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The Study of temperature depression and its association with grain yield in six wheat cultivars under heat stress conditions and salicylic acid application

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ABSTRACT- In order to evaluate canopy and organs temperature depression (TD) under heat stress conditions and the effects of plant morphology on organs temperature depression and their association with grain yield, two field experiments were conducted using six wheat cultivars (Behrang, Chamran, Kauz, Koohdasht, Karim and Montana) planted on three dates (early, optimum, late) in 2014-2015 and 2015 -2016 cropping seasons in Dashtestan, Bushehr, Iran. In addition, three concentrations of salicylic acid (0, 0.5 and 1 mM) were applied to alleviate the effects of heat stress. Canopy and organs (flag leaf, peduncle and spike) temperature were measured by a hand-held infra-red thermometer (IRT). Also, some morphological traits in addition to yield components were measured. Results showed that the effects of cultivars and heat conditions were significant for most of the studied traits but salicylic acid application showed no significant effects. Under late sowing date, canopy and organs temperature depression were significantly higher than those at early and optimum sowing dates. No significant differences were found between early and optimum sowing dates for all temperature depressions. Among cultivars, Behrang had higher canopy temperature reduction (CTD), flag leaf temperature depression (FLTD) and peduncle temperature depression (PTD). Spike temperature depression (STD) was higher in Chamran and Kauz cultivars. Among plant organs, peduncle had higher temperature depression followed by flag leaf and spike. Canopy and organs temperature depression had positive correlation with stomatal conductance and grain yield. This research suggests that temperature depression can be used as an important criterion for the selection of stable genotypes under late sowing conditions. This is very helpful to improve wheat productivity under terminal heat stress resulting from late sowing conditions.

INTRODUCTION

Temperature stress is becoming a major concern for plant scientists due to the changing climate (EPAA 2011). Heat stress can be defined as the rise in temperature beyond a threshold for a period which causes irreversible damage to plant growth and development (Hall 2001). High temperature stress which reduces plant growth and productivity is classified as a major stress for many crops (Hassan 2006). In wheat, when heat stress occurs during reproductive stage, it leads to more yield reduction (Hays et al. 2007). Optimum temperature for wheat grain growth is 15 °C (Chowdhury and Wardlaw 1978). During grain filling, moderately high temperatures of 25°C to 32 °C for longer periods and very high temperatures of 33 °C to 40 °C for a shorter period are common in Mediterranean environments (Stone and Nicolas 1994). Although high temperatures accelerate growth, they also reduce the phenology, which is not compensated for by the increased growth rate (Zahedi and Jenner 2003). When temperature increases from anthesis to grain maturity, grain yield is reduced due to the limited time to gain resources (Gautam 2013). Water status and transpiration play a major role in controlling temperature stress as stress develops (Reynolds et al. 1994). Leaf and canopy temperature can influence on leaf relative water contents (LRWC), leaf water potential, stomatal conductance and rate of transpiration (Farooq et al. 2009). In hot dry environments, higher vapor pressure deficits leads to higher evapo-transpiration (Farooq et al. 2011). Munjal and Rena (2003) have reported that a cool canopy during grain filling stage in wheat crops was physiologically important for heat stress tolerance. The degree of cooling is influenced by the rate of transpiration in a plant canopy (Amani et al. 1996). Canopy temperature can be used to evaluate heat stress in wheat varieties (Balota et al 2007). Fischer et al (1998) reported positive correlations between stomatal conductance and grain yield in wheat under irrigated conditions. Varieties with different canopy architecture may show different canopy temperature (Blum 1988). Some morphological features like leaf color, leaf size, spike size, peduncle length and awns, can affect canopy temperature (Balota et al 2008). Canopy temperature reduction (CTD) which shows the reduction of canopy temperature relative to ambient air temperature indicates the efficiency of transpiration. Canopy temperature depression (CTD) which is defined as the difference between canopy temperature and air temperature, is a positive number in irrigated wheat stands (Bilge et al. 2008). Several authors found that awns reduced canopy temperature in hot and dry environments because they develop later than flag leaf; so they can help the plant to overcome high temperature waves (Blum 1986). Despite the abundance of investigations on canopy temperature depression under heat stress in wheat across the world, studies that explore plant organs temperature depression under high temperature and their associations with grain yield are scarce. In addition, in Dashtestan plain such study has not previously been done. The objectives of this study were designed. (1) to evaluate canopy and organ (flag leaf, peduncle, and spike) temperature depression in some wheat cultivars and their interactions (2) to determine the effect of morpho-physiological traits on organ temperatures and (3) to determine the effect of organ temperatures on grain yield.

