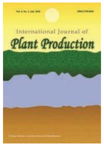

International Journal of Plant Production 11 (4), October 2017
ISSN: 1735-6814 (Print), 1735-8043 (Online) www.ijpp.info
DOI: 10.22069ijpp.2017.3717

GUASNR

The impact of terminal heat stress on yield and heat tolerance of bread wheat

A. Moshatati[a,*], S.A. Siadat[a], Kh. Alami-Saeid[a], A.M. Bakhshandeh[a], M.R. Jalal-Kamali[b]

[a]*Department of Agronomy and Plant Breeding, Ramin Agriculture and Natural Resources University of Khouzestan, Ahwaz, Iran.*
[b]*International Maize and Wheat Improvement Center (CIMMYT), Karaj, Iran.*
*Corresponding author. E-mails: A.Moshatati@ramin.ac.ir & Alimoshatati@gmail.com

Received 27 January 2017; Accepted after revision 20 August 2017; Published online 3 October 2017

Abstract

In arid and semi-arid regions of the world bread wheat (*Triticum aestivum* L.) yield is highly limited due to late season heat stress, mostly occurring during the reproductive phase. Hence the current study was conducted to evaluate the effect of late season heat stress on grain yield and yield components of 20 spring bread wheat cultivars. For this purpose, a stripe block experiment including four sowing dates (6th of November, 6th of December, 5th of January and 4th of February) as vertical plots and 20 cultivars in horizontal plots was implemented with three replicates in North-East of Ahwaz, Khuzestan, Iran during 2007-2008 and 2008-2009 growing seasons. The results indicated that the main effect of year, sowing date, cultivar and interaction between sowing date and cultivar were significant for all studied traits. However, no significant interaction was found between year and other factors. Comparison of means showed that grain yield in the second year was higher than the first year. The maximum and minimum values (6.048 ton ha^{-1} and 1.754 ton ha^{-1}) were obtained when seed sowing was performed on 6th of November and 4th of February, respectively. The maximum grain yield (5.019 ton ha^{-1}) was related to Atila cultivar whereas the minimum yield (3.662 ton ha^{-1}) was obtained from Inia 66 cultivar. In general, the maximum and minimum grain yields were produced by Atila cultivar sown on 6th of December and Seri82 and Roshan sown on 4th of February, respectively. The results suggest that Arvand, Vee/Nac, Atila and Baiat cultivars as heat tolerant cultivars and Roshan, Hamoon, Seri82, Star, Inia66 and Darab2 as susceptible cultivars may be used in heat tolerance studies.

Keywords: Wheat; Terminal heat stress; Cultivar and grain yield.

Introduction

Wheat is the most important cereal crop in the world and the first staple food crop in Iran. For instance, in 2014, wheat harvested area was reported as 222 million ha with 729 million ton production as compared to 163 million ha and 741 million ton of rice and 183 million ha and 1038 million ton of corn (FAO, 2016). During 2013-2014 growing seasons, about 6.1 million ha land was allocated to wheat in Iran of which 2.3 million ha were irrigated and 3.8 million ha were rain-fed. In addition, the total production reached to 10.6 million ton of which 67% was produced from irrigated land (average yield of 3.1 ton ha^{-1}) and 33% was produced from dry-land (average yield of 0.9 ton ha^{-1}) (MAJ, 2016).

Wheat is often grown as a winter type crop in subtropics regions, despite the relatively high temperatures that occur during spring (Reynolds et al., 1994). But with the increased availability of adapted semi-dwarf germplasms, wheat production has expanded into warmer regions, where production had been restricted to higher altitudes or cooler latitudes (Badaruddin et al., 1999). Over 7 million ha of land allocated to wheat are located in about 50 countries suffering from continual late season heat stress, namely in environments with mean daily temperatures greater than 17.5 °C in the coolest month (Fischer and Byerlee, 1991). There are areas across the world where the temperature in the spring months rises and crops are exposed to late season heat stress, especially during the critical period of grain filling (Rane et al., 2007). Late season heat stress can be a major concern in up to 40% of the irrigated wheat-growing areas in developing countries, as well as in developed countries, which covers 36 million ha (Reynolds et al., 2001). Several studies under controlled conditions have confirmed that rise in temperature above a daily average temperature of 15 °C during grain filling period reduced grain yield (Gibson and Paulson, 1999; Wardlaw, 2002). In Mediterranean climates, like South-West of Iran, late season heat stress, occurring during anthesis and grain filling period, is an important environmental stress that limits spring bread wheat grain yield up to 40% in 10% of the total cultivated area (Jalal Kamali and Duveiller, 2008). In Khuzestan Province, late sowing is responsible for a significant wheat yield loss compared with cooler regions, as temperatures often exceed 30 °C during the grain filling period (Figure 1). Late season heat stress, often occurring during the last phases of spring wheat development, (booting, heading, anthesis and grain filling period) is considered as one of the major environmental limiting factors that drastically reduces grain number per spike, grain weight and final grain yield throughout most of the bread wheat growing areas in the region and other warm and dry regions of Iran (Modhej et al., 2008; Mohammadi, 2012).

