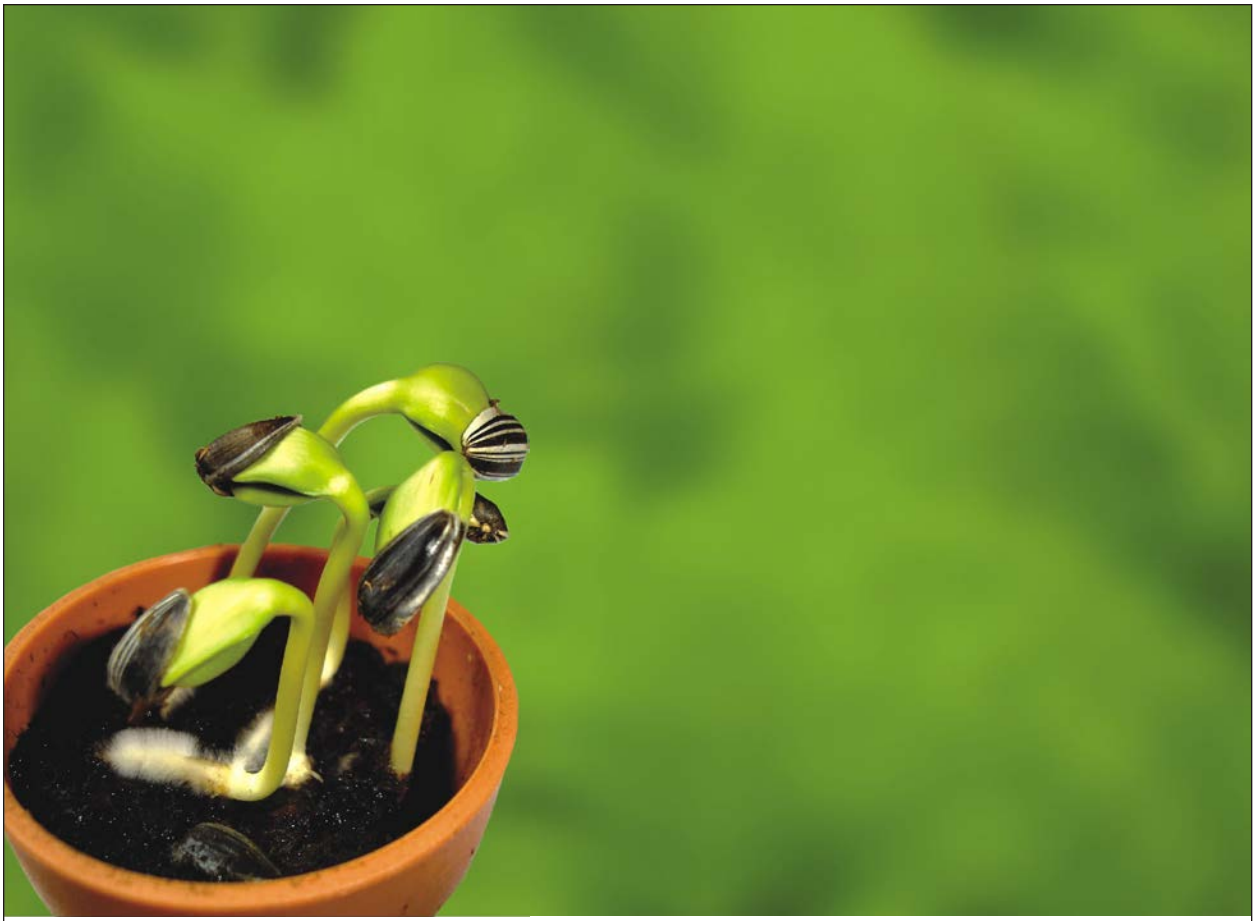

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Screening of Tolerant Spring Barleys for Terminal Heat Stress: Different Importance of Yield Components in Barleys with Different Row Type

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ABSTRACT

To comparing barleys with different spike type in terms of yield and substantial yield components under terminal heat stress, 12 spring barley genotypes were tested at two levels of sowing dates i.e., normal (5 Dec) and late sowing (20 Jan) during the years 2005-2007. The crop-physiological status of plants was remarkably affected by terminal heat stress which ultimately reduced grain yield. Optimum Plant Height (PLH) of two types of barleys were about 90 and 80 cm under optimum and heat stress condition, respectively indicating that under heat stress, the genes for reduced height may have increased the portion of assimilate to grain rather than to the stem. Observed difference in yield of 2-row genotypes was primarily caused by heat-induced reduction of S m^{-2} and GW, instead of reduction of G S^{-1}, whereas in 6-row barleys, G S^{-1} has higher contribution to grain yield than GW. According to comparing genotypes and using stress indices, genotypes which have higher grain yield in both stress and optimum conditions, such as L6 and L8 were identified as heat-tolerant genotypes.

Key words: Barley, spike type, yield components, crop-physiological traits, terminal heat stress, stress indices

INTRODUCTION

It is not seems to be easy to raise the yield potential further, because advanced genotypes already possess a relatively high yield potential (Slafer and Araus, 2007). In fact, researchers may trust that selecting for higher yield potential may bring about improved performance under a wide range of environmental conditions may be the good way. Moreover, further success in this subject need the identification of important applied tools and strategies to complement screening approaches under the pressure of abiotic stress. Introduction of relatively simple crop-physiological traits that determine yield in a wide range of conditions may be helpful for supplementary future breeding. If researchers were able to identify relatively simple traits associated with yield under stress conditions, there would be a way to take advantage of the enormously powerful tools for screening high yielding stress-tolerant genotypes. For example, selection for an optimal plant height has been important, particularly under stress condition to achieve maximum yield and to maximize harvest index. On the other hand, in barley, few studies have attempted to identify the yield component(s) which have higher contribution to grain yield of two- and six-row barleys and few works accomplished based on comparing barleys with different spike type in respect of yield determination. Arisnabarreta and Miralles (2008) reported different critical period for grain yield determination among two- and six-row barley lines. Accordingly, there are important differences between the species and among barley genotypes (i.e., two and six-rowed types) suggesting that this field requires more studying.

In Mediterranean condition, heat and drought are normally associated at the end of the growing season. The combined stress produced by heat + drought is perceived by the plant as a new stress and originates specific responses. But in well-irrigated farms, even when water is not a limiting factor, crop productions with late sowing in Mediterranean environments such as in Southwest part of Iran (where high temperatures occur at the end of the cycle) have lowered yields; Mostly, as a result of heat stress during anthesis and grain filling (Ramos *et al.*, 1982; Wardlaw and Wrigley, 1994; Savin *et al.*, 1997; Garcia del Moral *et al.*, 1991, 2003). Thus, this study focused exclusively on heat stress that take place at the end of the cycle. Although, in an accompanying study, the impacts of drought stress on agro-physiological traits of these genotypes were investigated by Vaezi *et al.* (2010).

The sowing dates in terms of changed temperatures are critical for determining appropriate crop yields (Sial *et al.*, 2005). Sowing at an appropriate time is necessary for ensuring maximum yield but sometimes, farmers are forced to do delay sowing because sowing time depends on weather, topography and harvesting time of the previous crops. Sowing of barley is done in early December in the dry-land areas particularly southwest part of Iran which in these water deficit and hot areas, early December is usually moderate and soil moisture is favorable but the temperature decreases to the lowest level in early February when the crop is in the vegetative stage. The reproductive phase commences when the temperature starts rising in the end of March and beginning of April and in delayed sowing, barley plants suffer by high temperature during the generative growth.

