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Effects of post-anthesis heat stress and nitrogen levels on grain yield in wheat (*T. durum* and *T. aestivum*) genotypes

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Abstract

In order to study the effects of post-anthesis heat stress and nitrogen levels on grain yield and yield components of wheat genotypes, two separate field experiments were conducted in delayed and optimum sowing dates under Ahvaz conditions (2006-2007). The Ahvaz site located in south west of Iran ($32^{\circ}20'$ N, $40^{\circ}20'$ E) with subtropical climate condition. The experiment site had a moderate winter and dry and hot summer. Plants in delayed sowing date experienced heat stress at post-an thesis growth stage. Each split-polt experiment had a randomized complete block design with three replications. The application rates of N at three levels (50, 100, and 150 KgNha^{-1}) were assigned in main-plots. Sub-plots were consisted of six bread and durum wheat genotypes. The results indicated that the grain yield reduction in 50 and 100 KgNha^{-1} compared with 150 KgNha^{-1} treatments was 41% and 21% under optimum and 44% and 26% under heat stress conditions, respectively. In all genotypes, grain yield and 1000-grain weight (TGW) reduction under post-anthesis heat stress conditions was 33% and 42%, respectively. The highest and the lowest grain yield reduction due to heat stress were observed in Star (39%) and Vee/Nac (27%) genotypes. The Grain yield reduction in nitrogen deficiency treatments and post-anthesis heat stress was due to significant reduction in number of grains. m^{-2} and TGW, respectively. In nitrogen deficiency treatments grain number per area was reduced due to reduction in number of fertile florets. Spikelets^{-1}, spikes. m^{-2}, and spikelets. spike^{-1}. Further research are recommended for full understanding the effects of heat stress and low N level on yield and yield components of recommended wheat genotypes under agroclimatic conditions such as south west of Iran.

Keywords: Wheat; Post-anthesis heat stress; Nitrogen deficiency; Grain yield

Introduction

Wheat is traditionally grown as a cool-season crop, but with the increased availability of more widely adapted semi dwarf cultivars, wheat production has expanded into warmer regions of countries, where production had been restricted to higher altitudes or cooler latitudes (Badrruuddin et al., 1999).

Heat, drought and nutrient deficiency are the most important stresses that limit crop production (Entez and Flower, 1990; Rawson, 1988). Wheat, which is one of the most broadly adapted cereal crops, is cultivated on about 7 million hectares in the subtropics under continual heat stress, defined as having a mean daily temperature greater than 17.5 °C in the coolest month of the growth cycle. Terminal heat stress is a problem in 40% of temperate environments, which cover 36 million ha (Reynolds et al, 2001). Optimal crop growth requires a no limiting supply of resources (water, nutrients, and radiation) and, as temperature rises, the demand for growth resources increases due to higher rates of metabolism, development, and evapotranspiration (Rawson, 1988). Under mediteranian conditions such as western part of Iran, heat stress after anthesis is the major grain yield limiting factor in winter sown wheat genotypes. The optimum temperature range to achieve maximum kernel weight is 15-18$^{\circ C}$; higher temperatures (up to 30) reduce the duration of grain filling and this reduction is not balanced by the increase in rate of assimilate accumulation (Wardlaw et al., 1980, 1989; Stone et al., 1995). Heat stress during after anthesis growth stages mainly affects assimilates availability, translocation of photosynthates to the grain and starch synthesis and deposition in the developing grain. The net result is a lower grain yield due to lower thousand grain weight (Gibson and Paulsen, 1999; Rao et al, 2002). we indicated that TGW average in post-anthesis heat stress decreased 24% compared with optimum conditions (unpublished data).