MATERIALS AND METHODS

A two- year field experiment was conducted during 2014-2015 and 2015 -2016 cropping seasons at the research field of College of Agriculture, Persian Gulf University, Bushehr, Dashtestan (southwestern part of Iran). Climatically, the area is located in the arid zone with mild winter and hot summer. Average annual rainfall is about 250 mm, mostly concentrated between autumn and winter. Annual relative humidity is about 35%. Also 30-years data of air temperature shows that minimum, optimum and maximum temperatures are 12.5, 22.5 and 34.2°C, respectively. To investigate the impact of heat stress during vegetative and reproductive phases of wheat cultivars in Dashtestan plain, three sowing dates, including Early (1st November), Optimum (22nd November) and Late (5th January), were used to study heat stress. In this study, six wheat cultivars differing in thermo-tolerance including Chamran, Kauz, Montana, Koohdasht, Karim and Behrang were used (Table 1). Some of these cultivars are now cultivated in the area and some other have potential to be introduced and cultivated by farmers of Dashtestan region. To study and assess heat alleviation by hormonal application, salicylic acid (SA) was used in three concentrations (0 mM, 0.5 mM, and 1 mM) during reproductive stage when heat stress occurs. These concentrations were chosen according to the previous studies. A split-split plot design arranged in randomized complete block with three replicates was used for each sowing date in which wheat cultivars and salicylic acid were used as sub plots and sub-sub plots, respectively. According to soil analysis (Table 2), 100 kg ha^{-1} nitrogen as urea (1/3 preplanning and 2/3 at tillering), 90 kg ha^{-1} phosphorus as triple supper phosphate and 90 kg ha^{-1} potassium as potassium sulphate were applied. Drip irrigation system was implemented using PVC pipes and tapes. Each tape was used for two adjacent rows. Seeds were sown in 1.4m×2.8m plots, consisting of 6 rows, at the rate of 450 per square meter maintaining 20 cm between line and 2 cm distance between plants on the rows. The experiment was optimally managed to avoid any stresses, especially water stress. Weeds were controlled manually and chemically and the pesticides were applied to control insects.

For measuring yield and its components, plants of one square meter area in each plot were harvested after maturity. Twenty main stems from each plot were randomly selected to measure individual grain weight, number of spikelets per spike, number of spikes per square meter and number of grains per spike. The number of days to booting (ZGS=40), days to anthesis (50% of spikes showing complete emergence from flag leaf, ZGS=62) and days to maturity (50%of spikes showing no green tissue, ZGS=91) were also reported. Ten observations from randomly selected plants were recorded for peduncle, spike and awn length.

Table 1. Origin and pedigree of wheat cultivars

NO	Cultivar	Origin	Pedigree
1	Behrang	CIMMYT, Mexico	ZHONG ZUO/2*GREEN-3
2	Chamran	CIMMYT, Mexico	ND/VG9144//KAL/BB/3/YACO/4/VEE#5
3	Kauz	CIMMYT, Mexico	JUP/BJY//URES
4	Karim	no info	Triticum aestivum/Sprw “s”//CA8055/3/Baconora88
5	Koohdasht	CIMMYT, Mexico	BB/RON//CNO67/TOTA/3/JAR

Table 2. Physical and chemical soil properties of the experimental site

Soil Depth (cm)	Silt (%)	Sand (%)	Clay (%)	N (%)	K (ppm)	P (ppm)	pH	EC(dSm^{-1})	OC (%)
0-30	23	68	10	0.03	190	8.4	7.3	4.30	0.29

Flag leaf area was measured on five leaves and the average was used. Heat Tolerance Index (HTI) was used to measure heat tolerance as the resistance of plant to reduce its yield caused by unfavorable (late sowing condition) in comparison to favorable (optimum sowing condition) conditions. HTI was calculated according to the formula by Fisher and Maurer (1978):

$$\mathrm{HTI} = \frac{\mathrm{Yp} \times \mathrm{Ys}}{(\overline{\mathrm{Yp}})^2} \quad (1)$$

Where

Ys= mean of grain yield for each cultivar at late sowing condition;

Y_p= mean of grain yield for each cultivar at optimum sowing condition;

$\overline{Yp}$= mean of grain yield of all cultivars at optimum sowing condition;

Temperatures were measured at anthesis (ZGS, 60) and medium milk (ZGS, 75) stages for all three heat conditions. To measure the temperature of organs (flag leaf, peduncle, and spike), five samples were taken for each organ and their average was recorded. Temperature depression (TD) was calculated by subtracting the temperature of the canopy or organs from the ambient air temperature. For measuring temperatures, a hand held IRT (Model IRTS-P, Apogee Instrument, Inc., Logan, UT, USA) was used. For this purpose, the instrument was held at the angle of 30 ° to the horizontal plane, about one meter from the edge of the plot and 50 cm above the plants. For the measurement of organs temperature, the relationship between distance and spot was 10:1. Measurements were taken between 12:00 and 14:00 pm in full sunshine. Stomatal conductance was measured by a hand–held instrument (SC-1 leaf porometer, Decagon Devices Inc. Pullman, Washington, USA). This device measures the actual vapor flux from the leaf through the stomata and out to the environment. About 24 hours after full irrigation, five fully expanded leaves from upper part of three randomly selected plants in each plot were selected and the stomatal conductance was measured. The measurement was done twice during the season, first at the beginning of pollination (ZGS 60) and the second at medium milk (ZGS, 75). For analysis of variance, GLM procedure of statistical analysis system (SAS version: 9.2) was used. Means were compared by LSD test

RESULTS AND DISCUSSION

Average of minimum, maximum and daily temperature in addition to phenological parameters and yield attributes for three sowing dates are summarized in Table 3. At early sowing condition (1st November), during vegetative phase, maximum temperature exceeded 25 °C and the minimum temperature was less than or equal to 15 °C; while at the grain-filling stage, the maximum was recorded as ≥25 °C and the minimum was 10-12 °C. The temperature at the vegetative stage was not suitable for a proper yield performance because maximum temperature was >25 °C (Fig. 1). In contrast, at optimum sowing condition (22nd November), mean maximum temperature in the vegetative stage was near to 20 °C and the minimum was near to 10 °C, but at the grain-filling stage mean maximum temperature also reached to 23 °C and minimum reached to 13-15 °C, which was suitable for good yield in wheat crop. Under late sown condition (5th January), at the vegetative growing stage, maximum temperature was ≥25 °C and minimum ≤10 °C, but at the grain filling stage, maximum temperature was ≥30 °C and the minimum was 19-23 °C (March-April), which is not suitable for proper growth and good yield performance in wheat, because the crop faces hot temperatures as the result of being sown late. In late sown condition, the temperature during germination stage was <10 °C and in the grain-filling stage, it was >30 °C, which affected the growth and development of the late sown crop (Fig. 1). Analysis of variance showed that the effects of year, sowing date, cultivar and their interactions were highly significant (*P*<0.01) for all TD traits but the effect of salicylic acid and its interactions with other factors were not significant, except for canopy temperature depression (CTD_M), flag leaf temperature depression ($FLTD_M$) and peduncle temperature depression (PTD_M) at milk stage (Table 4).

