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Association of canopy temperature depression with yield of durum wheat genotypes under supplementary irrigated and rainfed conditions

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Abstract

The objectives of this study were to evaluate the ability of five selection indices to assess drought tolerance of durum wheat genotypes under a variety of environmental conditions and the relationships of canopy temperature depression (CTD) with drought indices. Eight durum wheat genotypes were planted in the rainfed and supplementary irrigation conditions for two years (2007-2009). 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) was used to estimate crop yield and to rank genotypes. CTD was measured at three stages, from the emergence of fifty percent of inflorescence (Zadoks Growth Scale54) to watery ripe stage (ZGS71). The results showed that the average values of CTD in durum wheat genotypes changed from 3.3 to 5.7°C at the ZGS69 stage. Genotypes in this stage (ZGS69) had highly significant differences and average of CTD showed that durum wheat canopy was the largest value in all ZGSs under both conditions. The significant and positive correlation of YP, MP, GMP, SSI, STI and CTD showed that these indices were more effective in identifying high yield genotypes under both conditions. Results also showed that CTD has played an important role to search physiological basis of grain yield of wheat, and can be successfully used as a selection criterion in breeding programs.

Keywords: canopy temperature depression, drought stress, durum wheat, grain yield

Abbreviations: SSI – stress susceptibility index, STI – stress tolerance index, TOL – stress tolerance, MP – mean productivity, GMP – geometric mean productivity, YS – grain yield under drought condition, YP– grain yield under normal conditions, CTD– Canopy Temperature Depression, ZGS– Zadoks Growth Scale

Introduction

Durum wheat is one of the most important cereal crops which is better adapted to semi-arid conditions. Durum wheat is grown on 10% of the world wheat area. It occupies approximately 11 million ha in the Mediterranean basin. The world's durum wheat acreage is concentrated in the Middle East, North Africa, the former USSR, the North American Great Plains, India, and Mediterranean Europe (Golabadi et al., 2006). In spite of its low acreage, durum wheat is an economically important crop because of its unique characteristics and end products. Iran has had an important durum breeding program in recent years, supported by both International Maize and Wheat Improvement Center (CIMMYT) and International Centre for Agricultural Research in Dry Areas (ICARDA). Increasing the genetic potential of yield in water deficit condition is one of 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 overall plant water status (Ehrler 1972; Blum et al., 1982; Jackson et al., 1981; Idso 1982) and used in such practical applications as evaluation of plant response to environmental stress (Ehrler et al., 1978; Idso etal., 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; 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

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

Genotype Code	Name and Pedigree
G1	GREEN-14//YAV-10/AUK
G2	BCR//MEMO/GOO/3/STJ7
G3	SERRATOR-1//SRN-3/AJAIA-15
G4	GA//2*CHEN/ALTAR84
G5	D68-1-93A-1A//RUFF/FG/3MTL-5/4/LAHN
G6	BCR/3/CH1//GTA/STK/4/BCR/LKS4ICD92-01 50-CABL -11AP-0AP-8AP-0TR-4AP-0AP
G7	BISU-1//CHEN-1/TEZ/3/HUI//CIT71/CLL
G8	SEIMAREH

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

Month	2007-08 Season		2008-09 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

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 and Balota et al., 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 effected 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 is generally comes by mass selection in early generations like F_3. According to this method, firstly, bulks which show high CTD value (have cool canopy) were selected in F_3 generation. Later, single plants which show high stomata conductance (g) with cool canopy among bulks at the same selection generations, were used in drought 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) for wheat cultivars. 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

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

Source	Degree of Freedom	Mean Square	F. Value
Environment (Year×Condition)	3	46490612	35.583^{**}
Error 1	12	1306536	-
Genotype	7	1576409	6.956^{**}
Genotype×Environment	21	883514	3.898^{**}
Error 2	84	226622	-
Total	127	-	-

*P<0.05 and ** P<0.01

Table 4. Drought tolerance indices and two first Principal Components of 18 durum wheat genotypes under supplementary and rainfed conditiond

Genotypes Code	YS	YP	TOL	MP	GMP	SSI	STI
G1	3137.7	5277.8	2140.0	4207.7	4067.7	2.069	0.620
G2	3342.0	4839.1	1497.1	4090.6	4018.4	1.586	0.605
G3	3100.5	4878.3	1777.8	3989.4	3888.3	1.869	0.570
G4	3553.8	4815.8	1262.0	4184.8	4125.8	1.351	0.645
G5	3772.0	4757.0	985.0	4264.5	4233.0	1.070	0.681
G6	3374.4	5468.4	2094.0	4421.4	4293.1	1.962	0.692
G7	3626.2	4349.0	722.9	3987.6	3970.4	0.856	0.592
G8	2697.5	4052.8	1355.3	3375.2	3300.6	1.724	0.411