Heat stress due to high ambient temperatures is a serious threat to crop production worldwide (Hall, 2001). High temperatures can cause considerable pre- and post-harvest damages, including scorching of leaves, sunburns on leaves and stems, leaf senescence and abscission, shoot and root growth inhibition, reduces duration of tillering and grain-filling period, reduced dry matter production and yield (Ellis *et al.*, 1990; Wallwork *et al.*, 1998a, b; Ismail and Hall, 1999; Giaveno and Ferrero, 2003; Vollenweider and Gunthardt-Goerg, 2005). Yield is very important trait, is the function of many components which when modified, has direct influence on the productivity and has high effect with environment conditions (Stone and Nicolas, 1994; Wardlaw and Wrigley, 1994; Ehdaie and Waines, 2001). Arisnabarreta and Miralles (2008) suggested that in two-rowed barley genotypes, changes in the number of grains per unit area have been frequently associated with variations in the number of spike m^{-2}. On the contrary, changes in the number of grains per unit area in six-rowed barleys were better explained by the ability to modify the number of grains per spike.

The timing of heading is a major trait related to the adaptation of cultivars to particular areas, thus determining crop performance under prevalent field conditions. Early heading (avoiding frost damage) permits a long grain-filling period during which photosynthetic components remain green, improving grain filling because the contribution to grain yield of post-anthesis assimilate is important in barley (Bidinger *et al.*, 1977). Also, stay-green (syn. non-senescence) which has been so well discussed by Thomas and Howarth (2000) is considered an important component for sustaining yield potential and in some cases also for sustaining yield under stress during grain filling (Sanchez *et al.*, 2002).

Several stress indices or selection criteria, such as GMP = Geometric mean yield (Ramirez-Vallejo and Kelly, 1998); SSI = Stress Susceptibility Index (Fischer and Maurer, 1978); STI = Stress Tolerance Index (Fernandez, 1992) have been proposed as ways to identify genotypes with better stress tolerance. A larger value of SSI show relatively more sensitivity to stress, thus a smaller values of SSI are favored. Fernandez (1992) claimed that selection based on STI and GMP would result in genotypes with higher stress tolerance and good yield potential.

The international research centers are not searching for cultivars and they just develop the germplasms and distribute to different countries. Enormous efforts are, therefore needed to identify genotypes with better performance and desirable traits at both stress and optimum conditions for target environments. Present experiment was set up (1) to determine which yield component(s) have more contribution to yield and (2) to introduction of relatively simple crop-physiological traits that determine yield for (3) screening the genotype(s) which have better yield performance under terminal heat stress at field conditions.

MATERIALS AND METHODS

Ten advanced spring barley genotypes (L1 to L10) from ICARDA and two landraces of Izeh (6-row spring barley as L11) and Mahour (2-row spring barley as L12) that largely cultivated in the Southwest of Iran were used in this experiment (Table 1). These genotypes were sown in different temperature regimes by two sowing dates i.e., 5th December (optimum) and 20th January (delayed) during two years 2005-2007 at the dry land agricultural research station, Gachsaran (50°50'N, 30°17'W, altitude 710 m) in a calcareous type soil with a Silty Clay Loam texture, pH: 7.3 and organic matter less than 1%. The experiment site had a hot climate with a moderate winter and dry and hot summer. Daily maximum, minimum and mean temperatures were recorded by a meteorological station situated in the experimental site (Fig. 1). These genotypes were used to compare the responses of different, widely used cultivars and breeding lines selected for their tolerance to heat stress. The experiments were conducted in three replicates using Randomized Complete Block Design (RCBD) with six rows, 4.7 m long and border of 17.5 cm in wide. Plant density was 250 plants per m^2. The fertilization rate was 50 kg ha^{-1} N plus 50 kg ha^{-1} P_2O_5. The plots were irrigated when necessary and they were maintained at field capacity to avoid water stress.

Phenological traits and yield evaluations: The phenological characteristics of the different genotypes were determined taking into account the number of days observed from sowing until the upper most spikes appeared beyond the auricles of the flag leaf sheath (50% heading on plants basis) i.e., days to heading (DHE). To estimate days to maturity (DMA), the number of days between the sowing date and the time at which 50% of the spikes had matured was counted. When the crops were mature, spikes from the centre square meter of each subplot were counted, cut and threshed to obtain the grain yield (g m^{-2}). After the spikes were harvested, the stalks were cut at ground level. The Thousand-Grain Weight (TGW) was obtained by counting out 1000 grains in each microplot with a grain counter and weighing them. The number of grains per spike (G S^{-1}) was calculated from the equation:

$$\text{Yield} = \text{No. of spike per m}^2 \times \text{G S}^{-1} \times (\text{TGW}) \times 10^{-3}$$

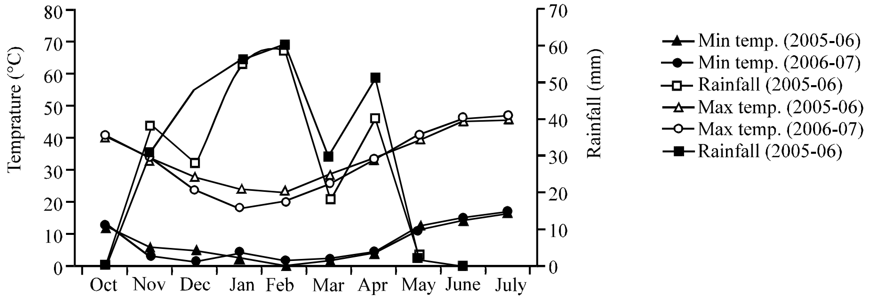

Fig. 1: Temperature and rainfall status of experimental site, averaged over 30-day periods for the 2005-6 to 2006-7 growing seasons

Table 1: Barley promising lines involved in this study, their pedigrees and row types

Genotypes	Origin	Pedigrees	Row type
L1	ICARDA	Alanda/5/Aths/4/Pro/Toli//Cer *2/Toli/3/5106/6/Avt/. -8G -3 G	6
L2	ICARDA	Bda/Cr. 115/Pro/Bc/3/Api/Cm67/4/ Giza121/... -9G -2 G	2
L3	ICARDA	Emir/Nacta//As907/3/Avt_(9-9)ACSAD-1290-6AP-OTR-OAP-6AP-OAP-OAP	2
L4	ICARDA	Lth/3/Nopal//Prol/11012-2/4/Kabaa-03ICB94-0498-OAP-3AP-OAP-OAP	6
L5	ICARDA	Himalaya-12/Plaisant ICBH95-0630-OAP-OAP-16AP	6
L6	ICARDA	MK1272//Manker/Arig8/3/Alanda ICB93-0448-OAP-6AP-OAP	6
L7	ICARDA	Hyb 85-6//As46/Aths*2	6
L8	ICARDA	Alanda/Harma-01/7/Gustoe/6/M64-76/Bon....	6
L9	ICARDA	Zanbaca/3/H.spont.21-3/Arar84//Wi2291/Bgs ICB 94-0314-OAP	2
L10	ICARDA	Pld10342//Cr.115/por/3/Bahtima/4/DS	2
L11	Iran	Izeh. - (CONTROL)	6
L12	Iran	Mahour - (CONTROL)	2