Mean values of canopy and organs-TD at two stages of growth cycle and six cultivars under three heat conditions are presented in Table 5. The comparison of means showed that TDs were different in two years of the experiment and comparatively, the traits in 2015-2016 growing season were higher than those in 2014-2015 growing season except in CTD and PTD at anthesis (Table 4). These differences between years might be due to variation in maximum and ambient air temperatures during wheat growing season in two years (Fig. 1). All TDs were highest at late sowing date and lowest at early sowing date. However, no significant differences were found between early and optimum sowing dates for these traits. Genotypic variability was found for all TDs. For both growth stages, Behrang cultivar had the highest canopy and organ –TD values, followed by Kauz and Koohdasht cultivars. Chamran, Karim, and Montana showed lower TD values (Table 4). Among all temperature depressions, the values recorded at milk stage were higher than those at anthesis. Fig. 2 shows average canopy and organ-TD values in three heat conditions (mean of years, cultivars and growth stages). Peduncle - TD was highest and spike –TD was lowest. The differences among TDs for each sowing date were similar, but there were significant differences between three sowing dates. Late sowing date in comparison with two other sowing dates showed significantly higher TD values. Early and optimum sowing dates showed no significant differences in TD values (Fig. 2).

Table 6 shows the average TD of canopy and organs, stomatal conductance and grain yield for 6 cultivars (mean of years, sowing dates and growth stages). Genotypic variability existed for all TDs but this variability was not similar for all TDs. Behrang, Kauz and Koohdasht had greater temperature reduction and higher CTDs in comparison to other cultivars. Montana showed lowest CTD. For FLTD, the cultivars Behrang, Karim and Koohdasht showed higher values. Genotypes with short peduncle (Chamran and Kauz) showed higher PTD and conversely, genotypes with long peduncle (Behrang, Koohdasht and Karim) showed lower PTDs. For STD, Kauz and Chamran reduced heat better than other cultivars. Higher TD values were associated with higher stomatal conductance and grain yield. Genotypes with higher TD values (Behrang,Koohdasht and Kauz) showed higher stomatal conductance and grain yield.

Table 3. Mean temperatures, phenology and yield attributes of wheat cultivars grown on three sowing dates during 2014-2015 and 2015-2016

Parameters	Sowing dates					
	Early		Optimum		Late	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Average of minimum temperature (whole cycle) ◦c	14.7	13.8	15.5	14.4	16.4	15.2
Average of maximum temperature (whole cycle) ◦c	27.4	26.2	28.9	27.3	29.7	28.6
Mean daily temperature (whole cycle) ◦c	21.1	20.0	22 .3	20.8	23.3	21.5
Average of minimum temperature (grain filling) ◦c	15.8	14.0	18.3	18.1	20.6	19.3
Average of maximum temperature (grain filling) ◦c	28.8	27.2	33.0	32.2	36.2	33.8
Mean daily temperature (grain filling) ◦c	22.3	20.6	25.5	25.1	28.2	26.2
Number of days with temperature exceeding 32◦c	2.8	2.1	10.0	9.0	19.5	16.0
Days to booting	55.1	59.3	64.4	64.6	53.4	53.0
Days to anthesis	77.9	82.1	85.6	87.9	69.6	70.5
Days to maturity	135.1	140.7	131.2	133.7	108.0	110.0
Biomass (t/ha)	14.9	15.9	15.0	15.9	13.0	12.5
Yield (t/ha)	6.32	6.79	6.58	7.12	4.87	4.72
HI (%)	42.6	42.7	44.0	44.8	37.1	37.9
Grains per spike	46.8	49.0	52.5	51.0	54.2	46.1
Spikes per square meter	334.6	389.0	326.6	396.6	461.8	390.2
Thousand kernel weight (g)	46.8	48.9	48.1	48.8	33.0	41.1