Wheat crops are frequently faced to nitrogen (N) deficiency, due to low rates of N fertilizer application, organic farming practices (David, 1997), or a delay between the optimal time for N application, corresponding to a period when the crop has a high N requirement, and the date on which the N fertilizer is applied by the farmer (Meynard, 1985). The N deficiency may continue until harvest if no extra N fertilizer is applied (continuous deficiency) or the crop may be supplied with N fertilizer for one to several weeks after the beginning of the deficiency (temporary deficiency). Kernel number (KN), the principal determinant component of grain yield (Midmore et al., 1985), is reduced in crops subjected to pre-anthesis N deficiency (Jeuffroy and Bouchard, 1999). The reduction in KN may result from decrease in the various components of kernel set: the number of spikelets per spike, the frequency of spikelets bearing grains, the number of differentiated florets, the survival of florets, the frequency of grain setting by florets (Peltonen-Sainio and Peltonen, 1995; Peltonen-Sainio et al., 2007). we indicated that N deficiency significantly decreased grain number per area via spike per area and kernel per spike reduction, but there was no significant effect on kernel weights (unpublished data). Therefore, it seems that N deficiency and post anthesis heat stress is going to reduce grain yields due to kernel number and kernel weight, respectively. This study had three main aims. The first was to describe the effects of N deficiency on wheat genotypes with different growth duration. The second was to evaluate the effect of post-anthesis heat stress on TGW and grain yield of these genotypes and third was to determine interaction effects of this two important stresses on grain yield of six durum and bread wheat genotypes with different susceptibility to heat and N deficiency stresses.

Materials and methods

The experiment was conducted at Ahvaz, south-western of Iran, in 2006-2007 growing season. The Ahvaz site located at 20 m above sea level ($32^{\circ}20^{'}$ N, $40^{\circ}20^{'}$ E). Wheat was sown on delayed (20nd Jan) and optimum (22nd Nov) sowing dates. Treatments of each individual experiment (sowing date) were arranged as a split-plot experiment in a randomized complete block design with three replications. Nitrogen rates (50, 100 and 150 kgNha^{-1}) were in main plots and wheat genotypes were in sub-plots. Plants in delayed sowing date experienced heat stress after anthesis. Six genotypes with different growth durations were used (Table 1). The N rate of 50 kgNha^{-1} will be referred as N1, 100 kg N ha^{-1} as N2 and that with 150 kgNha^{-1} as N3. Nitrogen fertilizer was applied to wheat plots as ammonium nitrate. At all application rates, half was applied before sowing (incorporated by disk). The remaining N was applied as a top dressing at the beginning of wheat tillering corresponding to stage 21 of Zadoks scale (Zadoks et al., 1974).

The soil was clay loam in texture, alkaline in reaction, pH 8.0 with low organic carbon (less than 1%), moderate phosphorus (7.2 ppm) and high potassium (220 ppm) status. The experiment site had a hot climate with a moderate winter and dry and hot summer.

Table1. Characteristics of the examined wheat genotypes.

Genotypes		Growth Duration	Origin
Bread			
	Veer/Nac	Short-season	CIMMYT
	Attila	Middle-season	CIMMYT
	Star	Long-season	CIMMYT
Durum			
	Show/mald	Middle-season	ICARDA
	D-83-8	Short-season	CIMMYT
	D-84-5	Long-season	ICARDA

Mean temperature in grain growth period was 22 and 28 °C, in optimum and delayed sowings, respectively (Figure 1).

Normal cultural and management practices for fertilizers, irrigation and pest control of wheat plants were used. Three replication plots of 1.2 by 3.0 m were planted for each genotype. Based on research recommendation and different tillering capacity of bread and durum wheat genotypes, seeds were drilled in 18 cm rows at about 400 and 500 seeds.m^{-2} for bread and durum genotypes, respectively. Total dry matter, relative grain yield and, hence, the Harvest index (HI) (Eq. 1) and yield components were estimated after physiological maturity by harvesting interior rows (the outer rows excluding at least 0.5 m from either end of the rows).

$$HI = \left(\frac{GY}{BY}\right) \times 100 \tag{1}$$

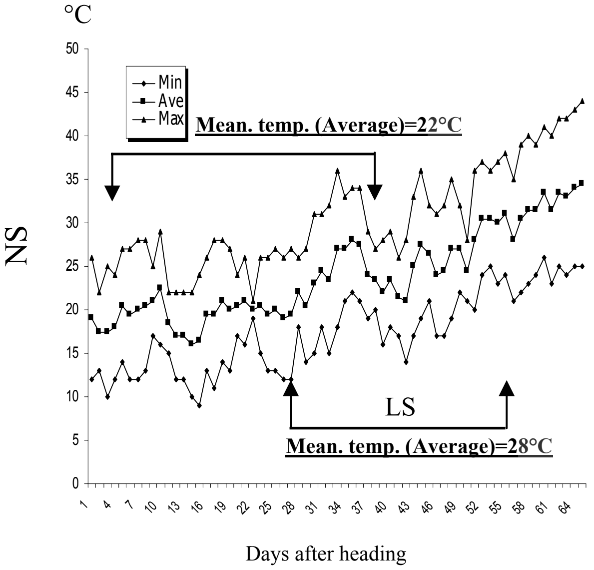

Figure 1. Maximum daily air temperature (°C) during heading and grain growth. NS=normal sowing date and LS=late sowing date. Arrows indicate the beginning and ending of grain filling period for each sowing date.