Disease, stay-green and plant height studies: During growing season, reaction to disease such as Scald [e.g., immune, resistance, medi-resistance, tolerant, medi-sensitive and sensitive (as O, R, MR, T, MS and S)], Powdery Mildew (PM), Barley Dwarf Virus (BDV) were recorded (Saari and Prescott, 1975). The stay-green rating was visually scored at or soon after physiological maturity on a plot basis. Scoring was done on a 1-5 scale based on the proportion of leaf area of normal-sized leaves which had prematurely senesced and died. A rating of 1 indicated essentially no leaf death, 3 indicated approximately 50% mature leaf area dead while 5 indicated 100% plant (leaves and stem) death (Xu *et al.*, 2000). In addition, the days to 100% flag leaf death were recorded. Mean plant height in centimeter from base of the culm to the tip of the spike of the main culm was estimated.

Tolerance and susceptibility indices: Genotypes were compared for their yield potentials in optimum and heat stress condition using the Stress Susceptibility Index (SSI) recommended by Fischer and Maurer (1978), Stress Tolerance Index (STI) according to Fernandez (1992) and geometric mean (GMP) by Ramirez-Vallejo and Kelly (1998).

Statistical analysis: Combined analyses of variance for grain yield and its related characters were performed over trials after verifying the homogeneity of trial variance errors using Bartlett's test. Least Significant Difference (LSD) values were calculated at the 5% probability level. Correlation coefficients between all characters and yield were computed from the mean values. SAS and EXCEL software were used for these analyses.

RESULTS AND DISCUSSION

Rainfall distribution patterns were almost the same in the two years of study, although in 2005-2006, rainfall in December was lower than in 2006-2007 (Fig. 1). Mean temperature during reproductive growth was 28 and 35°C, in optimum and delayed sowings, respectively in 2005-2006 while in 2006-2007 mean temperature of generative growth duration in optimum and delayed sowing was 26 and 34°C, respectively. High temperatures beyond 40°C persisted in October and first week of November. The temperatures became favorable by the beginning of December and continued (below 30°C) up to 3rd week of February. Moderately temperatures (22-25°C) were recorded during 4th week of February. The linear increase in temperature continued in the month of March and by the end, it reached to about 30°C. Disastrous temperature to barley crop (≥35°C) happened to be in the month of April. Overall, high temperatures in the range of 35 to 41°C prevailed from 3rd week of April to the end of May (Fig. 1). Sowing dates substantially modified the temperature during the generative growth periods considered in the present study. However, the average temperature for each period was similar between the genotypes, since they reached booting, anthesis and physiological maturity at similar dates (data not shown). Seasonal ranges in average temperature in two years of study were 17.4-18.61°C from sowing to physiological maturity, 13.67-15.27°C from sowing to anthesis and 19.71-21.11°C between anthesis and physiological maturity in normal planting. While, average temperature in two years of study in delayed planting were 18.71-19.42°C from sowing to physiological maturity, 13.97-14.98°C from sowing to anthesis and 29.36-29.38°C between anthesis and physiological maturity in delayed planting. This data verified that range of temperature at generative duration was about 8-10°C greater in delayed sowing than normal sowing.

The combine analysis of variance (Table 2) revealed that main effects (genotypes, sowing date and their interaction) were significant but the effect of year was not significant for all the characters studied. The significance of genotypes and sowing date indicated that varieties performed differently and late sowing also significantly affected the plant traits. These results also indicated that studied genotypes responded differently to the different environmental conditions suggesting the importance of the evaluation of genotypes under different conditions in order to identify the best genetic make up for a particular condition. None of the genotypes showed symptoms of disease studied.

Days to heading and maturity: The average of days to heading ranged from 92 days for L6 and L9 to 100 days for L7 in non-stress condition. In late sowing condition, number of days to heading varied from 87 to 94 for L6 and L7, respectively. Genotype L7 had greater DHE and DMA in both stress and non-stress condition. L9 needed lower days to reach maturity under both optimum and terminal heat stress condition (late sowing) (Table 3). Phenological traits such as photoperiod sensitivity and the duration of the crop's various growth phases are for dryland crops keys to agro-ecological adaptation to semi-arid environments such as south-west of Iran. This is partly a consequence of abiotic stresses affecting the crop when its cycle is weakly adjusted to local seasonal patterns of climate. Development and yield of barley were obviously affected by temperature during plant growth: vegetative, stem elongation and grain development (Kouressy *et al*., 2008). Results

Table 2: Combine analysis of variance for 12 barley genotypes over 2 years (2005-6 and 2006-7) and 2 sowing dates

		Mean squares							
Source of variation	df	PLH	DHE	DMA	S m^{-2}	G S^{-1}	TGW	GY	SG
Year (Y)	1	4.19^{ns}	5.4^{ns}	3.08^{ns}	7.09^{ns}	5.4^{ns}	6.4^{ns}	4.01^{ns}	4.3^{ns}
Rep/Y	4	2.58	8.33	1.34	1.27	2.83	2.58	2.35	0.74
Genotypes (G)	11	540.46^{**}	197.36^{**}	23.72^{**}	280.9^{**}	175.89^{**}	2294.73^{**}	264.74^{**}	64.34^{**}
G×Y	11	0.14^{ns}	0.36^{ns}	0.02^{ns}	0.41^{ns}	0.48^{ns}	0.79^{ns}	0.14^{ns}	0.03^{ns}
Sowing Date (D)	1	315.3^{**}	601.1^{**}	642.4^{**}	$188.\ 7^{**}$	150.8^{**}	$399.\ 8^{**}$	$180.\ 2^{**}$	191.4^{**}
D×Y	1	1.20^{ns}	1.76^{ns}	0.38^{ns}	1.41^{ns}	1.23^{ns}	1.07^{ns}	0.20^{ns}	1.29^{ns}
D×G	11	274.22^{**}	95.67^{**}	10.74^{**}	235.53^{**}	60.21^{**}	70.02^{**}	274.22^{**}	8.04^{**}
Error	44	5.58	8.33	5.34	15.96	6.83	13.58	4.58	4.74
CV (%)		19.96	1.36	6.22	15.45	2.81	17.14	5.36	12.49

*, **: Significant at 5 and 1% level, respectively, ns: Not significant at 5% level

Table 3: Means† of agronomic traits for evaluation response of advance barley genotypes to terminal heat stress at 2005-6 and 2006-7