Table 4. Combined analysis of canopy and organs temperature depression

Source	df	Mean of squares							
		CTD_A	CTD_M	$FLTD_A$	$FLTD_M$	PTD_A	PTD_M	STD_A	STD_M
Year	1	4.24*	0.513**	0.790**	10.13**	5.81**	1.32**	0.035^{ns}	3.61**
Year (Block)	4	0.121^{ns}	0.182*	0.038*	0.221**	0.275*	0.105^{ns}	0.112 *	0.109*
Sowing date	2	4.71**	3.10**	4.17**	2.07**	5.37**	3.49**	1.98**	1.06**
Year× Sowing date	2	1.21**	0.467**	2.46**	0.259**	1.87**	0.071^{ns}	0.243**	0.120*
Cultivar	5	4.73**	10.87**	6.91**	12.05**	10.62**	13.72**	7.09**	12.09**
Year×Cultivar	5	1.98**	1.50**	3.26**	2.00**	0.88**	1.54**	3.62**	2.11**
Sowing date×Cultivar	10	0.65**	0.49**	0.38**	0.54**	0.41**	0.42**	0.43**	0.36**
Salicylic acid	2	0.56^{ns}	0.73*	0.34^{ns}	0.48*	0.64^{ns}	0.77*	0.29^{ns}	0.59^{ns}
Year×Salicylic acid	2	0.005^{ns}	0.011^{ns}	0.019^{ns}	0.003^{ns}	0.002^{ns}	0.004^{ns}	0.012^{ns}	0.003^{ns}
Sowing date×acid	4	0.008^{ns}	0.026^{ns}	0.008^{ns}	0.018^{ns}	0.026^{ns}	0.014^{ns}	0.008^{ns}	0.010^{ns}
Cultivar×acid	10	0.014^{ns}	0.012^{ns}	0.016^{ns}	0.012^{ns}	0.012^{ns}	0.015^{ns}	0.004^{ns}	0.009^{ns}
Sowing date×cultivar×acid	20	0.018^{ns}	0.013^{ns}	0.020^{ns}	0.013^{ns}	0.015^{ns}	0.008^{ns}	0.006^{ns}	0.005^{ns}
R.error	238	0.096	0.070	0.094	0.072	0.085	0.057	0.042	0.039
C.V (%)	-	7.63	6.24	8.42	7.12	6.31	4.92	6.86	6.26

ns, * and ** are non-significant, significant at the 0.05 and 0.01 Probability level, respectively
df: Degree of freedom, CTD_A /CTD_M: Canopy temperature depression at anthesis /milk stage $FLTD_A$/ $FLTD_M$: Flag leaf temperature depression at anthesis/ milk stage
PTD_A /PTD_M: Peduncle temperature depression at anthesis/milk stage STD_A /STD_M: Spike temperature depression at anthesis/milk stage

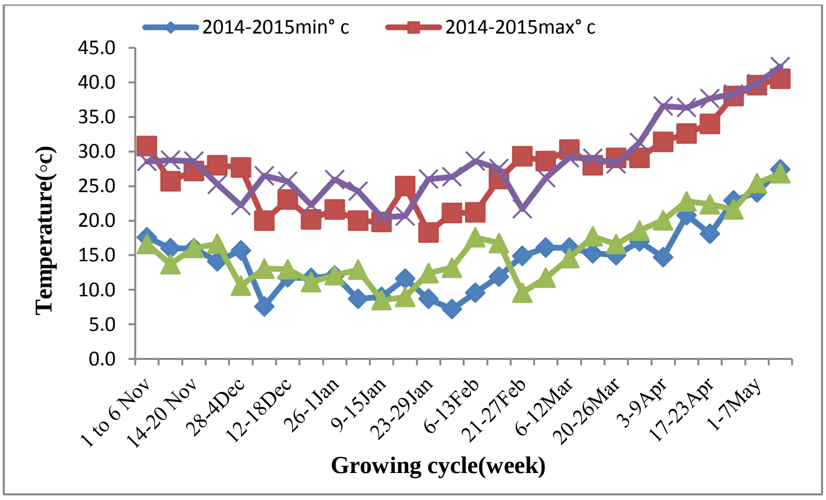

Fig. 1. Weekly minimum (min) and maximum (max) temperatures during wheat-growing cycles and two growing seasons

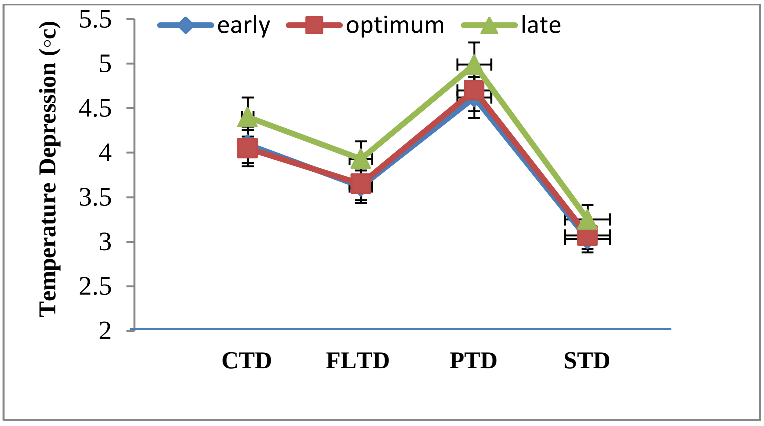

Fig. 2. Average TD (◦**c**) of six wheat cultivars for canopy, flag leaf, peduncle and spike at three sowing dates (mean of two years and two growth stages). **CTD**: Canopy Temperature Depression; **FLTD**: Flag Leaf Temperature Depression **PTD**: Peduncle Temperature Depression; **STD**: Spike Temperature Depression

The correlations between canopy and organs-TD values and some morpho-physiological traits in addition to grain and biological yield are presented in Table 7. All correlations were significantly positive except for peduncle length which was negative. Higher grain yields were associated with high TD values. As it was expected, CTD and FLTD in comparison with PTD and STD had higher correlation with stomatal conductance. Correlations among TD values are presented in Table 8. All TDs were highly associated with each other.