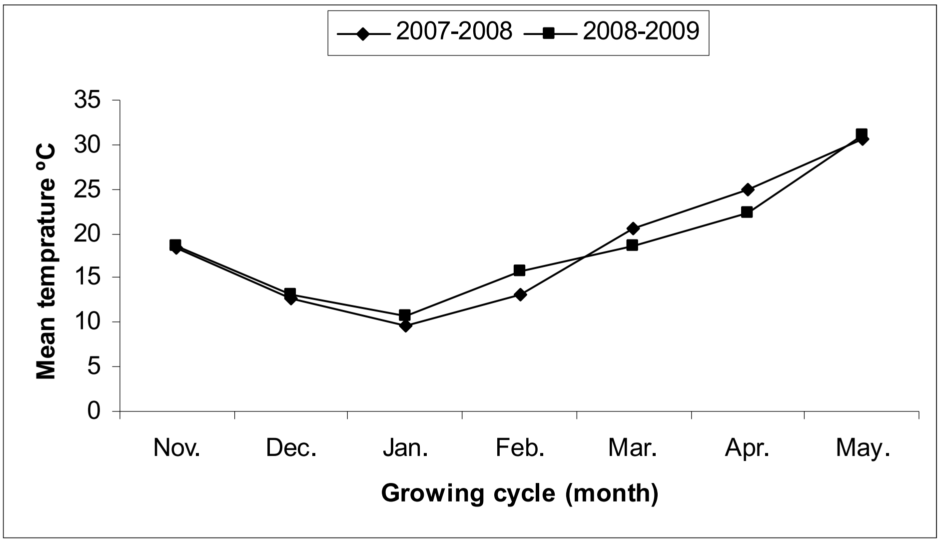

Figure 1. Monthly mean temperatures during wheat-growing cycles in Ahwaz, Iran during 2007-2008 and 2008–2009 growing seasons.

Many authors have reported that heat stress is responsible for reduced crop stand, shortened life cycle, reduced tiller number, suppressed biomass production, decreased fertilization and grain development, reduced spike size, spike number per m^2 and grain number per spike as well as grain weight, so that all these changes are translated into reduction in final grain yield (Gibson and Paulson, 1999; Ayeneh et al., 2002; Modhej et al., 2008; Omidi et al., 2013). Post-anthesis heat stress in wheat induces several physiological effects which eventually result in smaller grains due to shortened grain filling period or/and reduced grain filling rate (Wahid et al., 2007). Furthermore, Joshi et al. (2016) reported that late season heat stress due to late sowing decreased 1000-grain weight and grain yield by 67.3 and 47%, respectively. Choosing a suitable sowing date and appropriate genotype with the proper phenology that matches crop growth to the climate conditions may help to improve grain yield (Chen et al., 2003). It has also been reported that different genotypes showed different responses in terms of grain number per spike and grain weight when temperature increased in post-anthesis stage (Hossein et al., 2013). Gupta et al. (2015) showed a considerable reduction in yield and yield components in heat stressed wheat plants, however, heat tolerant genotypes such as RAJ 4083 and RAJ 4037 could maintain higher yield by maintaining relatively higher grain weight and grain number. Moreover, Okechukwu et al. (2015) have stated that early maturing genotypes are ideal for heat stressed environments, whereas late maturing genotypes would be suitable for heat favorable environments. Generally, genotypes are tested across space and time under field conditions by manipulating the sowing date or choosing sites, which are featured by high temperature at grain filling period i.e., ‘hot spots’ (Rane and Nagarajan, 2004). Increased heat tolerance in late sown wheat is essential to enhance and stabilize wheat productivity in the tropical and subtropical regions (Wahid et al., 2007).

Despite the abundance of research on the effect of late season heat stress on wheat across the world; studies that explore this effect on yield and heat tolerance of spring bread wheat cultivars in Ahwaz remain scant. In an attempt to contribute to this research, a stripe block experiment with 3 replicates was carried out in research farm of Ramin Agriculture and the Natural Resources University of Khouzestan. The study was aimed to evaluate the effect of late season heat stress on grain yield and yield components of 20 spring type bread wheat cultivars and to compare the cultivars in terms of heat tolerance under Ahwaz climatic conditions.