The harvest area was 1.2 m^{-2}. TGW was estimated on a sample of 250 grains.

Grain yield in heat stress after anthesis was investigated with stress susceptibility index (SSI) recommended by Fischer and Maurer (1978) and stress tolerance index (STI) recommended by Fernandez (1992). SSI was calculated as equation 2.

$$SSI = \frac{1 - \frac{Y_{Si}}{Y_{Pi}}}{1 - \frac{Y_{S}}{Y_{P}}} \tag{2}$$

Ysi, *Ypi*, *Ys* and *Yp* were grain yield of each cultivar under stress conditions, grain yield of each cultivar under optimum condition, mean of grain yield in all genotypes in stress and optimum conditions, respectively.
STI was calculated as equation 3:

$$STI = \frac{Y_{Si} . Y_{Pi}}{Y^{\text{۲}}{}_{P}} \tag{3}$$

Ysi, *Ypi* and Y^2p were grain yield of each genotype under stress condition, under optimum condition and square of mean grain yield in all genotypes under optimum condition.

The Agronomic efficiency (ANE) was calculated according to Novoa and Loomis (1981) and Craswell and Godwin (1984):

$$AN_E \text{ (kg per kg)} = \text{(grain yield at } N_x \text{ - grain yield at } N_0\text{) / N applied at } N_x \tag{4}$$

Statistical analysis was made using the SAS statistical program. Differences between traits means were assessed using Duncan's Multiple Range Test. Stepwise was made between grain yield and yield components. Pearson correlation analysis was also conducted among different variables (SAS Institute Inc, 1989).

Results

Normal sowing date (optimum conditions)

Results indicated that nitrogen had significant effects on grain yield, spike per m^{-2}, grain per spike, floret per spikelet, spikelet per spike, biological yield (BY) and HI in 1% probability level, but there was no significant effect on TGW (Table 2). Treatments with small amounts of N fertilizer gave lower spike per m^2 (Table 2). Spike per m^2 averages was 26% and 19% lower in 50 and 100 kgNha^{-1} treatments compared with 150 kgNha^{-1} treatment (optimum rate), respectively (Table 2). we showed that, lower amount of N fertilizer, decreased spike number due to lower tiller production and higher tiller death (unpublished data).

Grain per spike significantly affected by N levels (Table 2). N fertilizer reduction, lowered grain no. per spike approximately 18% and 5% on 50 and 100 kgNha^{-1} treatments compared to 150 kgNha^{-1} treatment, respectively. Grain no. per spike reduction was due smaller spikelet per spike and floret per spikelet (Table 2). Peltonen-Sainio and Peltonen (1995) indicated that the reduction in grain no. per spike may result from reduction in the various components of grain set such as the number of spikelets per spike, the frequency of spikelets bearing grains, the number of differentiated florets, the survival of florets, the frequency of grain setting by florets. The number of floret per spikelet also affected significantly by different rates of N fertilizer. Mean floret per spikelet, decreased by 15%, as N decreased from 150 to50 kgha^{-1}.

Mean grain yield decreased by 41% and 21%, respectively, as N decreased from N3 to N1 and N2. According to positive and significant correlations between grain yield and spike per m^2 (r=44%), grain per spike (r=52%), spikelet per spike (r=33%) and floret per spikelet (r=49%), it seems that grain yield reduction in low N fertilizer treatments was due to smaller grain per unit area (unpublished data).

Decrease in N input had a negative impact on HI, with a mean decrease of 20% in N1 compared with N3 (Table 2). These results were in agreement with the results of Ehdaie and Waines (2001). Genotype×N interactions for all grain yield related characters were significant, indicating that the genotypes responded dissimilar to decrease in N for these characters.

