Cereal Research Communications 38(1), pp. 23–31 (2010)
DOI: 10.1556/CRC.38.2010.1.3

Response of Wheat Yield and Yield Related Traits to High Temperature

M. MODARRESI[1], V. MOHAMMADI[1]*, A. ZALI[1] and M. MARDI[2]

[1]Department of Agronomy and Plant Breeding, College of Agriculture, University of Tehran, Karaj, 3158777871, Iran
[2]Department of Genomics, Agricultural Biotechnology Research Institute of Iran (ABRII), Mahdasht Road, Karaj, P.O. Box 31535-1897, Iran

(Received 14 May 2009; accepted 9 September 2009;
Communicated by A. Pécsváradi)

High temperature is a major determinant of wheat development and growth and causes yield loss in many regions of the world. This study was conducted to assess heat stress effects on yield and yield related traits of wheat. The 144 recombinant inbred lines derived from the cross of Kauz (heat tolerant) and MTRWA116 (susceptible) together with some commercial cultivars were evaluated during 2006–2007, 2007–2008 under normal and heat stress (late sowing) conditions. Grain yield, head length, kernels per spike, spiklets per spike, plant height, grain filling duration, peduncle length and 1000 kernels weight were measured. The results showed a significant difference among RILs for all traits in stress and control conditions. High temperature significantly decreased all traits specially grain yield (46.63%), 1000-kernel weight (20.61%) and grain filling duration (20.42%). Grain yield was most affected and spikelets per spike was least affected (11.77%). Grain yield under heat stress was directly correlated (r = 0.49) with yield in normal condition. Head length and grain yield had the highest (93.18%) and the lowest (62.97%) heritability, respectively. Peduncle length and grain filling duration showed the highest correlation with yield under both normal and heat stress conditions suggesting that these two traits could be used as reliable screening tools for development of heat-tolerant genotypes.

Keywords: heat stress, wheat, tolerance, yield components

Abbreviations: grain yield (GY), peduncle length (PL), grain filling duration (GFD), kernels per spike (K/S), kernel weight (KW), head length (HL), plant height (PH) and spikelets per spike (S/S), MTRWA116 (MT), maximum (max), minimum (min)

Introduction

Global-warming-related changes are gradually affecting agriculture (Reynolds et al. 2001; Wahid et al. 2007). Wheat (*Triticum aestivum* L.) is a temperate cereal with an optimum temperature regime of 15–18°C during the grain filling stage (Wardlaw and Wrigley 1994; Stone 2001) but daily high temperature of 25–35°C or greater is common across

* Corresponding author; E-mail: vmohammadi@ut.ac.ir

many regions of the world where wheat is grown (Porch and Jahn 2001; Stone 2001). Heat stress is defined by a mean daily temperature of over 17.5 °C in the coolest month of the season and over 50 countries (importing more than 20 million tons of wheat per year) experience this type of stress throughout the wheat growth cycle (Reynolds et al. 2001). Exposure to higher than optimal temperatures, or heat stress, reduces yield and decreases quality of cereals (Gibson et al. 1998). Higher temperatures affect all phases of crop growth, accelerate floral initiation, reduce the period of spike development, resulting in shorter spike with lower number of spikelets, and adversely affecting pollen development (Stone 2001; Ayeneh et al. 2002; Wahid et al. 2007; Mitra and Bhatia 2008). Furthermore, as the world population grows exponentially, there is a need both to increase agricultural productivity and to expand productive areas of the world into warmer climates. Both of these goals require significant breeding efforts to improve high-temperature tolerance of crops. Genetic variation in heat tolerance was identified in domestic wheat (Ayeneh et al. 2002; Tahir and Nakata 2005; Rosyara et al. 2008) and its wild relatives (Damania and Tahir 1993; Waines 1994; Sun and Xu 1998). Ehdaie and Waines (1992) reported that grasses with the D genome had a higher survival rate in hot summer temperature than grasses with only the A or B(S) genome.