Materials and Methods

Experimental design and growing conditions

The experiment was conducted in the research field of Ramin Agriculture and Natural Resources University of Khouzestan (31º N, 48º E and 20 m above sea level) situated in South-West of Iran during 2007-2008 and 2008-2009 growing seasons. Experimental factors were included four sowing dates (6th of November (early), 6th of December (timely), 5th of January (late) and 4th of February (very late)) as vertical plots and 20 spring bread wheat cultivars (Table 1) as horizontal plots in strip block arrangement using a randomized complete block design with three replicates. The soil texture was clay loam, pH 7.5 and EC 3 mmohs cm^{-1}. Each horizontal plot had 10 rows with 2 m length and 20 cm row spacing. The seeds were sown manually at plant density of 400 plants per square meter. The plots were fertilized for each sowing date using 150 kg ha^{-1} Nitrogen (N) supplied from urea and 75 kg ha^{-1} phosphorus (P_2O_5) supplied from triple superphosphate. Urea was applied in two halves, the first half on sowing time of each sowing date and the rest at the beginning of stem elongation phase. The experiment was optimally managed to avoid any stresses, especially water stress. Weeds were controlled manually and chemically and the pesticide was applied to control insects

Table 1. Origin and pedigree of bread wheat cultivars.

No.	Cultivar	Origin	Name/Pedigree [Iranian cultivar name]
1	Kauz"s"	CIMMYT, Mexico	JUP/BJY//URES, [Atrak]
2	Arvand 1	Ahwaz, Iran	Rsh//Mt-Ky/My48
3	Debeira	Sudan	[S-80-18]
4	Star	CIMMYT	LFN/SDY//PVN
5	Inia 66	CIMMYT, Mexico	Lr64/Sn64
6	Bolani	Sistan, Iran	Local Variety
7	Bayat	Darab, Iran	C271/Wte-on64//CIR
8	Pishtaz	Karaj, Iran	Alvand/Alvand?Ias58
9	Atila	CIMMYT, Mexico	(CM85836-50Y-OM-OY-3M-OY), [Chamran]
10	Chenab 70	Pakistan	NA*
11	Darab 2	CIMMYT, Mexico	Maya"s"/Nac
12	Dez	CIMMYT, Mexico	Kauz*2/Opata/Kauz
13	Roshan	Isfahan, Iran	Local variety
14	Shoeleh	Ahwaz, Iran	Local variety
15	Seri82	CIMMYT, Mexico	Kvz/Buho"s"//Kal/Bb, [Falat]
16	Kavir	Zabol, Iran	Stm/3/Kal//V534/Jit716
17	Maroon	Gachsaran, Iran	Adv*Pchu(28mt54A*N10-Brv21-c/Kt54b)Nar59,1093))7c
18	Hamoon	Zabol, Iran	Seri82/Rsh
19	Hirmand	Zabol, Iran	Byt/4/Jar/Cfn/Sr70/3/Jup"s"
20	Vee/Nac	CIMMYT, Mexico	[Veery Nack]

* Not available.

Grain yield and yield components

Grain yield (GY) and biological yield (BY) were determined at physiological maturity by harvesting 1 m^2 of each plot. The spike number per m^2 (SM2) was recorded from harvested area. The average number of grains per spike (GS) was calculated based on 20 spikes. The 1000-grains weight (TGW) was determined by counting the grains using an electronic seed counter. Harvest index was calculated as the ratio of grain yield to the total above ground biomass yield.

Stress tolerance index (STI) was calculated using following equation (Fernandez, 1992):

$$STI= (Ysi.Ypi)/Yp^2$$

Ysi, Ypi and Yp were grain yield of each cultivar under stress condition, under the best condition and mean grain yield of all cultivar under best condition.

Statistical analysis

Analysis of variance was performed by using general linear model (GLM) procedure of statistical analysis system (SAS version: 9.1). Comparison of means was carried using LSD test, LS means and physical slicing method (Soltani, 2006).

Results and Discussion

The results showed that the effect of year, sowing date, cultivar and interaction between sowing date and cultivar were significant (P<0.01) for all studied traits. However, there was no significant interaction between year and other factors (Table 2).

Table 2. Variance analysis of terminal heat stress effect on measured traits of wheat.