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) used SSI criterion and suggested that SSI more than 1 indicates 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) found the relative significance of antioxidative enzymes, photosynthetic activity and membrane permeability at seedling stage in drought-tolerant and susceptible maize genotypes. Sanjeewanie Ginigaddara and Ranamukhaarachchi (2009) determined effects of reduced irrigation period on growth and yield of rice in order to conservation of irrigation water beyond SRI practices while increasing or maintaining rice yields. Mostafa Kamal et al. (2010) also determined induction of specific proteins by abiotic stress, particularly heat shock, drought, cold, salt and others environmental stress by proteomic approaches. The objectives of this study were (i) to evaluate the ability of several selection indices to identify drought tolerance cultivars under a variety of environmental conditions and (ii) to determine the relationships of CTD with drought indices, grain yield and yield components in eight durum wheat genotypes in Gachsaran, semi-warm condition of Iran.

Materials and methods

Plant materials

Trial was conducted in 2007-2008 and 2008-2009 growing seasons at Gachsaran agricultural research station situated at 710 meters altitude above sea level with longitude 50° 50' east and latitude 30° 20' north located in south-western of Iran. Soil texture of experimental site is silty clay loam with 460 mm of 20 years rainfall average. In this study, eight durum wheat genotypes (Table 1) were planted into two sets (4 replicates included on each set) using a randomized complete block design in four replicates under two supplementary irrigation and rainfed conditions. Plots were planted at a seeding rate of 300 seed per m^2 by WINTERSTEIGER AG trial drilling machine on 25 November 2007 and 28 November 2008. Plot size was containing 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 detected 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 similar to: average monthly temperature and rainfall

Table 5. Correlation coefficients between YP, YS and drought tolerance indices

	YS	YP	TOL	MP	SSI	GMP	STI
YS	1	-0.143	-0.619*	0.452	-0.690*	0.643*	0.643*
YP		1	0.833**	0.667*	0.738**	0.501	0.501
TOL			1	0.357	0.976**	0.119	0.119
MP				1	0.286	0.952**	0.952**
SSI					1	0.048	0.048
GMP						1	0.988**
STI							1

*P<0.05, ** P<0.01, *** P<0.0001,

Table 6. Correlation coefficients among CTD values, drought indices, grain yield and its components in durum wheat genotypes in stress and non-stress conditions

CTDs	YS	YP	TOL	MP	STI	CTD ZGS 69	CTD ZGS 71
	Rainfed Condition						
CTD,ZGS 54	0.419	0.671*	0.371	0.958**	0.898**	0.451	0.106
CTD,ZGS 69	-0.563*	0.790**	0.946**	0.419	0.179	1.000	-0.543*
CTD,ZGS 71	0.655*	-0.594*	-0.752**	0.012	0.218	-0.543*	1.000
	Supplementary Irrigation Condition						
CTD,ZGS 54	0.554*	0.554*	0.229	0.904**	0.120	0.164	-0.109
CTD,ZGS 69	-0.479	0.551*	0.755**	0.395	0.838**	1.000	-0.300
CTD,ZGS 71	0.533	-0.583*	-0.761**	-0.190	-0.672*	-0.300	1.000

*P<0.05, ** P<0.01, *** P<0.0001

according to months (November to June) in Table 2. Total rain amount were 334.4 and 231.7 mm in 2007-2008 and 2008-2009 growing seasons respectively, although, from emergence of eighty percent of inflorescence to completing of 50 percent anthesis, rain amount were zero for 18 and 29 days, respectively. Maximum air temperature at measurement dates (14, 16 & 23 March and 6 & 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 reports 2008 and 2009). Twice irrigation for trial under supplementary irrigation condition at 18 March, 10 April 2008, and 20 March, 15 April 2009 were conducted.

Measurement of Canopy Temperature

CTD measurements were made by infrared thermometer (Model 8866, JQA Instrument, Inc., Tokyo, Japan) which was focused to 10:1 meter and at late morning to early afternoon cloudless periods (10:00 to 14:00 hours). As similar to 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 defines 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 determined by testing against the error mean square. Genotypes means over all dates were compared by the least significant difference method at P < 0.05 by Genstat 11 statistical packed program. Correlations between two traits were evaluated by MINITAB 14.