Although vulnerability of species and cultivars to high temperatures may vary with the stage of plant development, all vegetative and reproductive stages are affected by heat stress to some extent (Wahid et al. 2007). Heat stress during post-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 grain weight (Gibson and Paulsen 1999; Rao et al. 2002). Under Mediterranean conditions, post-anthesis heat stress is the major grain yield limiting factor in winter sown wheat genotypes. Progresses in heat stress tolerance have been very limited due to lack of suitable selection criteria. Several screening methods such as membrane thermal stability (Fokar et al. 1998), canopy temperature depression (Reynolds et al. 2001; Rosyara et al. 2008), and pollen viability (Wahid et al. 2007) have been proposed by different researchers. However, the correlation of these criteria with performance under field condition and their repeatability need to be studied and proved by breeders.

Researchers believe that yield safety can only be improved if future breeding attempts are based on the valuable new knowledge acquired on the processes determining plant development and its responses to stress (Barnabas et al. 2008). Studies looking directly at temperature effects on growth and yield at the field level generally use either multiple locations or sowing dates (Midmore et al. 1982, 1984; Lafitte and Edmeades 1997) or temperature treatments applied to either open top chambers or temperature gradient tunnels (Batts et al. 1998). A number of studies have been carried out at field condition to study the effects of high-temperatures on growth and grain yield (Midmore et al. 1984; Shpiler and Blum 1986; Zhong-hu and Rajaram 1994; Ishag and Mohamed 1996; Tahir and Nakata 2005). However, most of these studies reported either the effects of prolonged moderately high temperature (<32 ºC) or short period of very high temperature (>35 ºC). Studies on the effect of prolonged high temperature (>35 ºC) during most of the grain-filling period under field condition on grain yield are scarce. Further research was, therefore, required for full understanding the effects of heat stress on yield and yield components of wheat under agroclimatic conditions. So this study was performed under field condition over two years with the following objectives: (1) To assess the effect of high temperatures on yield and yield related traits, (2) to study the relationship between yield and agronomic traits under heat stress and normal conditions, and (3) to find reliable screening characters for heat tolerance.

Materials and Methods

The 144 recombinant inbred lines with parents derived from the cross of Kauz (heat tolerant) and MTRWA116 (susceptible) and 8 commercial cultivars were evaluated during 2006–2007, 2007–2008 by normal and late sowing. These germplasms were planted in middle of November (optimum planting date) and middle of January (late planting date). The experiments were carried out through a rectangle lattice design with two replications in a very hot area in Agriculture and Natural Resources Research Field of Persian Golf University located in Borazjan (29°.12'.21"N, 51°.15'.07"E, altitude 105 m), Boushehr, Iran. Soil type was sandy loam and the experiment was optimally managed to avoid unwanted nutrient or water stress. The temperatures and date of anthesis in four experiments were given in Table 1. Materials were seeded with hand (4 rows by 2.5 m long, spaced 25 cm apart and 2 cm intrarow space). The average temperature during grain fill was warmer in 2007–2008 than 2006–2007.

Grain dry weight, head length, kernels per spike, spiklets per spike, 1000-kernel weight, plant height and peduncle length were measured. The grain filling duration (GFD) was also calculated as the number of days from anthesis to ripeness (approximately 90% of spikes devoid of green color). Data were analyzed statistically by SAS (SAS Institute, Inc. 2006) for *t*-test, analysis of variance and Pearson's correlation. As blocks of lattice designs were not significantly different, the experiments were analyzed through separate and combined complete block designs. Heritabilities of traits were calculated as: $\sigma^2_G/(\sigma^2_G + \sigma^2_{GY}/y + \sigma^2_{GT}/t + \sigma^2_{GYT}/yt + \sigma^2_E/ryt)$, where σ^2_G, σ^2_{GY}, σ^2_{GT}, σ^2_{GYT} and σ^2_E represents genotypic variance, genotype×year variance, genotype×temperature condition, genotype×year×temperature condition and error variance, respectively.

Results and Discussion

Combined analysis of variance for grain yield, peduncle length, grain filling duration, kernels per spike, kernel weight, head length, plant height and spikelets per spike are presented in Table 2. There were significant differences among entries and conditions (normal and stress) for all traits showing that RILs were different in their response to high temperature. The genotype×year interaction was highly significant, indicating that cultivars performance changed from one year to another. Genotype×temperature condition was also highly significant showing that the genotypes respond differently to normal or stress condition.