Canopy Temperature Depression (CTD)

Canopy temperature depression (CTD) which shows temperature reduction relative to ambient air temperature shows the efficiency of transpiration in cooling the leaves under environmental heat conditions (smith et al, 1986). Canopies are able to transfer heat to atmosphere by reflection and convection and therefore become cooler than surrounding environment. LAI and stomatal conductance showed positive high association with canopy temperature depression which justified the role of leaf area and stomatal conductance in canopy cooling (Table 7). It was reported that genotypes with different canopy architecture could behave differently in reducing canopy temperature (Blum, 1988). In the current study, the correlation of CTD and grain yield under different heat stress conditions was positive (Table 5) which was in accordance with the results obtained by Ayeneh et al. (2002) and Amani et al. (1996). They indicated that genotypes with cooler canopies had more grain yield. In this study, it was shown that the correlation between TD and yield was associated with relation of TD to stomatal conductance (Table 7).

Flag Leaf Temperature Depression (FLTD)

The values for FLTD were less than those for CTD because flag leaf, spike and peduncle temperatures integrate to canopy temperature. Genotypic differences for FLTD were observed in wheat cultivars (Tables 6 and (7).

Table 5. Means comparison of canopy and organs temperature depression (◦ C) for years, sowing dates and cultivars

Treatments	Traits											
	CTD_A	CTD_M	Mean	$FLTD_A$	$FLTD_M$	Mean	PTD_A	PTD_M	Mean	STD_A	STD_M	Mean
2014-2015	4.17^{a}	4.22^{a}	4.20^{a}	3.59^{b}	3.60^{b}	3.60^{b}	4.77^{a}	4.80^{a}	4.78^{a}	2.99^{a}	3.07^{b}	3.03^{b}
2015-2016	3.95^{b}	4.30^{a}	4.15^{a}	3.69^{a}	3.95^{a}	3.84^{a}	4.50^{b}	4.63^{b}	4.57^{b}	3.01^{a}	3.19^{a}	3.11^{a}
Early	3.96^{b}	4.17^{b}	4.11^{b}	3.51^{b}	3.68^{b}	3.60^{b}	4.49^{b}	4.71^{b}	4.62^{b}	2.89^{b}	3.12^{b}	3.03^{b}
Optimum	3.92^{b}	4.14^{b}	4.09^{b}	3.53^{b}	3.72^{b}	3.63^{b}	4.53^{b}	4.82^{b}	4.68^{b}	2.96^{b}	3.13^{b}	3.07^{b}
Late	4.30^{a}	4.45^{a}	4.37^{a}	3.86^{a}	3.93^{a}	3.90^{a}	4.89^{a}	5.06^{a}	4.97^{a}	3.16^{a}	3.29^{a}	3.22^{a}
Monthana	3.27^{d}	3.41^{d}	3.34^{d}	3.29^{c}	3.48^{c}	3.38^{c}	4.45^{b}	4.48^{b}	4.47^{b}	2.39^{c}	2.57^{d}	2.46^{C}
Kauz	4.15^{a}	4.08^{b}	4.12^{a}	3.35^{b}	3.65^{b}	3.55^{b}	4.62^{c}	4.77^{b}	4.70^{c}	3.05^{a}	3.17^{a}	3.11^{a}
Chamran	3.65^{c}	3.80^{c}	3.72^{c}	3.48^{b}	3.65^{b}	3.56^{b}	5.15^{b}	5.24^{b}	5.20^{b}	3.06^{a}	3.19^{a}	3.13^{a}
Koohdasht	3.90^{b}	3.97^{b}	3.94^{b}	3.71^{a}	3.85^{a}	3.78^{a}	4.09^{a}	4.14^{a}	4.11^{a}	2.81^{b}	2.87^{bc}	2.83^{b}
Karim	3.86^{b}	4.01^{b}	3.94^{b}	3.69^{a}	3.94^{a}	3.82^{a}	4.01^{b}	4.04^{b}	4.02^{b}	2.70^{b}	2.80^{c}	2.75^{b}
Behrang	4.09^{a}	4.42^{a}	4.25^{a}	3.79^{a}	4.00^{a}	3.92^{a}	4.05^{a}	4.35^{a}	4.20^{a}	2.85^{b}	3.06^{a}	2.94^{ab}

Means, in each column, followed by similar letter are not significantly ($P > 0.05$) different based on LSD test.
CTD_A: Canopy temperature depression at anthesis, CTD_M: Canopy temperature depression at milk stage, $FLTD_A$: Flag leaf temperature depression at anthesis, $FLTD_M$: Flag leaf temperature depression at milk stage, PTD_A: Peduncle temperature depression at anthesis, PTD_M: Peduncle temperature depression at milk stage, STD_A: Spike temperature depression at anthesis, STD_M: Spike temperature depression milk stage

Table 6. Canopy and organs temperature depression, stomatal conductance and yield for six cultivars (mean of years, sowing dates and growth stages)

No.	Cultivars	TD (° C)				S.C	GY
		CTD	FLTD	PTD	STD	(mmol m^{-2} s^{-1})	(Kg/ha)
1	Behrang	4.27^{a}	3.92^{a}	4.19^{c}	2.94^{ab}	550.1^{a}	6953.1a
2	Koohdasht	4.04^{a}	3.77^{a}	4.11^{c}	2.83^{b}	511.6^{a}	6636.3b
3	Kauz	4.13^{a}	3.55^{b}	4.69^{c}	3.10^{a}	547.7^{a}	6410.5bc
4	Chamran	3.71^{b}	3.56^{b}	5.17^{a}	3.13^{a}	485.5^{b}	6283.3c
5	Karim	3.95^{b}	3.82^{a}	4.01^{c}	2.75^{b}	442.8^{b}	6225.4c
6	Monthana	3.35^{b}	3.39^{b}	4.45^{b}	2.46^{C}	436.7^{c}	4665.5d