Line No.	Row type	Diseases (SCA, PM, BDV)	DHE (day)	PLH (cm)	DMA (day)	Tgw (g)	G S^{-1}	S m^{-2}	Yield (t ha^{-1})	SG (day)
Terminal heat stress condition										
1	6	0	89^{c}	83.96^{ab}	116^{de}	38.9^{def}	44^{b}	116^{e}	1.99^{defg}	114^{c}
2	2	0	92^{ab}	85.03^{a}	117^{cd}	41.1^{bc}	21^{e}	198^{c}	1.75^{fg}	107^{e}
3	2	0	91^{bc}	74.86^{c}	114^{fg}	43.3^{ab}	20^{e}	239^{ab}	2.07^{cdefg}	111^{d}
4	6	0	90^{bc}	85.56^{a}	116^{de}	38.2^{ef}	43^{bc}	108^{e}	1.77^{efg}	114^{c}
5	6	0	89^{c}	78.26^{bc}	118^{bc}	33.6^{g}	43^{bc}	178^{c}	2.57^{b}	115^{bc}
6	6	0	87^{c}	80.03^{b}	116^{de}	44.8^{a}	49^{a}	150^{d}	3.30^{a}	119^{a}
7	6	0	94^{a}	76.33^{bc}	120^{a}	31.2h	44^{b}	141^{d}	1.93^{defg}	116^{b}
8	6	0	90^{bc}	80.70^{b}	119^{ab}	40.4^{cd}	43^{bc}	138^{d}	2.4^{bc}	118^{a}
9	2	0	88^{c}	84.83^{ab}	111h	42.5^{bc}	20^{e}	249^{a}	2.12^{cdef}	108^{e}
10	2	0	88^{c}	83.63^{ab}	113^{g}	42.8^{bc}	22^{de}	234^{ab}	2.15^{cde}	111^{d}
11	6	0	90^{bc}	85.63^{a}	117^{cd}	37.1^{f}	40^{c}	114^{e}	1.69^{g}	115^{bc}
12	2	0	88^{c}	83.26^{ab}	115^{ef}	42^{bc}	23^{d}	226^{b}	2.18^{cd}	109^{de}
LSD value ($\alpha = 5\%$)			2.695	4.394	1.122	2.469	2.5	20.3	0.4322	1.887
Line No.	Row type	Diseases (SCA, PM, BDV)	DHE (day)	PLH (cm)	DMA (day)	Tgw (g)	G S^{-1}	S m^{-2}	Yield (t ha^{-1})	SG (day)
Non-str^{e}ss condition										
1	6	0	93^{de}	83.83^{c}	121^{d}	42.13^{e}	48^{bc}	175^{d}	3.53^{bcd}	120^{b}
2	2	0	97^{b}	93.93^{a}	122^{cd}	48.66^{ab}	22^{d}	306^{bc}	3.28^{def}	112^{e}
3	2	0	93^{de}	88.01^{bc}	118^{ef}	44.86^{cd}	23^{d}	347^{a}	3.58^{bcd}	115^{d}
4	6	0	96^{bc}	93.16^{a}	121^{d}	41.9^{e}	51^{b}	137^{e}	2.92^{f}	117^{c}
5	6	0	95^{bcd}	93.0^{a}	124^{b}	39.66^{f}	51^{b}	164^{de}	3.31^{cde}	123^{a}
6	6	0	92^{e}	89.0^{b}	123^{bc}	47.9^{ab}	56^{a}	152^{e}	4.09^{a}	123^{a}
7	6	0	100^{a}	83.0^{c}	126^{a}	32.16^{g}	48^{bc}	144^{e}	2.23^{g}	117^{c}
8	6	0	96^{bc}	90.0^{ab}	123^{bc}	43.96^{de}	48^{bc}	181^{d}	3.82^{ab}	122^{a}
9	2	0	92^{e}	88.0^{bc}	117^{f}	46.60^{bc}	22^{d}	332^{ab}	3.4^{cde}	112^{e}
10	2	0	94^{cde}	92.0^{ab}	119^{e}	49.36^{a}	23^{d}	323^{b}	3.67^{bc}	117^{c}
11	6	0	95^{bcd}	94.7^{a}	121^{d}	39.16^{f}	46^{c}	161^{de}	2.91^{f}	117^{c}
12	2	0	94^{cde}	87.5^{bc}	119^{e}	44.46^{cd}	21^{d}	329^{b}	3.07^{ef}	115^{d}
LSD value ($\alpha = 5\%$)			2.647	4.813	1.354	2.159	3.608	10.855	0.3859	1.565

Means followed by the same letter are not significantly different at the 5% probability level

of the present study clearly show the differences between temperature regimes in determining DHE and DMA, accounting for differences in grain yield between the delayed sowing and normal conditions.

Reduction in number of days to heading and maturity for 2-row genotypes when planting was delayed to January, were 4.9 and 4.2%, respectively while for 6-rows were 5.55 and 4.3%, respectively. This effect probably resulted from slower emergence and rapid accumulation of heat units for late planting. This reduction was more obvious in the genotypes which required higher number of days for heading under normal planting. The phenomenon is almost common as days to heading shorten, in a curvilinear fashion as temperature increases (Slafer and Whitechurch, 2001). Similarly, the genotypes matured 6 to 7 days earlier when planted late, indicating forced maturity due to high temperatures.

At least one genotype, L6 was identified which possessed inherent earliness for heading under normal and late planting and seems to have tolerance capability to high temperature (Table 3). Reducing heading time has been a successful strategy when breeding for environments characterized by terminal stress factors (Alvaro *et al.*, 2008). This strategy has achieved good results because earliness is probably the most effective way to increase yield in conditions where heat occurs during anthesis and grain filling. Evans and Wardlaw (1967) indicated that variation in the DHE accounted for 5 to 10% of the variation in grain yield.

Due to fact that a few number of genotypes used in present trails and since low degree of freedom, some correlation coefficients were not significant, although they were almost high. A negative correlation was fond between yield and DHE under stress condition in both 2-row ($r = -0.85^{*}$) and 6-row genotypes ($r = -0.62^{ns}$) (Table 4). There were several hot days during barley growth season, especially high of temperature around heading and during grain-filling period when sowing was delayed. Heat stress may have affected the seed setting. This could be the critical factor that reduced yield and caused a negative correlation between days to heading and yield especially in 2-row barley genotypes. Precocity has also a strong influence on the length of the grain-filling period and number of days to reach maturity shows a negative correlation with grain yield under stress condition in both 2-row ($r = -0.69^{ns}$) and 6-row genotypes ($r = -0.11^{ns}$). Higher correlation between yield, DHE and DMA in 2-row genotype than 6-rows revealed that the developmental stages in 2-rows are most sensitive to heat stress and yield in these genotypes most affected by time of heading and maturity. The association between precocity, grain-filling period and yield under stress conditions has also been observed in other cereals such as wheat (Talbert *et al.*, 2001) and triticale (Giunta *et al.*, 1993).

In stressful environments, it might be better to select for precocity since the late maturity is more subject to the influence of environmental conditions (such as high temperature) that can prematurely stop grain growth and accelerate physiological maturity.