Means of genotypes under normal and stress conditions outlined in Table 3. Comparison of means demonstrated that parents of population were significantly different in their response to heat stress. For example Kauz had longer grain filling period than MTRWA116 in both years under control and stress conditions. Yield parameters of MTRWA116 (susceptible) grown under heat stress were more affected by high temperature. Heat stress decreased significantly all traits studied (Tables 3 and 4). Among the traits, grain yield was most affected (46.63%) by heat stress while the number of spikelets per spike was least affected (11.77%). Among yield components, kernels per spike was affected more by high temperature (23.61%). The decreased number of kernels per spike was most probably due to increased sterile spikelets. This reinforces previous reports by Ferris et al. (1998), Mohammadi et al. (2007), Ugarte et al. (2007) and Wahid et al. (2007). Greater than 1.5-fold differences in yield were between favorable and high temperature field environments. Similar results but more intensive have been reported by Midmore et al. (1984), Shpiler and Blum (1986) and Zhong-hu and Rajaram (1994). It is well established that high temperatures can affect many of the processes involved in photosynthesis (Reynolds et al. 2000). It is notable that susceptible parent had the highest reduction in grain yield (66.2%).

Table 1. Date of anthesis and temperature data

Conditions	Normal		Stress	
Year	2006–2007	2007–2008	2006–2007	2007–2008
Date of first anthesis	14/02/2007	11/02/2008	04/04/2007	02/04/2008
End of anthesis	18/03/2007	16/03/2008	26/04/2007	23/04/2008
Mean temp. during grain filling (ºC)	15.93	16.05	30.12	30.43
Max. temp. during grain filling (ºC)	23.15	24	34.75	36.35
Min. temp during grain filling (ºC)	8.2	9	21	22

According to Gibson and Paulsen (1999), Reynolds et al. (2000) and Hays et al. (2007) stress occurring after anthesis often has detrimental effects on wheat grain yield by hastening maturity, triggering premature senescence, shortening grain filling period and reducing net assimilates and 1000 kernels weight. Net photosynthetic rate (An) during the grain filling period is strongly associated with chlorophyll loss due to accelerated leaf senescence by heat stress. Average wheat yield loss due to moderately high temperatures is estimated 10–15%, mainly due to the decrease of single kernel weight. The decrease is estimated 4% for each ºC above the optimum in wheat. A heat wave of 3 or 4 days at 35–36 ºC can modify grain morphology and reduce grain size in wheat (Wardlaw and Wrigley 1994). As shown in Table 4, the reduction of yield under stress was due to decline both in number of kernels per spike and kernel weight. Impairment of pollen and anther development by elevated temperatures is an important factor contributing to decreased kernel number in many crops at moderate to high temperatures (Wahid et al. 2007). The results showed that high temperature begun in start of grain filling and continued until ripening had a negative impact on yield as measured by kernel weight (20.61% reduction). Similar results have been reported by Wardlaw et al. (2002), Ugarte et al. (2007) and Modhe et al.

Table 2. Combined analysis of variance for studied traits

Source	Df	GY	PL	GFD	K/S	KW	HL	PH	S/S
Year	1	5.84**	102.43**	607.89**	994.21**	42.87**	780.11**	17699.12**	154**
Temp. condition (T)	1	1269.92**	8359.49**	12193.75**	47504.31	13035.51**	75998.54**	114887.45**	2263.69**
Y × T	1	0.01 ns	0.09 ns	1.35 ns	0.63 ns	0.01 ns	0.78 ns	0.01 ns	0.01 ns
Replication/(Y*T)	1	0.16**	4.27**	53.79**	38.10**	0.15**	108.09**	69.82**	0.72**
Genotype (G)	155	6.14**	45.22**	65.11**	405.38**	112.86**	2204.94**	1478.76**	47.47**
G × Y	155	0.10**	1.02**	2.64**	12.01**	0.39**	10.47**	32.65**	1.76**
G × T	155	2.17**	10.73**	10.86**	79**	21.95**	140.09**	111.66**	2.21**
G × Y × T	155	0.01 ns	0.03 ns	0.10 ns	0.06 ns	0.01 ns	0.17 ns	22.03**	0.33**
Pooled error	620	0.01	0.14	0.61	0.48	0.01	1.12	0.99	0.03

*, ** Significantly different at 5% and 1% level, respectively. ns = non-significant.
See p. 23 for Abbreviations.