Late sowing date (Post-anthesis heat stress conditions)

N effect on grain yield in late sowing date period was similar to normal sowing date season (Table 2). According to Table 2, N treatments had no significant effect on TGW. It seems that grain number reduction in lower rates of N fertilizers lead to higher assimilate availability for grains and consequently compensate source limitation and TGW reduction. This result may agree with Sattore and Slafer (2000) and Slafer and Andrade (1993). They reported that, yield components were correlated with each other and changes in one's character may lead to subsequent changes in other's characteristics.

Table 2. Mean spike per m^{-2}, grain per spike (G.S^{-1}), spikelet per spike (Sp.S^{-1}), floret per spikelet (F.Sp^{-1}), TGW, GY, BY and HI for N fertilizer treatments and wheat genotypes in optimum and late sowing date.

Treatments	Means															
	Spike.m^{-2}		G.S^{-1}		Sp.S^{-1}		F.Sp^{-1}		TGW (g)		GY (g.m^{-2})		BY (g.m^{-2})		HI (%)	
	OS	LS	OS	LS	OS	LS	OS	LS	OS	LS	OS	LS	OS	LS	OS	LS
N (kg ha^{-1})																
150	420^{a}	415^{a}	42^{a}	41^{a}	16^{a}	15^{a}	3.00^{a}	2.7^{a}	45^{a}	27^{a}	5121^{a}	3541^{a}	13031^{a}	7814^{a}	40^{a}	46^{a}
100	340^{b}	335^{b}	40^{a}	38^{a}	15^{b}	14^{b}	2.80^{a}	2.6^{a}	44^{a}	25^{a}	4282^{b}	2592^{b}	10793^{b}	6671^{b}	43^{ab}	39^{b}
50	310^{b}	305^{b}	35^{b}	33^{b}	14^{c}	14^{b}	2.40^{b}	2.3^{b}	42^{a}	25^{a}	3134^{c}	2973^{c}	6564^{c}	6082^{b}	50^{b}	32^{c}
MS	62328**	62367**	269.24**	269.24**	8**	6.16**	0.77**	0.82**	53.68^{ns}	1.18^{ns}	180149**	112864**	1940978**	139948**	445.38**	819.26**
Genotypes																
Attila	447^{a}	447^{a}	32^{c}	32^{c}	14^{b}	14^{b}	2.3^{c}	2.2^{c}	36^{d}	21^{e}	4148^{ab}	2580^{ab}	10591^{ab}	6731^{abc}	41^{c}	36^{bcd}
Vee/Nac	345^{b}	345^{b}	37^{b}	37^{b}	15^{a}	14^{b}	2.5^{b}	2.5^{b}	39^{c}	23^{c}	3252^{c}	2354^{ab}	9641^{ab}	6364^{bc}	36^{cd}	35^{cd}
Star	304^{b}	305^{b}	37^{b}	37^{b}	14^{b}	15^{a}	2.6^{b}	2.4^{b}	40^{c}	22^{d}	3641^{bc}	2193^{b}	11802^{a}	7462^{ab}	31^{d}	29^{d}
Showa^{+}	342^{b}	341^{b}	35^{bc}	35^{c}	15^{a}	15^{a}	2.4^{c}	2.3^{b}	51^{a}	31^{a}	4690^{a}	3110^{a}	12082^{a}	7601^{a}	39^{cd}	41^{bc}
D-84-5^{+}	311^{b}	311^{b}	44^{a}	44^{a}	14^{b}	14^{b}	3.0^{a}	3.0^{a}	47^{b}	27^{b}	4521^{a}	3021^{a}	7724^{b}	6772^{abc}	58^{a}	44^{ab}
D-83-8^{+}	353^{b}	353^{b}	38^{b}	38^{b}	15^{a}	15^{a}	2.5^{b}	2.6^{b}	49^{a}	27^{b}	4532^{ab}	3092^{a}	8932^{ab}	6183^{c}	54^{b}	49^{a}
MS	23709**	23732**	127.88**	12.88**	1.31**	2.25**	0.48**	0.68**	332.24**	177.53**	35645**	320.43**	257109**	29810**	1292.78**	442.64**

Ns: Not significant **: significant at 1% probability level +: Durum genotypes MS: Mean square OS: Optimum Sowing LS: Late Sowin

Grain yield averages was 44% and 26% lower in 50 and 100 kgNha^{-1} treatments compared with 150 kgNha^{-1} treatments, respectively (Table 2). According to the results of stepwise regression, grain per spike and spike per unit area were the first and second traits in GY model (R_1^2=0.44 and R_2^2=0.30) under late sowing season condition. In post-anthesis heat stress conditions, the highest and the lowest GY were in Showa and Star cultivars, respectively (Table 2). we reported that long season genotypes had lower grain yield compared to middle and short season genotypes under post-anthesis heat stress conditions (unpublished data).