Source	df	Means of squares					
		SM2[i]	GS	TGW	GY	BY	HI
Year	1	18463.6^{ns}	4.2^{ns}	82.7**	2.90**	3.07**	0.01065**
Year (Block)	2	1362.3	0.9	3.2	0.03	0.07	0.00005
Sowing date	3	1382353.6**	6910.1**	9447.3**	499.81**	2346.47**	0.22446**
Year×Sowing date	3	319.5^{ns}	2.1*	0.1^{ns}	0.02^{ns}	0.06^{ns}	0.00069**
Year×Sowing date (Block)	6	270.2	0.9	0.8	0.13	0.50	0.00008
Cultivar	19	35579.8**	280.5**	246.6**	2.89**	24.40**	0.03122**
Cultivar (Block)	38	511.3	0.9	0.7	0.05	0.27	0.00016
Sowing date×Cultivar	57	9906.6**	38.4**	28.5**	1.56**	7.15**	0.00375**
Sowing date× Cultivar (Block)	114	249.4	0.6	0.7	0.03	0.22	0.00008
Year×Cultivar	19	228.9^{ns}	0.4^{ns}	0.2^{ns}	0.02^{ns}	0.03^{ns}	0.00031^{ns}
Year×Cultivar (Block)	38	259.8	0.8	0.9	0.05	0.30	0.00011
Year×Sowing date×Cultivar	57	84.3^{ns}	0.6^{ns}	0.2^{ns}	0.01^{ns}	0.03^{ns}	0.00015*
Remind error	114	269.2	0.5	0.8	0.05	0.31	0.00011

^{ns}, * and ** non-significant, Significant at the 0.05 and 0.01 Probability level, respectively.
i: SM2: Spike per M2, GS: Grain per spike, TGW: Thousand grain weight, GY: Grain yield, BY: Biological yield and HI: Harvest index.

Year

The comparison of means showed that except for spike number per m^2 and grain number per spike, 1000-grain weight, grain yield, biological yield and harvest index were different in two years of the experiment and these traits in 2008-2009 growing season were higher than those in 2007-2008 growing season (Table 3). Reduction in 1000-grain weight, grain yield, biological yield and harvest index in 2007-2008 growing season might be due to low-temperature stress in winter, particularly in January, early raise in temperatures in February and March, the sharper slope of temperature raising and the occurrence of drastic terminal heat stress in April and May (Figure 1).

Table 3. Mean comparisons of measured traits in two years.

Year	Mean					
	SM2[i]	GS	TGW (g)	GY(t/ha)	BY(t/ha)	HI (%)
2007-2008	383.0[a]	39.52[a]	35.09[b]	4.236[b]	11.940[b]	34.48[b]
2008-2009	395.4[a]	39.71[a]	35.92[a]	4.391[a]	12.100[a]	35.43[a]

Means, in each column, followed by similar letter are not significantly different at the 5% probability level-using LSD.
i: SM2: Spike per M2, GS: Grain per spike, TGW: Thousand grain weight, GY: Grain yield, BY: Biological yield and HI: Harvest index.

Late season heat stress (Sowing date)

Late sowing and consequently late season heat stress significantly decreased all studied traits (Table 4). The comparison of means showed that late sowing decreased spikes number per m^2, 1000-grain weight and biological yield from the first sowing date to the latest one. Appropriate climate condition during winter growing period allowed to high dry matter production for the first and the second sowing dates but late sowing and late season heat stress resulted in shorter vegetative phase and reduction in biological yield in the third and the fourth sowing dates. The negative effect of late sowing on spike number per m^2 and biological yield was also reported by Ayeneh et al. (2002) and Rane et al. (2007), respectively. Reduction in 1000-grain weight on account of late sowing is also due to high temperatures in March, April and May when temperature raises and late season heat stress is more likely to occur during grain filling period. Lower 1000-grain weight as a result of late sowing was also documented by Mohammadi (2012). In addition, the effect of late season heat stress on grain number per spike, grain yield and harvest index was different, as these traits increased when the seed was sown on 6th of December and then significantly decreased. Lower grain number per spike due to seed sowing on 6th of November was due to coincidence the anthesis and the fertilization phases with cold weather during January, whereas the reduction after 6th of December was due to a higher temperature during reproductive phase. These results are in line with Badaruddin et al. (1999) and Modhej et al. (2008). Based on these findings, it is clear that 6th of December was the most suitable sowing date for grain yield in both years. However, late sown crops were severely affected by heat damage during April and May in both years of the experiment. Several authors have reported that heat stress is responsible for reduced crop stand, shortened life cycle, reduced tiller number, suppressed biomass production, decreased fertilization and grain development, reduced spike size, spike number per m^2 and grain number per spike as well as grain weight, so that all these changes are translated into reduction in final grain yield (Gibson and Paulson, 1999 and Ayeneh et al. 2002). Harvest index was also affected by the late seed sowing. This result might be due to the greater negative effect of late sowing date and late season heat stress on reproductive phase and grain yield rather than vegetative phase and biological yield. These results are in agreement with those found by Badaruddin et al. (1999).

Table 4. Mean comparisons of different sowing dates.