Table 4: Correlation coefficients between grain yield and other traits under stress and non-stress conditions for 2005-6 and 2006-7

	2-row genotypes		6-row genotypes	
Traits	r (Stress)	r (Optimum)	r (Stress)	r (Optimum)
Plant height	-0.18^{ns}	0.19^{ns}	-0.48^{ns}	0.31^{ns}
Days to heading	-0.85^{*}	-0.30^{ns}	-0.62^{ns}	-0.82^{*}
Days to maturity	-0.69^{ns}	-0.30^{ns}	-0.11^{ns}	-0.31^{ns}
Spike per m^2	0.81^{ns}	0.32^{ns}	0.69^{ns}	0.55^{ns}
Grain per spike	0.29^{ns}	0.97^{**}	0.81^{*}	0.52^{ns}
1000-grain weight	0.69^{ns}	0.42^{ns}	0.55^{ns}	0.93^{**}
Stay-green	0.67^{ns}	0.43^{ns}	0.77^{*}	0.83^{*}

*: $p<0.05$, **: $p<0.01$, ns: not significant at $p<0.05$

Plant height: On an average, declines of 10% in plant height were caused by the heat stress conditions against no stress control which in these declines were 8.4 and 11.6% for 2-rows and 6-rows, respectively (Fig. 2). Plant height decreased with delaying of planting date in both 2-row and 6-row genotypes (8. 4 and 11.6%, respectively) during two years of study (Fig. 2); this may be due to changes in photoperiod which accelerated development towards reproductive stages and hence less time was available to vegetative growth. Okosun *et al.* (2006) reported that early sown plants had a longer period for vegetative growth which resulted in taller plants.

Low temperature during February and first weeks of March and high temperature during May and January may also be the reason for minimum plant height for late planting.

When growth resources are limited by heat stress, the size of plant organs such as leaves, tillers and spikes are reduced (Fischer, 1985). Azooz and Youssef (2010) reported that root and shoot dry weight of wheat significantly decreased due to heat stress.

Results with respect to plant height (Table 3) revealed that plant height ranged from 85.63 cm (L11) to 74.86 cm (L3) when terminal heat stress was subjected whereas medium plant heights given by genotypes L6 and L8 implied they are may being more tolerant to terminal heat stress (stress indices in Table 5). One possible reason that heat susceptible lines suffer from heat stress in their generative stage, maybe due to the increase of activatity of sucrose synthase. The enzyme sucrose synthase cleaves sucrose to make the energy source entry into growth and storage processes. This process may be associated with an increase in shoot growth (Lorenzen and Lafta, 1996). Therefore, heat susceptible plants may have taller plant height and large leaf area (this may explain present finding that heat susceptible lines have higher plant height). Heat susceptible lines may grow faster than tolerance ones under stress condition, so we hypothesis that the dwarfing effect may be caused by other genes that are closely linked to the heat-tolerance gene. Semi-dwarfism consistently combined improved yield potential with improved performance across a wide range of conditions (Richards, 1992; Miralles and Slafer, 1995). According to Richards (1992), in tall and short isogenic populations of wheat, the short populations yielded more than the tall populations even though they all contained dwarfing gene (Rht1). The expression of the major dwarfing genes and their effect on agronomic characteristics varied depending on the genetic background.

Correlation analysis under stress condition showed that yield had a negative correlation with plant height in 2-row ($r = -0.18^{ns}$) and 6-row genotypes ($r = -0.48^{ns}$). However, these correlations

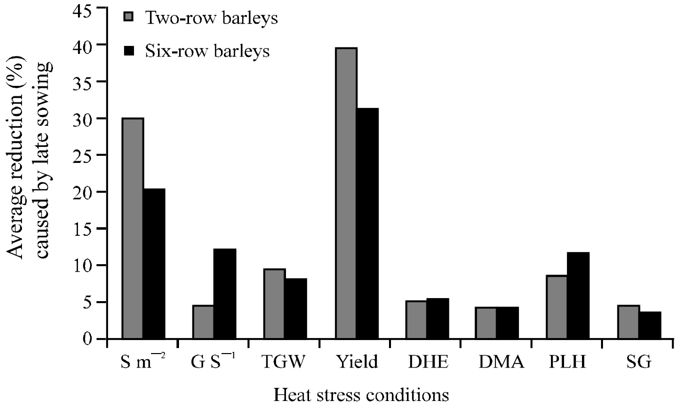

Fig. 2: Average reduction (percentage) in yield, yield components and other evaluated traits of two types of barleys caused by terminal heat stress (late sowing)

Table 5: Grain yield status and stress indices of 12 barley genotypes during two years of 2005-6 and 2006-7

	Yield (%) of genotypes comparing to yield of controls				Stress indices[†]				
	Late sowing	Normal sowing	Average of two conditions		Yp	Ys	SSI	STI	GMP
Line	2-rows compared to L12 (Mahour)			Averages reduction[‡]	2-row genotypes				
2	-19.72	6.84	-6.44	1530	3.28	1.75	1.08	0.50	2.40
3	-5.05	16.61	5.78	1510	3.58	2.07	1.07	0.64	2.72
9	-2.75	10.75	4.00	1280	3.40	2.12	0.97	0.62	2.68
10	-1.38	19.54	9.08	1520	3.67	2.15	1.07	0.68	2.81
12	0.00	0.00	0.00	890	3.07	2.18	0.81	0.58	2.59
Line	6-rows compared to L11 (Izeh)				6-row genotypes				
1	17.75	21.31	19.53	1540	3.53	1.99	1.26	0.66	2.65
4	4.73	0.34	2.54	1150	2.92	1.77	1.06	0.49	2.27
5	52.07	13.75	32.91	740	3.31	2.57	0.86	0.80	2.92
6	95.27	40.55	67.91	790	4.09	3.30	0.88	1.27	3.67
7	14.20	-23.37	-4.58	300	2.23	1.93	0.64	0.41	2.07
8	42.01	31.27	36.64	420	3.82	2.40	1.20	0.86	3.03
11	0.00	0.00	0.00	220	2.91	1.69	1.10	0.46	2.22

[‡] Average reduction in grain yield of 12 barley lines caused by terminal heat stress (kg ha^{-1}), [†] Yp and Ys: Grain yield of each genotype under optimum and stress condition respectively, SSI: Stress susceptibility index, STI: Stress tolerance index, GMP: Geometric mean yield

were not significant. Villareal *et al*. (1992) and Belay *et al*. (1993) reported the similar findings in which plant height had a strong negative correlation with grain yield of wheat. Actually, plant height values since it is not just a matter of associations, the plant height range is also important. An optimum relationship has been found when the grain yield and plant height were plotted (Richards, 1992; Miralles and Slafer, 1995). According to present results, in non-stress condition we can find optimum plant height by 90 cm (Fig. 3a, b). Therefore, it is possible to hypothesises that plants under heat stress also show an optimum relationship but at lower plant height values. This is reinforced by the fact that plant height was lower in the second sowing date. Under stress condition, an optimum relationship could be seen by 80 cm. For higher plant heights than this optimum range, there is no gain in biomass while there is a proportional reduction in the Harvest Index (HI) (Royo *et al*., 2007). Below this optimum range, further gain in the HI does not compensate for the loss in biomass because of highly poor radiation distribution within the canopy and consequent reductions in radiation use efficiency (Miralles and Slafer, 1997). Thus, reducing height to an optimum range increases yield potential and simultaneously reduces the risk of lodging. Richards (1992) reported optimum plant height in near-isogenic lines of wheat from 100 to 130 cm when grown in the normal condition, whereas highest grain yields under stress condition were achieved by lines with a height between 70 and 100 cm.

Present findings revealed that under heat stress, the genotypes that produced higher yield (especially in 6-row genotypes), have medium plant height (Table 3) indicating that the genes for reduced height have contributed to higher yields as they have increased the portion of assimilates to grain and the reproductive organs rather than to the stem.