Table 3. Mean of the traits for the parents and the RILs in stress and normal conditions

Traits	GFD		KW (gr)		K/S		GY (t/ha)	
	Normal	Stress	Normal	Stress	Normal	Stress	Normal	Stress
Kauz	32	26.50*	35.15	29.35*	57	51.05*	5.10	4.50*
MT	27.5	21**	31.02	21.78**	61.8	50.1*	4.26	1.44**
RILs	30.57	24.25**	30.85	24.41**	52.67	39.94**	4.31	2.25**

Traits	HL (mm)		PH (cm)		PL (cm)		S/S	
	Normal	Stress	Normal	Stress	Normal	Stress	Normal	Stress
Kauz	94.23	89.28*	77.84	58.09*	27.95	26.41*	21	19*
MT	126.15	106.08*	90.59	64.92**	25.25	18**	25	19**
RILs	117.66	101.87**	91.68	72.50**	25.58	20.02**	23	20.34**

*, ** Significantly different at 5% and 1% level, respectively (compared with normal condition).

(2008). Grain yield under heat stress was directly correlated (r = 0.49) with yield in normal condition (Table 5) implying that selection of high potential cultivars under normal condition would most probably result in improved yield under stress. This result confirmed the reported results of Tahir and Nakata (2005).

High temperature during grain-filling period decreased grain filling duration significantly (Tables 3 and 4) by 20.42%. Grain filling duration and yield were correlated significantly under both conditions (Table 5). The duration of grain growth in the post-anthesis period is considered the most significant determinant of yield in wheat (Stone 2001; Wardlaw et al. 2002; Mitra and Bhatia 2008). Brief exposure of plants to high temperatures during seed filling can accelerate senescence, diminish seed set and seed weight, and reduce yield (Wahid et al. 2007). Both the day and night temperatures have a pronounced effect on the duration of grain-filling. It can extend to over 80 days at 15/10 °C day/night temperature and reduce to less than 40 days at 30/25 °C. Higher temperatures further associate with limitation of water and cause rapid shrinkage of grain volume (Stone 2001; Mitra and Bhatia 2008). Grain filling duration contribute to the final yield of a plant that is a product of rate of grain filling and duration of the grain filling period. High temperature during grain-filling period may be with a degree of plant heat escape due to shortening of the GFD by 0.4 day for each 1 °C increase in mean temperature from optimum temperature. Shortening of the GFD generally decreases yield by decreasing kernel weight (Gibson and Paulsen 1999; Stone 2001; Irfaq et al. 2005; Tahir and Nakata 2005). This is proved by our data in Table 4 showing a 20.61% reduction in kernel weight.

Plant height was declined by heat stress (Table 4) and had a negative correlation with grain yield showing that poor yielding cultivars in the present study were generally tall (Table 5). This is in close agreement with the results of Irfaq et al. (2005) under natural heat stress and Ahmadi et al. (2008) under drought condition.

Shpiler and Blum (1986), Bessonova (1989) and Asseng and van Herwaarden (2003) reported that length of the uppermost internode, called peduncle, and its role in stem reserve remobilization was correlated with high grain yield under heat stress. Similarly, in

Table 4. Reduction percentage of traits affected by heat stress

	Parents		Population	
Traits	Kauz	MT	RIL	Total
Yield	11.80*	66.20**	47.80**	46.63**
PL	5.50*	28.71**	21.74**	20.23**
GFD	17.19*	23.64**	20.67**	20.42**
K/S	10.44*	18.93*	24.17**	23.61**
KW	16.50*	29.78**	20.88**	20.61**
HL	5.25*	15.91**	13.42**	13.37**
PH	25.37*	28.34**	20.92**	20.98**
S/S	9.52*	24**	11.57**	11.77**

*, ** Significantly different at 5% and 1% level, respectively.