Results and Discussion

The result of combined analyses of variance for grain yield, in supplementary irrigation and rainfed conditions for two years is shown in Table 3. In this table environment that defined as combination of year × condition and the genotypes showed highly significant difference at 0.01 probability level for grain yield; suggesting that high potential yield under optimal conditions does not necessarily result an improved yield under rainfed conditions. Thus, indirect selection for a drought prone environment based on

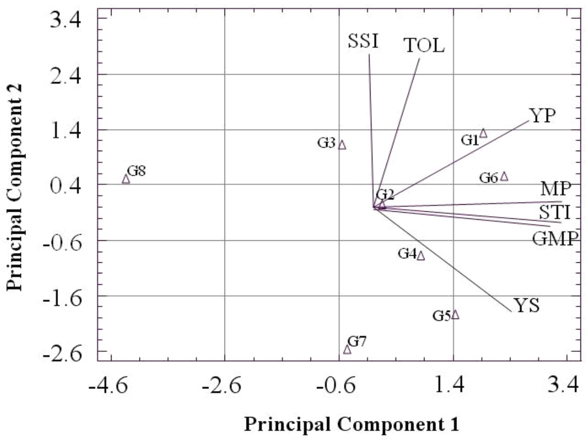

Fig 1. Biplot of Principal component analysis of drought tolerance indices

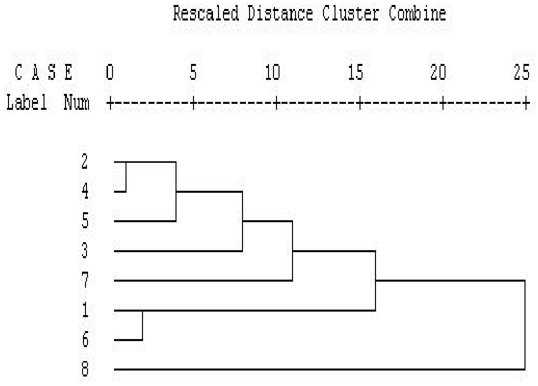

Fig 2. Dendrogram of durum genotypes on drought tolerant indices

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 (G×E) 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 4). As shown in Table 4, 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 between TOL and YP and the significant and negative correlation between TOL and YS indicated this relation very well (Table 5). This suggests 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 the present study, yield under irrigation, was about 45% higher than yield under rainfed. Since MP is a mean production under both rainfed and supplementary irrigation conditions, it will be correlated with yield under supplementary irrigation condition (Talebi et al., 2009). SSI showed a significant and negative correlation with yield under rainfed and significant and positive correlation with supplementary irrigation condition (Table 5). SSI has been widely used by researchers to identify sensitive and tolerant genotypes (Clarke et al., 1992; Sio-Se Mardeh et al., 2006; Golabadi et al., 2006; Talebi et al., 2009). There was a positive significant correlation between STI or GMP and yield under rainfed (Table 5). It was conclude that GMP 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, SSI, and TOL) and YS and (TOL, SSI, GMP and STI). The observed relations were in consistence with those reported by Fernandez (1992) in mungbean, Farshadfar and Sutka (2002) in maize, Talebi et al., (2009) and Golabadi et al., (2006) in durum wheat. The correlation coefficient for rainfed tolerance (TOL) vs grain yield under stress was r= -0.619. Thus, selection for tolerance, in the moisture rainfed environment, should decrease yield, and contrary increase grain yield under supplementary irrigation (r=0.833). 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 0.667 and 0.452, respectively. Fernandez et al., (1992) proposed STI index which 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 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 0.69 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 0.30 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. Therefore, genotypes 1(Green-14) and 6(BCR/3/CH1…) were superior genotypes for both environments with high PC1 and low PC2. Genotypes 2(BCR//MEMO/…), 4(GA//2*CHEN/…) and 5(D68-1-93A-1A//RUFF/…) 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 better comparison of genotypes, cluster analysis used in this research (Fig 2). Four groups are determined by application of cluster analysis and drought indices. It indicated that genotypes 1 and 6 located in the first group. This genotype was the best genotype for both rainfed and supplementary irrigation environments. Genotypes 2, 4 and 5 located in the second group. These genotypes were suitable for supplementary irrigation condition. Genotypes 7 and 3 located in group three. These genotypes were tolerant to drought and suited for rainfed condition

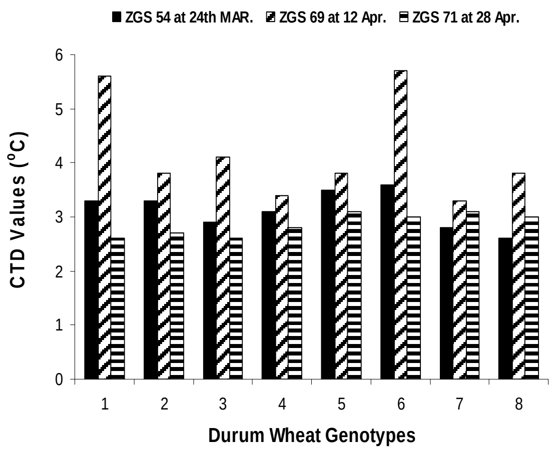

Fig 3. CTD (Canopy Temperature Depression) values of durum wheat genotypes in rainfed condition.