Stay-green: Stay-green duration under heat stress ranged from 107 days for L2 to 119 days for L6 and in non-stress condition ranged from 112 days for L2 and L9 to 123 days for L5 and L6

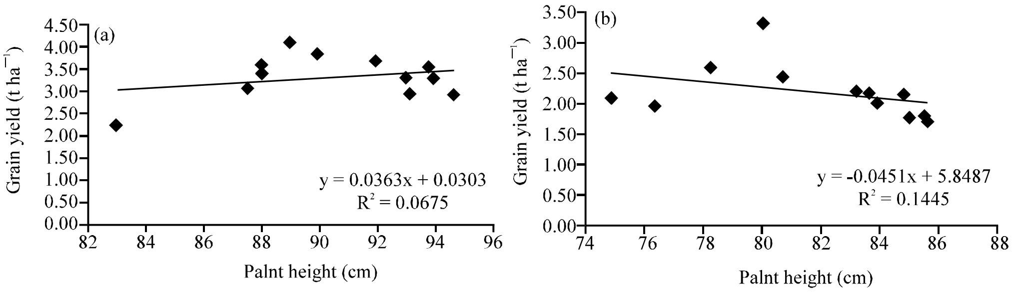

Fig. 3: Grain yields and plant heights of 12 barley genotypes under normal (a) and terminal heat stress conditions and (b) at two years of study

(Table 3). Stay-green may be particularly advantageous under conditions, such as high temperature, that tend to accelerate senescence and thus decrease the supply of assimilates to the grain. In our study, stay green duration was significantly lower under heat stress compared to non- stress condition and was differ for genotypes under both conditions (Table 3).

In this study, means of stay green durations of 6-rows were higher than of 2-rows in both optimum and stress conditions and the average reduction in stay green duration caused by terminal heat stress was approximately higher in 2-row (4.55%) than 6-row genotypes (3.34%) (Fig. 2). Genetic variation exists in the timing and rate of leaf senescence, both between two types and genotypes. High yielding genotypes (i.e., L6 and L8 among 6-rows; L3 and L10 among 2-rows) showed longer stay-green duration than other genotypes under stress condition (Table 3). When Leaf senescence is delayed, this enhances both radiation use efficiency and transpiration use efficiency resulting in higher yields. At the same time, non-senescent genotypes retain more of their photosynthate in the leaves (Borrell and Hammer, 2000) and stems, whereas rapid leaf senescence may be indicative of reserve mobilization to the grain under stress. This seems to be associated with accelerated export of nitrogen from leaves (Pell and Dann, 1991). Photosynthetic capacity is mislaid in proportion to level of damage to leaf tissues. According to these facts, positive association between yield and stay-green across genotypes under heat stress condition, was expected, that this correlation was lower in 2-rows ($r = 0.67^{ns}$) than 6-rows ($r = 0.77^{*}$) (Table 4). These largish correlations revealed that the extended period of flag leaf photosynthetic capability is linked with the production of larger grains, apparently because of increased carbohydrate content and finally higher grain yield production. Extending the competence of the plant to photosynthesize and produce assimilates during the afterward phase of grain filling by delaying the inception of senescence may therefore; increase the potential grain yield in plants. This is in agreement with the findings of Kuroyanagi and Paulsen (1985).

Spike number per square meter: Number of spike per unit area is an important character which ensured highest yield. Thermal stress imposed during heading significantly decreased spike number per m^2 (S m^{-2}) ($p<0.01$), Average reduction in number of spike per square meter caused by heat stress, were 30.01 and 20.36% for 2-row and 6-row genotypes, respectively (Fig. 2). These results corroborated the findings of Noworolnik (1989), Noworolnik and Leszczynska (1997) and Chun *et al.* (2000) which reported reduction in the spike number by delay in sowing.

In general, S m^{-2} penalties were highest in 2-row genotypes than in 6-rows when sowing was delayed (Table 3). This difference seems fairly in two types with differences produced by the grain weight, grain number and yield in terminal heat stress. Most effect of terminal heat stress (late sowing) on yield of 2-row genotypes was due to effects on S m^{-2} (Fig. 2). However, some residual effects of terminal heat stress on yield were due to effects of stress on grain weight (9.51%) and grain number (4.5%). These results indicated that in these all genotypes, number of spike per unit area were remarkably subjected to terminal heat stress. These results also revealed that negative effects of terminal heat on grain yield caused by reduction in S m^{-2} in six-row genotypes was lower than two-rows. Moreover, correlation between yield and spike number in 2-row genotypes was higher than other correlations and was higher than in six-row barleys ($r = 0.81^{ns}$ vs. $r = 0.69^{ns}$) (Table 4). It is concluded that in 6-rows, grain per spike and spikes per square meter were the yield components that most subjected to terminal heat stress, while grain weight remains relatively stable due to high remobilization of stored preanthesis assimilates. Reductions in the number of spikes from tillers because of unfavorable conditions would imposed a higher impact in two than in six-row genotypes, as a result of a limited plasticity in number of grains per spike, due to structural limitations in the two-row types (Arisnabarreta and Miralles, 2008).

Spike number per square meter ranged between 198 and 249 in 2-rows and ranged from 108 to 178 in late sowing condition during the 2-year experiments. Higher S m^{-2} was obtained from L9 followed by L3 and L10 among 2-row genotypes and produced by L5 followed by L6, L7 and L8 in 6-rows. More spikes per square meter found in these genotypes may have also contributed to superior grain yield compared with the others. This fact could have been due to the higher tillering potential, more heat stress tolerance at heading stage and ability of these genotypes to attain optimum energy reserves which reduced tiller mortality leading to a higher number of spikes per square meter under these conditions as described by Garcia del Moral *et al*., 2003. The relevant importance of spikes per square meter in determining grain yield of barley genotypes, as demonstrated in our study, confirms previous reports in barley at Mediterranean condition (Ramos *et al*., 1982; Garcia del Moral *et al*., 1991).

Grain number per spike: As expected, in non-stress condition, number of grain per spike was greater than in heat stress condition (Table 3). The difference of the number of grains per spike under normal and terminal heat stress was 4.5 and 12.07% in 2-row and 6-row genotypes, respectively (Fig. 2). Heat stress during flowering can negatively affect flowering and subsequently seed set. By seeding early, the crop flower earlier and thus avoids the heat that is typically associated with May.

Grain number in 2-row genotypes was less affected by terminal heat stress than 6-rows (Fig. 2). Reproductive development of cereals is vulnerable to environmental conditions during anthesis mainly affect the number of grains and final yield due to the number of grains produced per spike (Cooper *et al*., 1994; Christen *et al*., 1995). Therefore, it could be concluded that grain number per spike of six-row barleys was most sensitive to thermal stress during anthesis and the role of this component was more important in 6-row genotypes and when affected by stress, yields of 6-row barley genotypes were most affected than yields of 2-rows. To verifying these results, the correlation coefficient between yield and number of grains per spike was estimated (Table 4) and observed that this correlation in 2-row genotypes was much lower ($r = 0.29^{ns}$) than in 6-rows ($r = 0.81^{*}$). These data confirm that in our experiment, the reduction in yield of 6-row genotypes caused by terminal heat stress irrespective of number of spike per square meter is mainly due to grain number reduction. These data confirm that in present experiment, the reduction in yield of six-row genotypes caused by terminal heat stress is mainly due to grain number reduction.