Means, in each column, followed by similar letter are not significantly (***P*** > 0.05) different based on LSD test.
TD: Temperature Depression, CTD: Canopy Temperature Depression; FLTD: Flag Leaf Temperature Depression; Gy: Grain yield; PTD: Peduncle Temperature Depression; S.C: Stomatal Conductance; STD: Spike Temperature Depression

Table 7. The correlations between canopy and organs – TD (average of three heat conditions over two years) and some morpho-physiological traits of six wheat cultivars. Simple correlation between canopy and organs – TD (average of three heat conditions over two years) and some morpho-physiological traits of six wheat cultivars

	Boot	Anth	Matu	Pedun	Awn	LAI	S.C	Sp/m^2	GY	BY
CTD	0.54*	0.61**	0.66**	-0.51*	0.56*	0.76*	0.88**	0.74**	0.85**	0.79**
FLTD	0.45*	0.57*	0.62**	-0.43*	0.53*	0.70*	0.81**	0.55*	0.81**	0.72**
PTD	0.37	0.40*	0.47*	-0.64**	0.48*	0.58*	0.65*	0.63**	0.74**	0.66**
STD	0.44*	0.43*	0.40*	-0.49*	0.59*	0.56*	0.57*	0.71**	0.83**	0.69**

* Significant at p=0.05 ** Significant at p=0.01
Boot: Days to booting; Anth: Days to anthesis; Matu: Days to maturity; Pedun: Peduncle length; Awn: awn length; LAI: leaf area Index; S.C: Stomatal Conductance; Sp/m^2: Spike per square meter; Gy: Grain yield; BY: Biological yield; CTD: Canopy Temperature Depression; FLTD: Flag Leaf Temperature Depression; PTD: Peduncle Temperature Depression; STD: Spike Temperature Depression

These differences may be associated with variation in LAI, stomatal conductance and flag leaf area. Stepwise regression of FLTD with important traits such as flag leaf area, chlorophyll content, stomatal conductance and peduncle length showed that 63% of the variance in FLTD was explained by differences in stomatal conductance and flag leaf area (Table 9).Leaf rolling can affect canopy temperature. It was shown that the inside part of rolled leaf was cooler than the outside surface (Ayeneh et al. 2002). In our study, leaf rolling could not be measured but some leaf rolling which was known to reduce transpiration, was observed in a few cultivars such as Kauz. Genotypes which are able to roll their leaves, avoid stress (mainly drought) by reducing water loss from their leaves. Under flag leaf rolling, transpiration is continued steady and stable with low rate.

Table 8. Simple correlation between canopy and organs – TD

Organs	CTD	FLTD	PTD
FLTD	0.89***		
PTD	0.89***	0.89***	
STD	0.89***	0.89***	0.89***

Significant at *P*=0.01*Significant at ***P***=0.001

CTD: Canopy Temperature Depression; FLTD: Flag Leaf Temperature Depression;
PTD: Peduncle Temperature Depression; STD: Spike Temperature Depression

Peduncle Temperature Depression (PTD)

Among all organs, peduncle temperature depression was highest under all conditions. Small area of peduncle compared to leaves and spikes may result to less energy absorption and better ability to conduct and convert heat to atmosphere. Negative correlation of PTD with peduncle length, shows that as the peduncle becomes longer, its ability to cool itself, reduces. Genetic variability observed among wheat cultivars.
Varieties such as Koohdasht, Karim, Behrang with more peduncle length, showed less PTD compared to Chamran, Kauz and Montana with short peduncle. Under late sowing condition (heat stress), peduncle reduced temperature more than canopy and other organs for both growth stages (anthesis and milk).

Spike Temperature Depression (STD)

Among plant organs, spikes showed the lowest temperature depression. This may result from this fact that spikes do not transpire well and their temperatures are near to ambient air temperature. This was correspondent with the results obtained by Hatfield et al (1984) and Ayeneh et al (2002). However, Amani et al. (1996) reported that spikes could reduce their temperature well below air temperature. STD correlated with all traits positively except with peduncle length which showed negative correlation. This result shows that in genotypes with long peduncles, spikes maintain more temperature and consequently have less temperature depression. In the current study, genotypes with long peduncle (Behrang, Koohdasht, Karim and Monthana) showed less STD and genotypes with short peduncles (Chamran, Kauz) showed higher STD. When spikes are far from remaining canopy (stems and leaves) by long peduncles, heat exchange between spike and leaf canopy, declines and low CTD is resulted. STD had close association with canopy architecture and grain yield (Table 6). Step regression of STD with LAI, peduncle length, flag leaf area and stomatal conductance showed that 55% of STD values were explained by peduncle length and awn length (Table 9). Awn length had positive relations with canopy and organs temperature depression. This justifies the role of awn in cooling canopies mainly in cultivars in hot, dry conditions. Developing wheat cultivars with long awns may help to have a cool canopy especially for hot regions. At late sowing date which induced more heat stress to the canopy, STD was higher than early and optimum sowing dates.

Associations of Canopy and organs-TD with Grain Yield and HTI

Canopy and organs -TD showed positive associations with grain yield (Fig. 3) and heat tolerance index (Fig. 4). It was reported that high temperatures reduced the duration and rate of grain filling and consequently, affected grain yield negatively (Acevedo 1991). In the current study, grain yield was determined mostly by thousand kernel weight. Low grain filling rate reduced kernel weight. Positive association between CTD and grain filling rate (data not mentioned) showed that genotypes with cool canopy, had higher grain filling rate and duration. Among genotypes, those with higher temperature depression showed more grain yield (Table 6). The positive correlation between HTI and canopy and organ temperature depression proves that TD can be used as a tool to identify genotypes adapted to hot, dry conditions.

