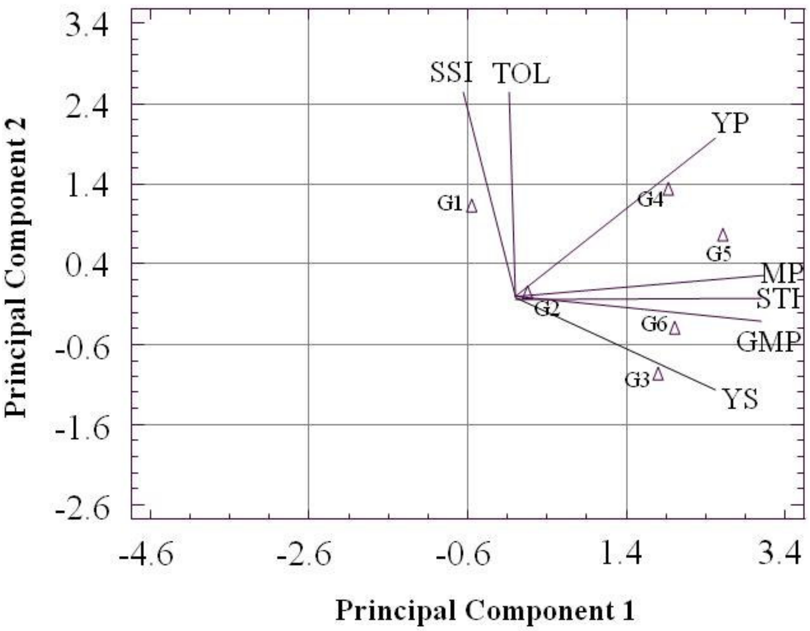

Figure 1. Biplot of principal component analysis of drought tolerance indices.

9.0 and 6.5°C before heading, at heading and grain filling periods. These values were respectively 7.1, 7.9 and 5.7°C at the same periods in susceptible genotypes. In this study, it was shown similar to the situation; for instance, CTD values were observed as 6.9, 9.1 and 5.3°C in G6 before heading, at heading and grain filling periods respectively in rainfed condition. It was understood that this genotype had cooler plant canopy than the other cultivars. Also, Barma et al. (1997) showed that CTD values changed between -2.4 and -5.5°C sometimes. At the stage of ZGS 54, these values changed between 3.42°C (Porron4/Yuan1) and 4.13°C (NN-90.E-3-14).

CTD values of ZGS 54(CTD1) in durum wheat showed significant and high positive correlation with CTD values of ZGS 69(CTD2), CTD3, chlorophyll content in grain filling (CHL3) and TOL indices (Table 7). CTD values of ZGS 69(CTD2) showed significant correlation with CTD1, CTD3, CHL3, YS, YP, MP and STI indices. He result of correlation among ZGS 71(CTD3) showed significant correlation among CTD3 and CTD1, CTD2, CHL3, YS, YP, MP and STI. CTD in ZGS 69 had best result of correlation coefficient with other indices. Cooler canopy temperature at heading and grain filling stages caused

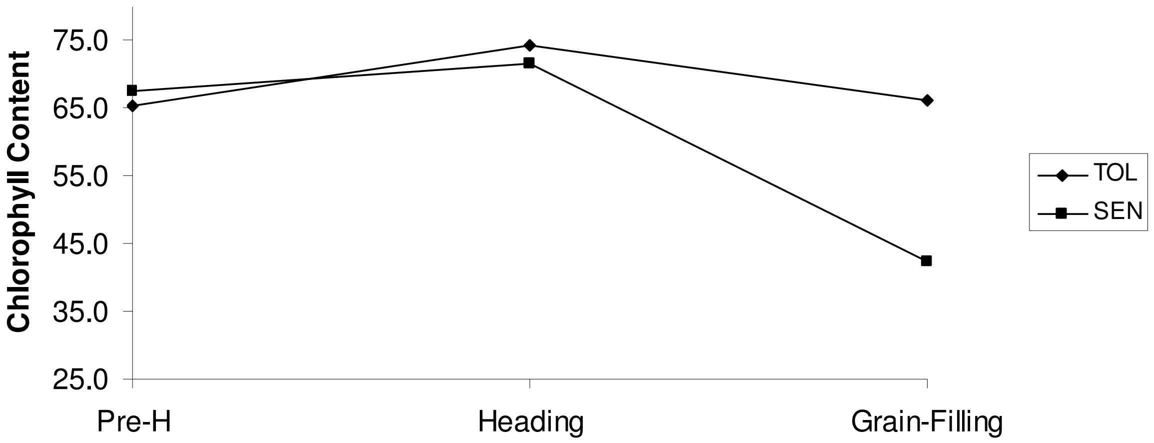

Figure 2. Chlorophyll content on three drought tolerant (TOL) and three drought sensitive (SEN) durum wheat varieties in supplemental irrigation condition at 2007 to 2009.