In late sowing period, N treatments had different effect on HI compared to optimum sowing season (Table 2). HI decreased as the N rate decreased (Table 2).

Comparison of the two environments

The Mixed ANOVA (not shown) indicated that the effect of environment (sowing date) on spike per unit area, grain no. per spike and fertile floret per spikelet characteristic was not significant. The effect of environment (sowing period) was significant for GY, TGW and spikelet per spike at 1% probability level.

In late sowing period, an increase average of 6°C in the average temperatures reduced TGW, GY, BY and HI approximately 42%, 33%, 32% and 11% compared to optimum sowing date, respectively. GY reduction was due to significant TGW decreasing (Table2). According to the results of stepwise regression, TGW, spike per unit area and grain per spike were the first, second and third traits in GY model (R_1^2=0.54, R_2^2=0.26 and R_3^2=0.11), based on the collected data of both conditions.

The highest and the lowest GY reduction in post-anthesis heat stress condition belonged to in Star (long-season) and Vee/Nac (short-season) genotypes (Table 3). The highest and the lowest SSI were in these two genotypes, respectively. Results indicated that, the highest and the lowest STI belonged to Showa and Vee/Nac genotypes, respectively (Table 3). We realized reported that, genotypes with high GY in optimum and post-anthesis heat stress conditions had higher STI compared to other genotypes (unpublished data). They also suggested that, the problem with using SSI as a measure of adaptation to the stress is that there are cases where SSI has been positively correlated with grain yield reduction in that genotypes whose yield was affected little by the stress also had very low yield potential. This means that the genotypes with low SSI also may have had low stress resistance yield and would not be useful for farmers. Generally, post-anthesis heat stress reduced GY 30%, 35% and 35% in short, middle and long season genotypes, respectively. In late sowing period, heat stress after anthesis reduced GY 32% and 34% on durum and bread wheat genotypes, respectively.

Evaluating Environment*N interaction for GY, BY and HI in both conditions indicated that the slope of BY reduction due to N fertilizer reduction was higher in optimum sowing season compared to heat stress condition, while the GY had same changes under both conditions, comparatively (Figure 2: a and b).

Table 3. STI and SSI for grain yield and GY reduction in heat stress condition (GYR) compared with optimum condition.

Genotypes	Grain Yield		GYR (%)
	STI	SSI	
Attila	0.58	1.14	37
Vee/Nac	0.44	0.79	27
Star	1.16	1.16	39
Mean	0.72	1.03	34
Showa+	0.83	0.96	33
D-84-5+	0.78	0.95	33
D-83-8+	0.80	0.90	31
Mean	0.8	0.93	32

SSI: Stress Susceptibility Index
STI: Stress Tolerance Index
+: Durum genotypes

Later-sown bread and durum wheat genotypes developed less extensive root systems and may be more vulnerable to drought and heat (Ehdaie and Waines, 2001). Less extensive root system in delayed sowing may also lead to smaller N absorption and lower agronomic N efficiency (AN_E) (Table4). Indeed, increasing or decreasing of N fertilizer may had lower effects on BY in late sowing compared with optimum condition (Fig.2: a & b).