Sowing dates	Mean of two years					
	SM2^{i}	GS	TGW (g)	GY(t/ha)	BY(t/ha)	HI (%)
06 Nov.	485.3^{a}	41.58^{b}	44.46^{a}	5.546^{b}	15.420^{a}	36.14^{b}
06 Dec.	463.0^{b}	48.91^{a}	41.33^{b}	6.048^{a}	15.155^{a}	40.12^{a}
05 Jan.	356.5^{c}	37.09^{c}	30.69^{c}	3.905^{c}	11.572^{c}	33.75^{c}
04 Feb.	252.1^{d}	30.89^{d}	25.56^{d}	1.754^{d}	5.931^{d}	29.80^{d}

Means, with similar letter, are not significantly different at the 5% probability level-using LSD.
i: SM2: Spike per M2, GS: Grain per spike, TGW: Thousand grain weight, GY: Grain yield, BY: Biological yield and HI: Harvest index.

Cultivars

Comparison of means showed that there were significant differences between wheat cultivars. In terms of spike number per m^2, Shoeleh showed the highest number (473.7) whereas the lowest (345.8) was belonging to Maroon cultivar (Table 5). The greatest grain number per spike (45.37) was related to Dez and the least (36.70) was belonging to Maroon cultivar. The maximum 1000-grain weight (40.41 g) obtained from Maroon cultivar, By contrast, the minimum value (30.31 g) was belonging to Shoeleh cultivar. The Atila cultivar produced the highest grain yield (5.019 ton ha^{-1}) whereas the lowest grain yield (3.6625 ton ha^{-1}) was found from Inia 66 cultivar. Roshan produced the greatest biological yield (14.020 ton ha^{-1}) and the least value obtained from Inia 66 (10.458 ton ha^{-1}). The highest harvest index was obtained from Dez (42.24%) and the lowest was achieved from Roshan (27.22%). Significant differences between wheat cultivars have been previously reported by Modhej et al. (2008).

Table 5. Mean comparison of wheat cultivars.

Cultivars	Mean					
	SM2^{i}	GS	TGW (g)	GY(t/ha)	BY(t/ha)	HI (%)
Kauz"s"	413.8^{c}	44.64^{b}	30.85^{l}	4.279^{cd}	10.979^{h}	38.17^{bc}
Arvand 1	449.0^{b}	34.06^{l}	39.21^{c}	4.595^{b}	12.950^{c}	34.69^{hij}
Debeira	389.5^{de}	38.10^{i}	33.06^{ij}	4.320^{c}	11.012^{h}	38.05^{bc}
Star	331.7^{i}	40.78^{fg}	39.76^{b}	4.331^{c}	12.004^{e}	33.87^{kl}
Inia 66	403.9^{c}	41.17^{f}	32.76^{j}	3.662^{i}	10.458^{i}	34.12^{jkl}
Bolani	355.6^{gh}	38.03^{i}	37.22^{f}	4.103^{efg}	13.137^{bc}	29.40^{m}
Bayat	414.6^{c}	42.24^{e}	35.61^{g}	4.944^{a}	13.050^{c}	36.45^{e}
Pishtaz	406.0^{c}	35.26^{k}	37.80^{e}	4.522^{b}	11.758^{ef}	37.65^{cd}
Atila	444.6^{c}	40.65^{fg}	33.28^{ij}	5.019^{a}	12.912^{c}	37.25^{d}
Chenab 70	359.2^{g}	39.52^{h}	35.85^{g}	4.172^{de}	11.825^{ef}	35.02^{ghi}
Darab 2	386.5^{c}	40.84^{fg}	33.53^{i}	4.006^{fg}	11.870^{h}	36.04^{ef}
Dez	355.5^{gh}	45.37^{a}	31.88^{k}	4.523^{b}	10.545^{i}	42.24^{a}
Roshan	402.5^{cd}	35.44^{k}	39.13^{c}	4.007^{fg}	14.020^{a}	27.22^{n}
Shoeleh	473.7^{a}	34.44^{l}	30.31^{m}	3.832^{h}	13.404^{b}	27.92^{n}
Seri82	354.2^{gh}	41.07^{f}	33.48^{i}	4.319^{c}	11.541^{fg}	35.50^{fg}
Kavir	373.0^{f}	43.93^{c}	34.70^{h}	4.327^{c}	12.491^{d}	33.44^{l}
Maroon	345.8^{h}	36.70^{j}	40.41^{a}	3.967^{gh}	11.387^{g}	34.41^{ijk}
Hamoon	359.8^{g}	36.62^{j}	38.48$_{d}$	4.138^{def}	11.604^{fg}	33.85^{kl}
Hirmand	354.1^{gh}	43.23^{d}	39.46^{bc}	4.552^{b}	12.525^{d}	35.40^{fgh}
Vee/Nac	411.7^{c}	40.28^{g}	33.38^{i}	4.652^{b}	11.920^{e}	38.40^{b}

Means, in each column, followed by similar letter (s) are not significantly different at the 5% probability level-using LSD.
i: SM2: Spike per M2, GS: Grain per spike, TGW: Thousand grain weight, GY: Grain yield, BY: Biological yield and HI: Harvest index.