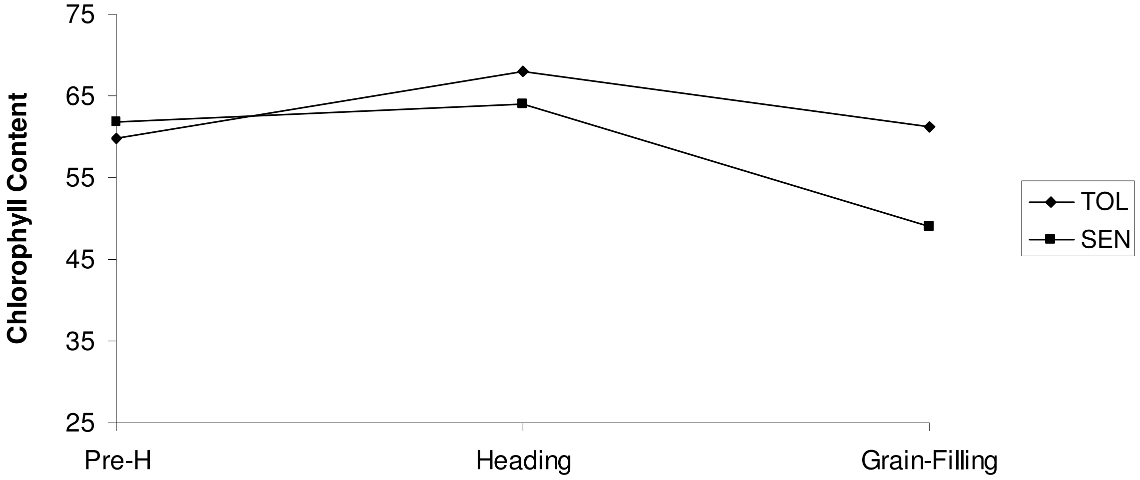

Figure 3. Chlorophyll content on three drought tolerant (TOL) and three drought sensitive (SEN) durum wheat varieties in rainfed condition at 2007 to 2009.

increase in yield for each condition. The physiological basis of drought tolerance among durum wheat genotypes was associated with improved chlorophyll content rates from heading onwards (Figures 2 and 3), as well as more leaf chlorophyll content during grain filling, greater weight of grain or thousand kernel weight (Table 7). These result showed that we can use CTD and chlorophyll content for determining drought tolerant genotypes.

Tolerance indices including STI and MP were able to identify cultivars producing high yield in both conditions. When the stress was severe, TOL, SSI and STI were found to be more useful indices discriminating resistant cultivars, although none of the indicators could clearly identify cultivars with high yield under both stress and non-stress conditions. It is concluded that the effectiveness of selection indices depends on the stress severity supporting the idea that only under moderate stress conditions, do potential yield greatly influences yield under stress (Blum, 1996; Panthuwan et al., 2002). Two primary schools of thought have influenced plant breeders who target their germplasm to drought-prone areas. The first of these philosophies states that high input responsiveness and inherently high yielding potential, combined with stress-adaptive traits will improve performance in drought-affected environments (Richards, 1996; Van Ginkel et al., 1995; Rajaram and Van Ginkle, 2001; Betran et al., 2003). The breeders who advocate selection in favourable environments follow this philosophy. Producers, therefore, prefer cultivars that produce high yields when water is not so limiting, but suffer a minimum loss during drought seasons (Nasir

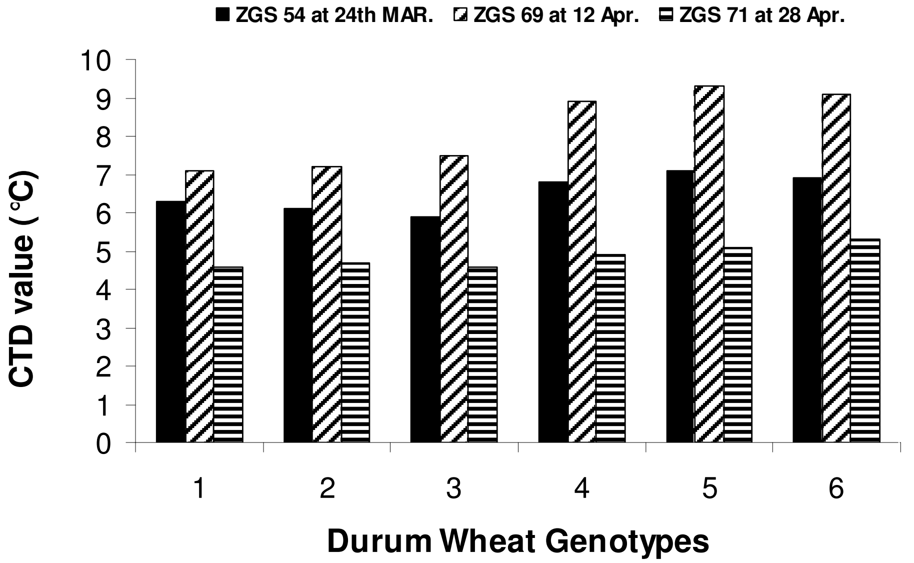

Figure 4. Canopy temperature depression values of durum wheat genotypes in rainfed condition.