Table 5. Pearson correlation coefficients between grain yield and studied traits under normal, stress and both conditions

Traits	Normal	Stress	Both conditions
PL	0.85**	0.60**	0.76**
GFD	0.63**	0.60**	0.66**
K/S	–0.19**	0.38**	0.04 ns
KW	0.32**	0.33**	0.35**
HL	–0.17*	–0.26**	–0.28**
PH	–0.11*	–0.16*	–0.15*
S/S	–0.24**	–0.33**	–0.35**
Yield†	–	0.49**	–

*, ** Significantly different at 5% and 1% level, respectively. ns = non-significant.
† Correlation between grain yield under normal and stress conditions.

our study peduncle length was highly sensitive to heat stress and decreased by 20.23%. Peduncle length showed the highest correlation with grain yield (r = 0.85). The role of peduncle in heat and drought resistance was already proved due to its role in photosynthesis and stem reserve remobilization (Asseng and van Herwaarden 2003; Pfeiffer et al. 2005; Tahir and Nakata 2005; Villegas et al. 2007).

Heritability of the traits is outlined in Table 6. It should be noted that this heritability is almost narrow sense heritability as the plant material were RILs. Head length and grain yield had the highest (93.18%) and lowest (62.97%) heritability, respectively.

Conclusion

Peduncle length and grain filling duration showed the highest correlation with yield under both normal and heat stress conditions. As these traits had quite high heritabilities (Table 6), we conclude that these two traits could be used as reliable screening tools for development of heat-tolerant genotypes.

Table 6. Heritability (%) of the traits

Traits	GFD	KW	K/S	GY	HL	PH	PL	S/S
Heritability	79.43	80.21	77.56	62.97	93.18	91.73	74.07	92.33

Acknowledgements

We wish to thank Dr. Patrick F. Byrne from Soil and Crop Science Dept., Colorado State University, Fort Collins, CO80523-1170, USA for providing the RIL population and the Dean and staff of College of Agriculture and Natural Resources, Persian Gulf University for their collaboration. The active participation of Mr. Darioush Heidari and Mr. Hasan Esfandiari is gratefully acknowledged.

References

Ahmadi, A., Mohammadi, V., Siosemardeh, A., Poustini, K. 2008. Mechanism of wheat yield increase various water regimes. American-Eurasian J. Agric. and Environ. Sci. **4**:514–524.

Asseng, S., van Herwaarden, A.F. 2003. Analysis of the benefits to wheat yield from assimilates stored prior to grain filling in a range of environments. Plant Soil **256**:217–229.

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.

Barnabas, B., Jager, K., Feher, A. 2008. The effect of drought and heat stress on reproductive processes in cereals. Plant Cell Environ. **31**:11–38.

Batts, G.R., Ellis, R.H., Morison, J.I.L., Nkemka, P.N., Gregory, P.J., Hadley, P. 1998. Yield and partitioning in crops of contrasting cultivars of winter wheat in response to CO_2 and temperature field studies using temperature gradient tunnels. J. Agric. Sci. **130**:17–27.

Bessonova, E.I. 1989. Correlation between yield characters and length of the uppermost internode in wheat. Wheat Breed. Abst. **6**:402.

Damania, A.B., Tahir, M. 1993. Heat and cold tolerance in wild relatives and primitive forms of wheat. In: Damania, A.B. (ed.), Biodiversity and Wheat Improvement. John Wiley and Sons, Chichester, West Sussex, UK, pp. 217–224.

Ehdaie, B., Waines, J.G. 1992. Heat resistance in wild Triticum and Aegilops. J. Genet. Breed. **46**:221–228.

Ferris, R., Ellis, R.H., Wheeler, T.R., Hadley, P. 1998. Effect of high temperature stress at anthesis on grain yield and biomass of field-grown crops of wheat. Ann. Bot. **82**:631–639.

Fokar, M., Nguyan, T., Blum, A. 1998. Heat tolerance in spring wheat. I. Estimating cellular thermotolerance and its heritability. Euphytica **104**:1–8.

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

Gibson, L.R., McCluskey, P.J., Tilley, K.A., Paulsen, G.M. 1998. Quality of hard red winter wheat grown under high temperature conditions during maturation and ripening. Cereal Chem. **75**:421–427.

Hays, D.B., Do, J.H., Mason, R.E., Morgan, G., Finlayson, S.A. 2007. Heat stress induced ethylene production in developing wheat grains induces kernel abortion and increased maturation in a susceptible cultivar. Plant Sci. **172**:1113–1123.

Irfaq, M., Muhammad, T., Amin, M., Jabbar, A. 2005. Performance of yield and other agronomic characters of four wheat genotypes under natural heat stress. Int. J. Botany **1**:124–127.