Interaction between cultivar and sowing date

Comparison of means on grain yield for cultivars in each sowing date in both years of the experiment (Table 6) showed that the highest grain yield for most of the cultivars was observed when seeds were sown on 6th of December, however, in both years; Star, Bolani, Roshan and Shoeleh (old, late maturity and heat susceptible cultivars) produced their greatest grain yield when sown on 6th of November. The minimum grain yield for all cultivars obtained when seeds were sown on 4th of February. On 6th of December, the highest grain yield obtained from Atila and Baiat cultivars, whereas the lowest grain yield was produced by Inia 66 and Shoeleh cultivars. On 4th of February, the highest grain yield was produced by Maroon, Virinak, Arvand and Kauz"s" cultivars whereas the lowest grain yield was belonging to Roshan, Seri82, Star and Hamoon cultivars.

Table 6. Mean comparisons of grain yield of 20 spring bread wheat cultivars in four sowing dates in Ahwaz.

Wheat cultivars	Mean of Grain Yield (t/ha)			
	Nov., 6	Dec., 6	Jan., 5	Feb., 4
Atrak	4.98^{f}	5.91^{ef}	4.15^{d}	2.09^{ab}
Arvand 1	5.32^{e}	6.64^{bc}	4.25^{cd}	2.17^{a}
S-80-18	5.49^{cde}	6.16^{de}	3.89^{e}	1.74^{de}
Star	6.67^{a}	5.81^{f}	3.55^{f}	1.30^{f}
Inia 66	4.50^{g}	4.77^{i}	3.56^{f}	1.83^{cde}
Bolani	6.63^{a}	5.51^{g}	2.63^{i}	1.65^{e}
Bayat	6.41^{a}	6.92^{ab}	4.55^{a}	1.90^{bcd}
Pishtaz	5.52^{cde}	6.48^{c}	4.43^{abc}	1.66^{e}
Chamran	6.41^{a}	7.15^{a}	4.58^{a}	1.94^{bc}
Chenab 70	5.35^{de}	6.02^{ef}	3.51^{g}	1.80^{cde}
Darab 2	4.71^{g}	5.39^{g}	4.27^{cd}	1.66^{e}
Dez	5.48^{cde}	6.52^{c}	4.30^{bcd}	1.80^{cde}
Roshan	5.97^{b}	5.50^{g}	3.28^{gh}	1.29^{f}
Shoeleh	5.59^{cd}	4.67^{i}	3.36^{fgh}	1.71^{de}
Falat	5.28^{e}	6.38^{cd}	4.31^{bcd}	1.31^{f}
Kavir	5.72^{bc}	6.52^{c}	3.27^{h}	1.80^{cde}
Maroon	4.71^{fg}	5.07^{h}	3.81^{e}	2.27^{a}
Hamoon	5280^{e}	6540^{c}	3490^{fgh}	1250^{f}
Hirmand	5510^{cde}	6600^{c}	4400^{abc}	1700^{e}
Veery/Nac	5420^{de}	6430^{cd}	4520^{ab}	2240^{a}

Means with similar letter (s) in each column are not significantly different at the 5% probability level- using LSmeans of SAS.

Stress tolerance index (STI)

Based on grain yield data obtained from different sowing dates (Table 6), STI calculated for all cultivars using the best sowing date as the potential environment and the latest sowing date as stress environment, then their averages were compared (Table 7). The most heat tolerant cultivars were Arvand (0.394) Virinak (0.393), Atila (0.378) and Bayat (0.356), respectively and the heat susceptible cultivars were Roshan (0.199), Hamoon (0.223), Seri82 (0.227), Star (0.233), Inia66 (0.237) and Darab 2 (0.244), respectively. The same heat tolerant or susceptibility was observed in both years of the experiment and minor differences may relate to year's weather variation or probably measurement errors. In this study, the international heat tolerant check cultivars i.e. Kauz"s" and Atila were found among the most tolerant cultivars and Seri82 that has been mentioned as a broadly adapted variety (Reynolds et al., 1994), placed among susceptible cultivars. These results show that all abiotic stresses, especially heat stress, are local and tolerance and susceptibility of genotypes should be tested in the same area to confirm the results. However, cultivars like Arvand or Bayat that their breeding process passed in the warm locations, or native cultivars that adopted with the site, are more precise standard for such investigations. Rooting from tolerance indices, cultivars showed 45 to 63% of their grain potential, in other words, heat damage ranged from 37% for Arvand to 55% for Roshan, with 46% average. Almost 93% of distributed seeds across Khuzestan belonged to both Atila and Veery Nack in 2008-2009, so heat yield loss of Khuzestan was estimated by 38% that agree with the upper level of heat loss calculated by Jalal-Kamali and Duveiller (2008).