CONCLUSIONS

In this study, differences in canopy and organs (flag leaf, peduncle, spike) temperature depression were observed among cultivars under different heat conditions. Late sowing date (induced much heat stress) in comparison with other two sowing dates (early and optimum) showed significantly higher TD values.

Among cultivars, Behrang and Koohdasht had higher CTD, FLTD and PTD but Chamran and Kauz had higher STD. Variation in LAI, stomatal conductance and peduncle length resulted to differences in canopy temperature depressions. Positive Correlation of organs –TD with awn length and negative with peduncle length showed that increasing the number and their size of awns and decreasing peduncle length might increase cooling effects. The results of this research can be used to identify heat sensitive and tolerant lines and genotypes under different heat conditions.

Table 9. Stepwise regression for FLTD and STD

Step Entered	Variable	Number Variables In	Partial R-Square	Model R-Square	C(p)	F Value	Pr>F
FLTD							
1	SC	1	0.474	0.475	22.19	10.13	0.001
2	FLA	2	0.165	0.626	5.13	6.05	0.009
STD							
1	PL	1	0.512	0.512	8.02	38.1	0.001
2	AL	2	0.041	0.553	10.33	1.9	0.01

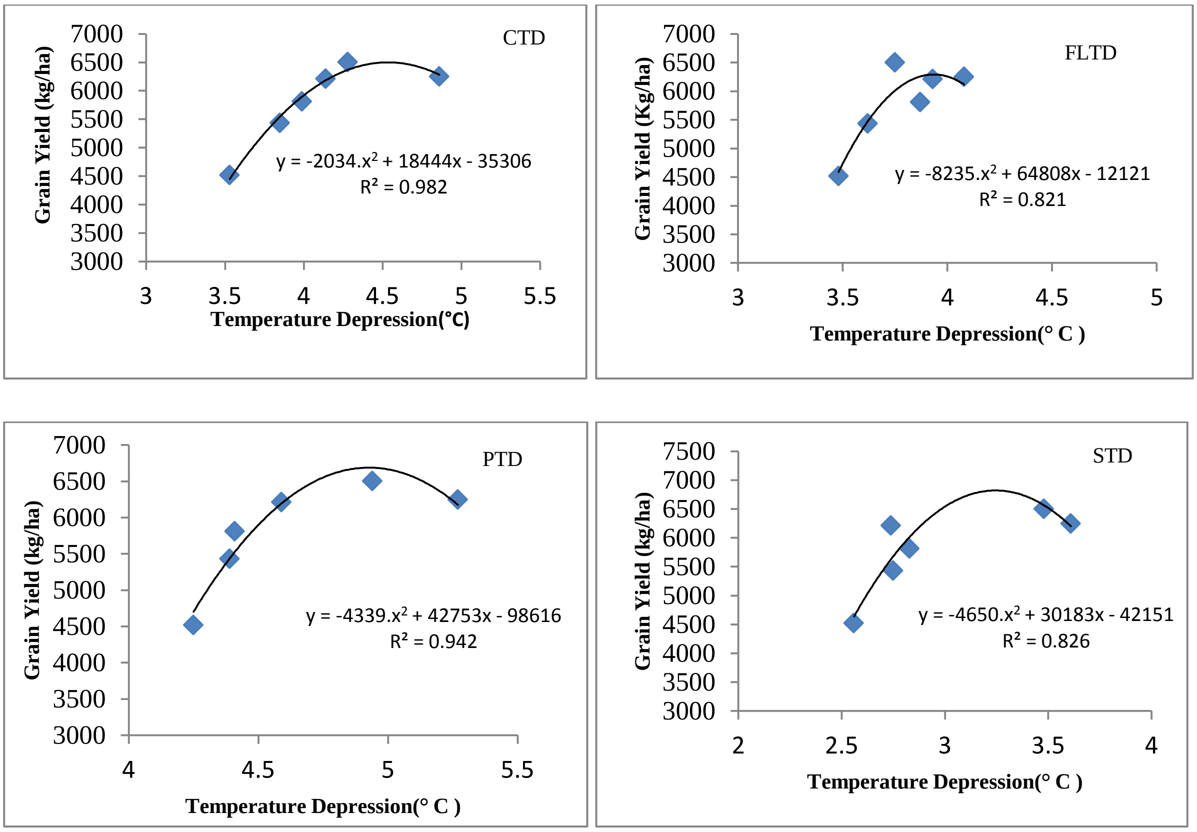

Fig. 3. Regression of PTD, STD, FLTD and CTD (°C) on Grain Yield; CTD: Canopy Temperature Depression; FLTD: Flag Leaf Temperature Depression; PTD: Peduncle Temperature Depression; STD: Spike Temperature Depression