As Arisnabarreta and Miralles (2008) reported, in two-row barleys, changes in the number of grains per unit area have been frequently associated with variations in the number of spikes m^{-2}, because these genotypes are limited in the number of grains that the spike can produce. On the contrary, changes in the number of grains per unit area in six-row barleys were better explained by the ability to modify the number of grains per spike more than the number of spikes m^{-2}, due to some intrinsic limitations in these genotypes to promote a large number of spikes per unit area. These results could be illustrated by the fact that plant height decreased in 2-row genotypes less than 6-rows (8.4 and 11.6%, respectively) when terminal heat stress was subjected. Therefore, it is possible to hypothesises that another reason of the fact which grain number of two-row genotypes less affected by heat stress is that those were less affected by plant height variations because according to Richards, 1992, grain number was highly sensitive to variation in height.

Maximum number of grain per spike ($G\ S^{-1}$) was obtained from L10 (among 2-rows) and L6 (among 6-rows) indicated that these genotypes were less affected by heat stress (see STI and GMP indices in Table 5), probably because of the higher growth rates of these genotypes during flowering which is a good predictor grain number per plant. Because it is correlated to the growth of reproductive structure and because seed setting and early seed development in plants appear to be highly dependent on a continued supply of assimilates from concurrent photosynthesis (Zinselmeier *et al*., 2000).

Stress-induced grain abortion is at least partially provoked by assimilate flux to generative construction at flowering as well at late planting. Since our experiment site had high temperature at the late harvesting time. Therefore, the number of grains per spike of all genotypes was significantly decreased in harvest after late planting. These results are in agreement with Thompson (1975), Boyle *et al*. (1991) and Andrade *et al*. (1999).

Thousand grain weight: In 2-row genotypes, heat stress led to average reduction of 9.51% grain weight compared to non-stress condition, whereas this reduction was 7.9% in 6-row genotypes (Fig. 2). The late-planted crop had a shorter period for the production of grains and a slightly lower rate of grain production due to reduced growth and exposure of plants to warmer and longer photoperiod (long day) after the late sowing. These differences were largely related to the time of grain-filling, because of high temperature at the late planting which reduced grain yield and yield components similar to the previous findings (Sofield *et al*., 1977; Tashiro and Wardlaw, 1990).

In present experiment, high temperatures during grain filling caused by delayed sowing decreased yield by reduction in grain weight. This may be due to high temperatures affecting the grain maturity that resulted in shriveled grains. The results, as the same trend with obtained by Menshawy (2007) who reported that high reduction in grain weight was found under late planting; it could be fully accounted by the reduction in grain filling period which is consistent with the our findings. It could be concluded that the impact of pre- and post-anthesis temperature on grain weight found in this study could be due to an indirect effect on the source of assimilates which was in more affected by terminal heat stress in two-row barleys than six-row barleys. In addition, the importance of the period immediately before anthesis on grain weight determination was also confirmed by modifying the availability of resources to the growing florets at heading as reported by Calderini and Reynolds (2000).

Among 6-row genotypes, L6 showed highest TGW in both non-stress and stress condition. Under stress condition, there was no significant difference among 2-row genotypes. The 2-row genotypes had highest TGW than 6-row genotypes, although L6 showed a TGW similar to the 2-rows.

Generally, because of negative correlation between grain number per spike and grain weight (Ramos *et al.*, 1982; Garcia del Moral *et al.*, 1991, 2003), the genotypes with lower G S^{-1} should have higher grain weight. This is in accordance to present findings except in genotype L6 which had highest grain weight in both non-stress and stress condition, however, it produced higher G S^{-1}, probably due to the lower evapotranspiration during flowering and the higher ovary weight.

According to the results, the correlation between yield and TGW (Table 4) was higher in two-rows ($r = 0.69^{ns}$) than in six-rows ($r = 0.55^{ns}$). This result indicated that in two-row genotypes, reduced yields were attributed mostly to lower grain weight (irrespective of spike number) and only slightly to lower grain number. While, reduction in yields of six-rows was attributed mostly to grain number. This is logical since the effects of heat stress were felt at a rather advanced stage of plant growth and therefore it mainly affected the number of secondary shoots. It is possible that the inability of secondary shoots to compensate for the effects of stress could also prevent the grain from filling adequately and influence the reduction in yield as seen in bread wheat (Christen *et al.*, 1995).

Yield: Grain yield as its component which be affected by stress showed 34.9% reduction by heat stress for all genotypes. While reduction in grain yield caused by delayed sowing of 2-row and 6-row genotypes were 39.59 and 31.39%, respectively.

In two years of present study, high temperature (35 to 41°C) occurred during flowering and grain-filling period in late sowing condition. Daily high temperature caused significant difference between genotypes for days to heading and caused the difference in average yield of genotypes. The results obtained in this study showed that the yield of barley genotypes grown in delayed sowing condition were the highest in earlier genotypes that showed a longer grain-filling period. It was determined that different planting dates had significant effects on the yield and agronomic and morphological characters of barley and the interactions among sowing date and genotypes were significant for yield and yield components. These characters significantly decreased with harvest of late planting in all genotypes in the experiment, since anthesis and grain-filling period were influenced by heat stress which was the biggest problem in late planting in south-west region of Iran and other similar regions. According to proportion of reduction in yield components caused by terminal heat stress (Fig. 2), correlations between yield and its components (Table 4), irrespective of highly magnitude of effect of reduction in spike number on grain yield reduction, the difference in yield of 2-row genotypes in our study may be primarily caused by heat-induced reduction of grain weight, instead of reduction of grain number. Whereas in 6-row barleys, the magnitude of contribution of grain number in grain yield was higher than contribution of grain weight.

The occurrence of yield depression due to late planting was also estimated in each genotype. As high as 1540 and 1530 kg ha^{-1} yield reduction was observed in genotypes L1 and L2, respectively followed by L2, L3 and L10 (Table 5). Some genotypes i.e., L7 and L11 did not show remarkable reduction in yield (300 and 220 kg ha^{-1}, respectively), when planted late and seems to possess tolerance to high temperature to some extent. The other genotypes having less yield depression were L8, L5, L6 and L12 (420, 740, 790 and 890 kg ha^{-1}, respectively). These results indicated that although these genotypes systemically showed small differences in yield under both conditions but as shown in Table 3, only two genotypes of L6 and L8 in contrast to other genotypes, not only have the higher mean yield under terminal heat stress but they also have better yield potential under non-stress condition. This suggests that they have wide adaptation to the environment, because the yield performance of a genotype under stress is a reflection of both its yield potential and its response to stress (Sadiq *et al.*, 1994). Averaged over the stress and non-stress environments, L6 produced maximum grain yield (67.91%) compared to 6-row control (L11) followed by L8 (36.64%) (Table 5), thus less affected, thus being more terminal heat stress tolerant genotypes. These results confirmed the results obtained from analysis of stress indices (Table 5). Among 2-row genotypes, L3 and L10 produced maximum grain yield (5.78 and 9.08%, respectively) compared to their control (L12) indicated that these genotypes were more tolerant than other 2-row genotypes albeit they have high yield depression caused by terminal heat stress.