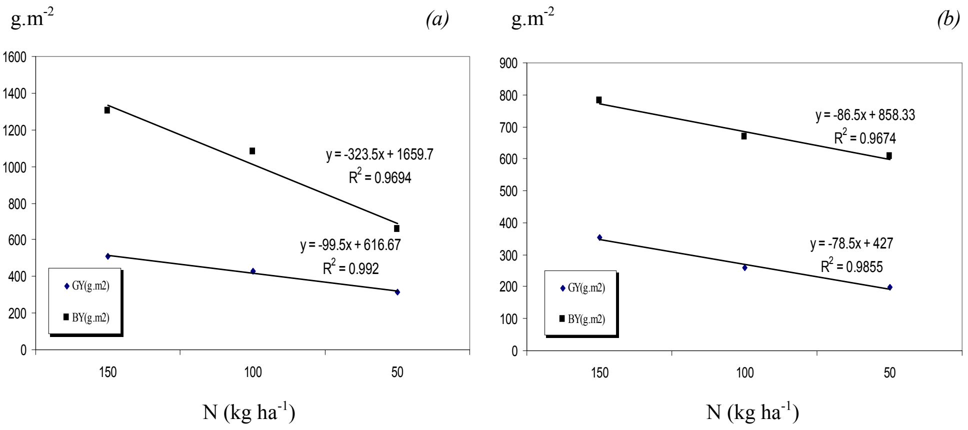

Figure 2. Linear regression between N rates and GY and BY under optimum *(a)* and delayed *(b)* sowing dates.

Table 4. Agronomic N efficiency (AN_E) of wheat genotypes at different N rates, under optimum and post-anthesis heat stress conditions.

Genotypes	N (kg ha^{-1})					
	150		100		50	
	LS	OS	LS	OS	LS	OS
Attila	1.0	1.7	0.88	2.3	2.3	4.0
Vee/Nac	1.0	1.9	1.2	1.9	1.8	3.5
Star	0.7	1.4	0.88	1.6	2.1	3.0
Showa+	1.6	2.7	2.3	3.4	2.2	3.7
D-84-5+	1.2	2.2	1.6	2.5	2.4	4.4
D-83-8+	1.8	2.2	1.4	2.4	2.3	4.0
Mean	1.2	2.1	1.3	2.3	2.2	3.8

+: Durum genotypes
OS: Optimum Sowing
LS: Late Sowing

Discussion

Delay in sowing beyond the optimum period reduces wheat yields (Anderson and Smith, 1990).The late sowing yield reduction percentile depends on the type of wheat genotypes. Early sowing of wheat has been recommended as a means of reducing nitrate leaching (Addiscott et al., 1991). Widdowson et al. (1987) demonstrated large differences in N uptake between winter wheat sown mid-September and late sown in mid-October. The indicated results show that AN_E mean in optimum sowing (2.1 kg per kg) is greater than late sowing (1.2 kg per kg) (Table 4).

Greater N uptake in optimum sowing resulted in higher grain average yield at assigned duration compared to late sowing. Ehdaie and Waines (2001) reported that less extensive root system in delayed sowing date may lead to smaller N absorption and lower agronomic N efficiency. Results indicated positive and significant correlation between GY and AN_E in optimum ($r = 0.87$) and delayed ($r = 0.75$) sowing date (in 150 kg N ha treatment).

GY reduction in 50 and 100 KgNha^{-1} compared to 150 KgNha^{-1} treatments was observed 41% and 21% under optimum and 44% and 26% in heat stress conditions, respectively. In all genotypes, grain yield and TGW reduction under post-anthesis heat stress condition was 33% and 42%, respectively. The highest and the lowest grain yield reduction due to heat stress were in Star (39%) and Vee/Nac (27%) genotypes. We previously observed reported that in early mature genotypes such as Fong and Vee/Nac with early anthesis, grain growth period would be ended by heat stress conditions. Indeed grain yield and weight reduction was lower in these genotypes. Showa and Vee/Nac genotypes had the highest and the lowest STI for grain yield, respectively. we suggest that, genotypes with high GY in optimum and post-anthesis heat stress conditions, had higher STI compared to other genotypes. Although, the lowest STI was in Vee/Nac cultivar, but the lowest GY reduction in post-anthesis heat stress condition compared to optimum sowing date lead to lower SSI in this genotype.

Generally, grain yield reduction in nitrogen deficient treatments and post-anthesis heat stress was due to significant reduction in grain.m^{-2} and TGW, respectively. In nitrogen deficiency treatments grain number per unit area is reduced due to reduction in spike.m^{-2}, spikelet.spike^{-1} and fertile floret.spikelet^{-1}. Further researches are recommended for full understanding of the effects of heat stress and N deficiency on yield and yield components of recommended wheat genotypes under agroclimatic conditions of southern Iran such as Ahvaz with tropical climate.

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