Table 7. Stress tolerance index (STI) of cultivars in two years (2007-2008 and 2008-2009).

Cultivars	Stress Tolerance Index (STI)		
	First year	Second year	Average of both year
Kauz"s"	0.321^{bcd}	0.353^{abc}	0.337^{bc}
Arvand 1	0.385^{a}	0.402^{a}	0.394^{a}
Debeira	0.291^{def}	0.289^{defgh}	0.290^{de}
Star	0.227^{gh}	0.239^{hij}	0.233^{fg}
Inia 66	0.221^{gh}	0.254^{fghi}	0.237^{f}
Bolani	0.277^{defg}	0.314^{cdef}	0.295^{de}
Bayat	0.354^{abc}	0.358^{abc}	0.356^{ab}
Pishtaz	0.288^{def}	0.300^{cdefg}	0.294^{de}
Atila	0.369^{ab}	0.387^{ab}	0.378^{a}
Chenab70	0.295^{de}	0.300^{cdefg}	0.297^{d}
Darab 2	0.237^{fgh}	0.251^{ghij}	0.244^{f}
Dez	0.317^{bcd}	0.286^{defgh}	0.301^{cde}
Roshan	0.206^{h}	0.191^{j}	0.199^{g}
Shoeleh	0.247^{efgh}	0.271^{efghi}	0.259^{ef}
Seri82	0.219^{h}	0.236^{hij}	0.227^{fg}
Kavir	0.321^{bcd}	0.320^{cde}	0.320^{bcd}
Maroon	0.296^{de}	0.334^{bcd}	0.315^{cd}
Hamoon	0.225^{gh}	0.221^{ij}	0.223^{fg}
Hirmand	0.303^{cd}	0.300^{cdefg}	0.301^{cd}
Vee/Nac	0.398^{a}	0.389^{ab}	0.393^{a}

Means, in each column, followed by similar letter (s) are not significantly different at the 5% probability level-using LSD.

In general, it can be concluded that grain yield and yield components would decrease considerably due to late sowing beyond the optimum window in Ahwaz region, mostly because of high temperature during grain filling period. Under Ahwaz conditions, the best sowing date for most bread wheat cultivars was found to be 6th of December. In the present study, Atila was the best cultivar at early sowing (6th of November) and can be recommended because of its heat tolerance for early to timely sowing date. Grain yield of Star, Roshan, Bolani and Shoeleh (old, late maturity and heat susceptible cultivars) in early sowing show that in past years, sowing date was earlier than today, so late maturity cultivars were selected. Today, with some changes in cropping policies, the later sowing date (6th of December) and using early maturing cultivars are recommended. If there is no former cropping, water and equipment's limitation, late maturing and high yielding cultivars are recommended, but for harsh areas, heat tolerant cultivars such as Atila and Bayat and sowing date of 6th of December is highly recommended. If sowing date is delayed to after best time (for example 5th of January), Bayat and Vee/Nac as heat tolerant cultivars could be recommended. Although there was a significant reduction in grain yield in very late sowing (4th of February), due to shortness of growing period, Vee/Nac, Maroon and Arvand cultivars are still suitable.

Based on these results, Arvand and Baiat (because of their warm breeding origin), Vee/Nac and Atila (since being international checks) as tolerant cultivars; and Roshan (because of its native origin), Hamoon (because of its warm breeding origin), Seri82, Inia66 and Darab2 (since being international checks) as susceptible cultivars may be used in heat stress studies. The results of the current study confirm that genetic variability for post anthesis heat tolerance exists between spring type wheat cultivars in Iran, which could be used to develop new high yielding and heat tolerant wheat lines. More analysis of these data with the complicated statistical procedure may brighten heat tolerance nature in Khouzestan conditions.

References

Ayeneh, A., Van-Ginkel, M., Reynolds, M.P., Ammar, K., 2002. Comparison of leaf, spike, peduncle and canopy temperature depression in wheat under heat stress. Field Crops Res. 79, 173-184.

Badaruddin, M., Reynolds, M.P., Ageeb, O.A.A., 1999. Wheat management in warm environments: effect of organic and inorganic fertilizers, irrigation frequency and mulching. Agron. J. 91, 975-983.