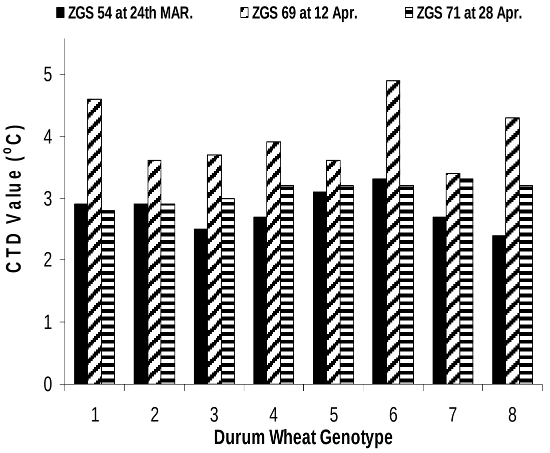

Fig 4. CTD (Canopy Temperature Depression) values of durum wheat genotypes in supplementary irrigation condition

and finally genotype 8 located in the fourth group. This genotype had smallest grain yield and must not be used for both conditions. All previous results were adapted by biplot analysis (Fig 1). The CTDs were measured when half of spikes were visible (ZGS 54), all of spikes were flowering and watery ripe (ZGS 69) and 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 2.6°C (Saimareh) and 3.6°C (BCR/3/CH1//GTA/…) at ZGS 54, between 3.3°C (BISU-1//CHEN-1/…) and 5.7°C (BCR/3/CH1/…) at ZGS 69 and between 2.6°C (GREEN-14// YAV-10/… and SERRATOR-1//SRN) and 3.1°C (D68-1-93A-1A//RUFF and BCR/3/CH1//…) at ZGS 71 in rainfed condition (Fig 3). CTD values changed between 2.4°C (Saimareh) and 3.3°C (BCR/3/CH1//GTA/…) at ZGS 54, between 3.4°C(BISU-1//CHEN-1/…) and 4.9°C(BCR/3/CH1// GTA/) at ZGS 69 and between 2.8°C (GREEN-14//YAV-10/…) and 3.3°C (BISU-1//CHEN-1/…) at ZGS 71 in supplementary irrigation condition (Fig 4). Differences among genotypes have been significantly out of measurements on 12th April (ZGS 69). Rees et al. (1993) reported that CTD values have been changed between 3.54 and 5.10 °C before anthesis, 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, 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, the same situation has been identified; for instance, CTD values have been observed such as 5.7 and 5.6 °C in G6 and G1, before heading, at heading and grain filling periods in rainfed condition, respectively. It is known that these genotypes have colder plant canopy than other cultivars. Also, Barma et al., (1997) showed that CTD values could have been changed sometimes between -2.4 and -5.5 °C. At the stage of ZGS 54, these values changed between 3.42 °C (Porron4/Yuan1) and 4.13 °C (NN-90.E-3-14). In this research, in supplementary irrigation condition, CTD values recorded as 4.2, 4.6 and 4.2 ºC in G15, G1 and G9, before heading, at heading and grain filling periods, respectively. In rainfed condition CTD values of ZGS 54 in durum wheat showed significant and high positive correlation with YP, MP and STI indices. CTD values of ZGS 69 showed significant correlation with YS, YP and TOL and showed significant correlation with ZGS 71 (Table 6). Result of correlation between ZGS 71 was similar to ZGS 69. In supplementary irrigation condition CTD values of ZGS 54 showed positive and high positive correlation with YS, YP and MP indices. CTD values of ZGS 69 showed significant and positive correlation with YP, TOL and STI tolerance indices and did not show significant correlation with ZGS 54 and 71. Finally, CTD values of ZGS 71 showed negative and high positive correlation with YP, TOL and STI indices, respectively. This study showed that durum wheat planted in rainfed condition has stayed colder than supplementary irrigation condition. Tolerance indices including STI, GMP and MP were able to identify cultivars, producing high yield in both conditions. When the stress was severe, TOL, SSI and SSI 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, potential yield greatly influences yield under stress (Blum, 1996; Panthuwan et al., 2002). Two thoughts 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 Ud-din 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 has been 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 the yield of some genotypes significantly and some of them revealed tolerance to drought, which suggests the genetic variability for drought tolerance in this material. Therefore, based on these 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. The results of 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 the stress severity of the environment into account 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 such as irradiance, air temperature, wind speed, and vapour pressure deficit. Fairly consistent rankings for genotypes can be obtained, if suitable days are used for CTD measurement, in terms of sufficiently high irradiance, low wind speed, no rainfall, and sufficient vapor pressure deficit to permit transpiration. However, measurements should be made in a shortest time as possible. It is doubtful whether the readings from different days can be combined without introducing a large error from genotype × environment interaction (Balota 2007).

Conclusion

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

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