In this study, the average reduction in grain yields of genotypes caused by heat stress indicated that in recognition of each day late sowing, the reduction in grain yield of 2-rows and 6-rows was approximately 30 and 22.7 kg ha^{-1} as reduction in main yield of the wheat inbred line population by 47% under heat stress as compared with normal winter growing conditions (non-stress) (Blum *et al.*, 2001).

Stress indices: In 2-row genotypes, highest Stress Tolerance Index (STI) and Geometric Mean Yield (GMP) were recorded in genotypes L10 (STI = 0.68 t ha^{-1} and GMP = 2.81 t ha^{-1}) and L3 (STI = 0.64 t ha^{-1} and GMP = 2.72 t ha^{-1}). Highest stress tolerance index (STI) and geometric mean yield (GMP) were recorded in 6-row genotypes L6 (STI = 1.27 t ha^{-1} and GMP = 3.67 t ha^{-1}), L8 (STI = 0.86 t ha^{-1} and GMP = 3.03 t ha^{-1}) and L5 (STI = 0.80 t ha^{-1} and GMP = 2.92 t ha^{-1}) (Table 5). The absolute reduction in grain yield gives no complete information on stress tolerance/susceptibility of genotypes. For the evaluation of stress tolerance of investigated barley genotypes, some important stress indices were calculated and each group of genotypes was assessed separately. The averages of STI and GMP in 6-rows were higher (0.71 and 2.69 t ha^{-1}, respectively) than in 2-rows (0.6 and 2.64 t ha^{-1}, respectively) in this experiment, indicating that they are the most tolerant to terminal heat stress that have higher grain yield under both optimum and stress conditions than 2-row barley genotypes.

An analysis of correlations between the some various stress indices used in this study provides interesting observations about the information reflected by each of them (Table 6). As described further, because of low degree of freedom, some correlation coefficients were not significant, although they were almost high. Yields in the normal condition (Yp) were not correlated with yields in the stress condition (Ys) ($r = 0.14^{ns}$ and 0.74^{ns} for 2-rows and 6-rows, respectively). As expected, correlations between Geometric Mean Productivity (GMP), Ys and Yp were high (although this correlations were not significant in 2-rows). Geometric Mean Productivity (GMP) was strongly correlated with Yp and Ys in 6-rows. GMP being slightly more influenced by the stress yield. Therefore, GMP can be considered to reflect a good performance under stress. The Stress Tolerance Index (STI) was perfectly correlated with GMP, from which it is calculated and therefore we can consider that it contains the same information. Like GMP, it is correlated with both Yp and Ys, the correlation with yield under stress ($r = 0.80$ and 0.95) being slightly better than under optimum condition ($r = 0.71$ and 0.91).

Among 2-rows, simultaneous use of SSI and higher Yp values pointed out L10 and L3 genotypes and among 6-rows, pointed out L6 and L5. The Stress Susceptibility Index (SSI) introduced by Fischer and Maurer (1978) was negatively correlated with yield under stress and presented positive correlation with yield in normal conditions for all genotypes (Table 6). Having in mind the fact that a small value of SSI is desirable, selection for this parameter would also tend

Table 6: Correlation between several stress susceptibility/tolerance parameters

	2-row genotypes				6-row genotypes			
	Yp	Ys	SSI	STI	Yp	Ys	SSI	STI
Yp	1				1			
Ys	0.14^{ns}	1			0.74^{ns}	1		
SSI	0.78^{ns}	-0.51^{ns}	1		0.48^{ns}	-0.24^{ns}	1	
STI	0.72^{ns}	0.79^{ns}	0.13^{ns}	1	0.89*	0.96**	0.03^{ns}	1
GMP	0.71^{ns}	0.80^{ns}	0.11^{ns}	1.00**	0.91**	0.95**	0.08^{ns}	0.99**

*$p<0.05$, **$p<0.01$, ns: not significant at $p<0.05$

to favor low yielding genotypes. Selection based on the SSI (Stress Susceptibility Index) favored L7, L12, L5, L6 and L9 genotypes under terminal heat stress. Nevertheless, SSI failed to identify the high yielding and stress tolerant genotypes under both optimum and stress conditions. For example, L7 had the lowest SSI value (0.64 t ha^{-1}), according to this result, L7 is most tolerant genotype. Nevertheless, this genotype had low grain yield under both conditions (Table 3). These findings are in accordance with the results of Fernandez (1992) and Modhej and Behdarvandi (2006). From the farmer's point of view, best cultivars should be top yielders both in normal and stress conditions.

Based on comparing grain yields of genotypes and using stress indices in our study, genotypes with high grain yield in both stress and optimum conditions, such as L6 and L8 may placed in Group A; Genotypes with low grain yield in stress condition and high grain yield in optimum conditions such as L1, L3 and L10 placed in Group B; Genotypes with High grain yield in stress condition and low grain yield in optimum conditions such as L5 placed in Group C and finally genotypes with low grain yield in both stress and optimum conditions, such as L2, L4, L7, L9, L11 and L12 placed in Group D.

CONCLUSION

Yield parameters are the most important agronomical traits in selecting heat tolerant genotypes. The differential effect could be explained by differences in these components determination between two- and six-row types. Considering the strong correlation found between yield and spike number per square meter (S m^{-2}) in both groups of genotypes under stress condition, it might be concluded that high S m^{-2} is the trait of most interest when selecting barley plants to improve yield under terminal heat stress conditions. On the other hand, in 2-row barley genotypes, irrespective of spike number, the most important yield component affecting yield variation among genotypes under terminal heat stress was grain weight and grain weight was positively associated across genotypes with yield. Whereas the most important yield component in 6-row genotypes which affecting yield variation among genotypes under terminal heat stress was grain number per spike. It is therefore concluded that spike number and grain weight under terminal heat stress are reasonable estimates of heat tolerance in yield of 2-row barley. Whereas in 6-row barley, grain number per spike and spike number are logical estimates of heat tolerance in yield. We can conclude that these differences between barley types could be related to the fact that the grain contribution from spikes number to the total number of grains per unit area and finally grain yield was higher in two- than in six-row lines.

Long stay-green duration would also be beneficial that allows plants to retain their leaves in active photosynthetic under stress conditions. Optimum plant height in two types of barleys was about 90 cm when grown in the normal condition, whereas highest grain yields under stress condition were achieved by lines with a height about 80 cm.

Results obtained from two years of this study indicate that chances of identifying genotypes with good yields both under optimum and stress conditions, in south-west of Iran, are better among 6-row barley genotypes than among 2-row genotypes.

Moreover, an important parameter for success in any plant breeding program under stressed environments is good performance of the genotypes under stress and maximum yield under optimum conditions. Therefore, two high yielding and terminal heat tolerant genotypes (genotypes L6 and L8) were identified as suitable genotypes for both optimum and late sown conditions. Among 2-row genotypes, L3 and L10 with an acceptable ability of grain yield production could introduce for regions subjected to terminal heat stress.

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ABBREVIATION

PLH = Plant hight
$S\ m^{-2}$ = Spike No. per square mater
G W = Grain weight
$G\ S^{-1}$ = Grain No. per spike

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