Chen, C., Payne, W.A., Smiley, R.W., Stoltz, M.A., 2003. Yield and water-use efficiency of eight wheat cultivars planted on seven dates in northeastern Oregon. Agron. J. 95, 836-843.

FAO (Food and Agriculture Organization)., 2016. Statistical database. Retrieved from http://faostat3.fao.org.

Fernandez, G.C.J., 1992. Effective selection criteria for assessing plant stress tolerance. In: Kuo, C.G., (Ed.), Adaptation of Food Crops to Temperature and Water Stress. Tainan, Taiwan, pp. 257-270.

Fischer, R.A., Byerlee, D.B., 1991. Trends of wheat production in the warmer areas: Major issues and economic consideration. In: Saunders, D.A., (Ed.), Wheat for the Nontraditional Warm Areas. Foz Do Iguazu, Brazil, pp. 3-27.

Gibson, L.R., Paulsen, G.M., 1999. Yield components of wheat grown under high temperature stress during reproductive growth. Crop Sci. 39, 1841-1846.

Gupta, N.K., Khan, A., Maheshwari, A., Narayan, S., Chhapola, O.P., Arora, A., Singh, G., 2015. Effect of post anthesis high temperature stress on growth, physiology and antioxidative defense mechanisms in contrasting wheat genotypes. Ind. J. Plant Physiol. 20 (2), 103-110.

Hossain, H., Sarker, M.A.Z., Saifuzzaman, M., Teixeira da Silvab, J.A., Lozovskaya, M.V., Akhter, M.M., 2013. Evaluation of growth, yield, relative performance and heat susceptibility of eight wheat (*Triticum aestivum* L.) genotypes grown under heat stress. Int. J. Plant Prod. 7, 615-636.

Jalal-Kamali, M.R., Duveiller, E., 2008. Wheat production and research in Iran: A success story. In: Reynolds, M.P., Pietragalla, J., Braun, H.J., (Eds.), Wheat Yield Potential: Challenges to International Wheat Breeding. CIMMYT, Mexico, pp. 54-58.

Joshi, M.A., Faridullah, S., Kumar, A., 2015. Effect of heat stress on crop phenology, yield and seed quality attributes of wheat (*Triticum aestivum* L.). J. Agrometeorology. 18 (2), 206-215.

MAJ (Ministry of Agriculture Jihad)., 2016. Statistical yearbook. Retrieved from http://www.maj.ir.

Modhej, A., Naderi, A., Emam, Y., Aynehband, A., Normohamadi, Gh., 2008. Effects of post-anthesis heat stress and nitrogen levels on grain yield in wheat (*T. durum* and *T. aestivum*) genotypes. Int. J. Plant Prod. 2, 254-267.
Mohammadi, M., 2012. Effects of kernel weight and source-limitation on wheat grain yield under heat stress. Afr. J. Biotechnol. 11, 2931-2937.
Okechukwu, E.C., Agbo1, C.U., Uguru, M.I., Ogbonnaya, F.C., 2016. Germplasm evaluation of heat tolerance in bread wheat in Tel Hadya, Syria. Chilean J. Agric. Res. 76 (1), 9-17.
Omidi, M., Siahpoosh, M.R., Mamghani, R., Modarresi, M., 2013. The influence of terminal heat stress on meiosis abnormalities in pollen mother cells of wheat Cytologia. 79, 49-58.
Rane, J., Nagarajan, S., 2004. High temperature index for field evaluation of heat tolerance in wheat genotypes. Agric. Sys. 79, 243-255.
Rane, J., Pannu, R.K., Sohu, V.S., Saini, R.S., Mishra, B., Shoran, J., Crossa, J., Vargas, M., Joshi, K., 2007. Performance of yield and stability of advanced wheat genotype under heat stress environments of the indo- gangetic plains. Crop Sci. 47, 1561-1572.
Reynolds, M.P., Balota, M., Delgado, M.I.B., Amani, I., Fischer, R.A., 1994. Physiological and morphological traits associated with spring wheat yield under hot, irrigated conditions. Aust. J. Plant Physiol. 21, 717-730.
Soltani, A., 2006. Re-consideration of application of statistical methods in agricultural researches. Jahad Daneshgahi Mashhad Press. Mashhad. (In Persian)
Wahid, A., Gelani, S., Ashraf, M., Foolad, M.R., 2007. Heat tolerance in plants: An overview. Environ. Exp. Bot. 61, 199-223.
Wardlaw, I.F., 2002. Interaction between drought and chronic high temperature during kernel filling in wheat in a controlled environment. Ann. Bot. 90, 469-476.