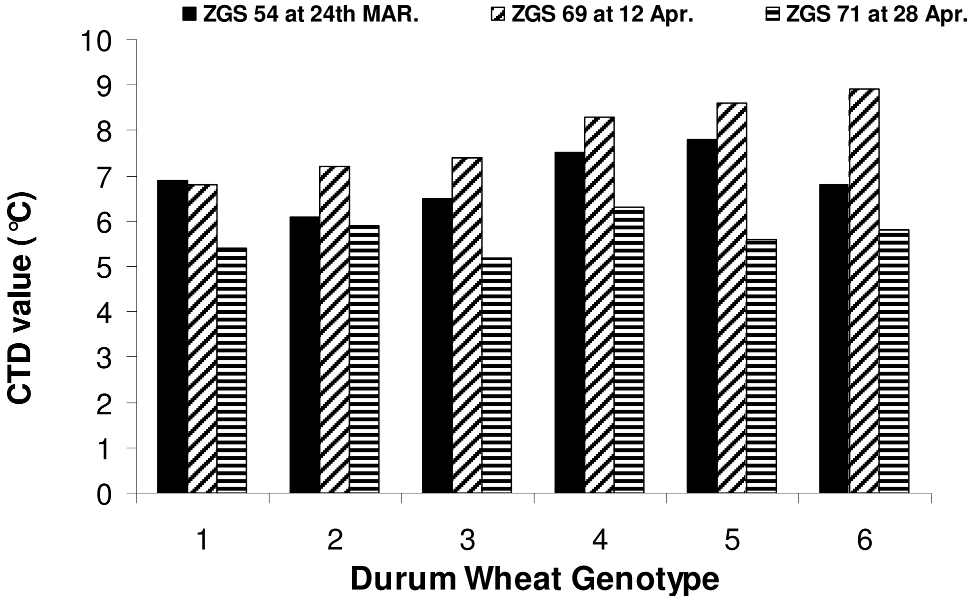

Figure 5. Canopy temperature depression values of durum wheat genotypes in supplementary irrigation condition.

Uddin et al., 1992). The second is the belief that progress in yield and adaptation in drought- affected environments can be achieved only by selection under the prevailing conditions found in target environments (Ceccarelli, 1987; Ceccarelli and Grando, 1991; Rathjen, 1994). The theoretical framework to this issue was provided by Falconer (1952) who wrote "yield in low and high yielding environments can be considered as separate traits which are not necessarily maximized by identical sets of alleles". Over all, drought stress reduced significantly the yield of some genotypes and some of them revealed tolerance to drought, which suggested the genetic variability for drought tolerance in this material. Therefore, based on this limited sample and environments, testing and selection under non-stress and stress conditions alone may not be the most effective for increasing yield under drought stress. The significant and positive correlation of YP and MP, GMP and STI showed that these criteria indices were more effective in identifying high yielding cultivars under different moisture conditions.

Conclusion

The results of the calculated gain from indirect selection in moisture stress environment would improve yield in moisture stress environment better than selection from non-moisture stress environment. Wheat breeders should, therefore, take into account the stress severity of the environment when choosing an index. Estimating yield from a small number of short-term CTD measurements seems much more dubious, however, since short-term CTD and transpiration rate are related to temporally variable environmental properties including irradiance, air temperature, wind speed and vapour pressure deficit. If suitable days are used for CTD measurement in terms of sufficiently high irradiance, sufficiently low wind speed, no rainfall and sufficient vapour pressure deficit to permit transpiration, fairly consistent rankings for genotypes can be obtained; however, measurements should be made in as short a time as possible. Unless one has high confidence in weather stability, it is doubtful whether readings from different days can be combined without introducing a large error from genotype × environment interaction (Balota et al., 2007).

Based on empirical comparisons under our conditions, CTD data from days in which mean solar irradiance was <500 w m^{-2} or mean wind speed was >4 m per s were unsuitable for estimating yield or ranking genotypes. In this study, positive correlation among CTD, chlorophyll content, YS, YP, TOL, MP and grain yield showed that CTD and chlorophyll content can be favourite indices in plant breeding. Finally, our data suggest that it is important that measurements are made in as little time as possible to reduce potentially large errors from a changing environment. In our experience, the traditional handheld infrared thermometer (IRT) is not well suited to this requirement. Currently, we are experimenting with radiometric thermal imagers. Alternatively, development of wireless IRTs in a meshed network environment would reduce the complexity of wiring and data logging IRTs and could be less expensive than a thermal imager approach.

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