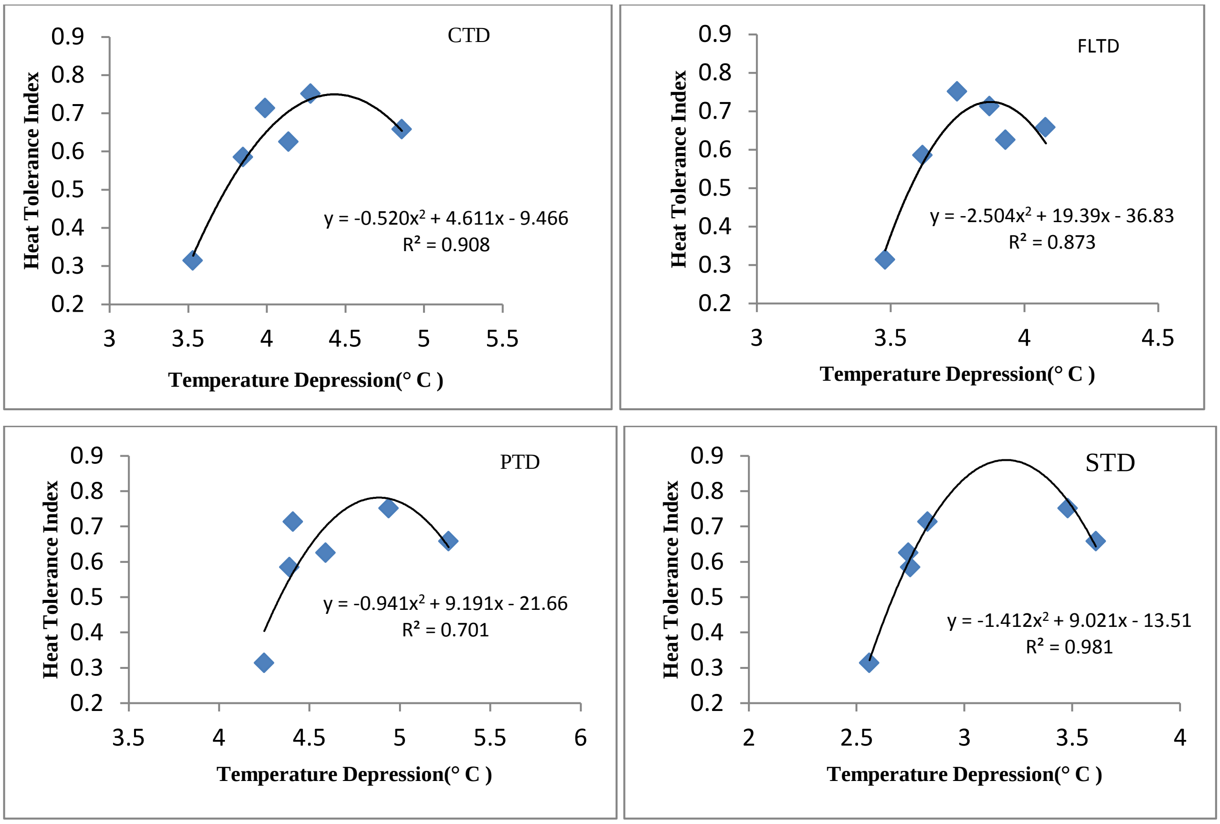

Fig. 4. Regression of PTD, STD, FLTD and CTD (°C) on Heat Tolerance Index; CTD: Canopy Temperature Depression; FLTD: Flag Leaf Temperature Depression; PTD: Peduncle Temperature Depression; STD: Spike Temperature Depression

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مطالعه تنزل دمایی و ارتباط آن با عملکرد در شش رقم گندم تحت شرایط تنش گرمایی

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چکیده – به منظور ارزیابی تنزل دمای سایه انداز و اندام های گیاهی تحت شرایط تنش گرمایی و اثر مورفولوژی گیاهی بر روی این تنزل و همچنین ارتباط آن با عملکرد دانه، دو آزمایش مزرعه بر روی شش رقم گندم (بهرنگ،کاز، چمران، کوهدشت، کریم و مانتانا) در سه تاریخ کاشت (زود، مناسب و تاخیری) در فصل های کاشت ۹۴-۹۳ و ۹۵-۹۴ در منطقه دشتستان استان بوشهر انجام گرفت. علاوه بر این، به منظور تعدیل اثر تنش گرمایی، سالیسیلیک اسید در غلظت های صفر ،۰/۵ و ۱ میلی مولار مورد استفاده قرار گرفت. دمای سایه انداز و اندام ها (برگ پرچم، پدانکل و سنبله) با استفاده از دماسنج مادون قرمز دستی اندازه گیری گردید. همچنین علاوه بر اجزای عملکرد ،تعدادی از صفات مورفولوژیکی مورد اندازه گیری قرار گرفتند. نتایج نشان داد که اثر رقم و شرایط گرمایی (تاریخ کاشت) بر روی اغلب صفات مورد بررسی معنی دار بود. اما اثر کاربرد سالیسیلیک اسید معنی دار نبود. تنزل دمای سایه انداز تحت شرایط کشت تاخیری نسبت به کشت مناسب و زود بیشتر بود. بین شرایط کشت مناسب و زود اختلاف معنی دار وجود نداشت. در بین ارقام، رقم بهرنگ دارای تنزل دمای سایه انداز، تنزل دمایی برگ پرچم و تنزل دمایی پدانکل بیشتری بود. تنزل دمایی سنبله در ارقام چمران و کاز از همه بیشتر بود. در بین اندام های گیاهی، پدانکل تنزل دمایی بیشتری را نشان داد و بعد از آن برگ پرچم و سنبله قرار داشتند. تنزل دمای سایه انداز و اندام ها رابطه مثبت و معنی داری با هدایت روزنه ای و عملکرد دانه داشت .این پژوهش بیان می کند که تنزل دمایی می تواند به عنوان یک معیار مهم جهت انتخاب ارقام پایدار تحت شرایط تنش گرمایی مورد استفاده قرار گیرد و می تواند به بهبود عملکرد و بهره وری گندم تحت شرایط تنش گرمایی پایان فصل کمک کند.