Ishag, H.M., Mohamed, B.A. 1996. Phasic development of spring wheat and stability of yield and its components in hot environments. Field Crops Res. **46**:169–176.

Lafitte, H.R., Edmeades, G.O. 1997. Temperature effects on radiation use and biomass partitioning in diverse tropical maize cultivars. Field Crops Res. **49**:231–247.

Midmore, D.J., Cartwright, P.M., Fischer, R.A. 1982. Wheat in tropical environments. I. Phasic development and spike size. Field Crops Res. **5**:185–200.
Midmore, D.J., Cartwright, P.M., Fischer, R.A. 1984. Wheat in tropical environments. II. Crop growth and grain yield. Field Crops Res. **8**:207–227.
Mitra, R., Bhatia, C.R. 2008. Bioenergetic cost of heat tolerance in wheat crop. Current Science **94**:1049–1053.
Modhe, 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. International J. Plant Prod. **2**:257–268.
Mohammadi, V., Bihamta, M.R., Zali, A.A. 2007. Evaluation of screening techniques for heat tolerance in wheat. Pakistan J. Biological Sci. **10**:887–892.
Pfeiffer, W.H., Trethowan, R.M., Van Ginkel, M., Oritz-Monasterio, I., Rajaram, S. 2005. Breeding for abiotic stress tolerance in wheat. In: Ashraf, M., Harris, P.J.C. (eds), Abiotic Stresses: Plant resistance through breeding and molecular approaches. Haworth Press Inc. New York, USA.
Porch, T.G., Jahn, M. 2001. Effects of high temperature stress on microsporogenesis in heat-sensitive and heat-tolerant genotypes of *Phaseolus vulgaris*. Plant Cell Environ. **24**:723–731.
Rao, V.S., Singh, G., Misra, S.C. 2002. Wheat: Technologies for warmer areas. Anamaya Publishers. 322p.
Reynolds, M.P., Ortiz-Monasterio, J.I., McNab, A. 2001. Application of Physiology in Wheat Breeding. CIMMYT. Mexico D.F., Mexico.
Reynolds, M.P., Delgado, M.I.B., Gutièrrez-Rodríguez, M., Larquè-Saavedra, A. 2000. Photosynthesis of wheat in a warm, irrigated environment. I: Genetic diversity and crop productivity. Field Crops Res. **66**:37–50.
Rosyara, U.R., Vromman, D., Duveiller, E. 2008. Canopy temperature depression as indication of correlative measure of spot blotch resistance and heat stress tolerance in spring wheat. J. Plant Path. **90**:103–107.
Shpiler, L., Blum, A. 1986. Differential reaction of wheat cultivars to hot environments. Euphytica **35**:483–492.
Stone, P. 2001. The effects of heat stress on cereal yield and quality. In: Basra, A.S. (ed.), Crop Responses and Adaptations to Temperature Stress. Food Products Press, Binghamton, NY, pp. 243–291.
Sun, Q.X., Xu, R.Q. 1998. Genetic control of tolerance to high temperature stress in wheat. In: Slinkard, A.E. (ed.), Proceedings of the 9th International Wheat Genetics Symposium. Saskatoon, Canada, pp. 236–244.
Tahir, I.S.A., Nakata, N. 2005. Remobilization of nitrogen and carbohydrate from stems of bread wheat in response to heat stress during grain filling. J. Agron. Crop Sci. **191**:105–116.
Ugarte, C., Calderini, D.F., Slafer, G.A. 2007. Grain weight and grain number responsiveness to pre-anthesis temperature in wheat, barley and triticale. Field Crops Res. **100**:240–248.
Villegas, D., Garcýa del Moral, L.F., Rharrabti, Y., Martos, V., Royo, C. 2007. Morphological traits above the flag leaf node as indicators of drought susceptibility index in durum wheat. J. Agron. Crop Sci. **193**:103–116.
Wahid, A., Gelani, S., Ashraf, M., Foolad, M.R. 2007. Heat tolerance in plants: an overview. Environmental and Experimental Botany **61**:199–223.
Waines, J.G. 1994. High temperature stress in wild wheats and spring wheats. Aust. J. Plant Physiol. **21**:705–715.
Wardlaw, I.F., Wrigley, C.W. 1994. Heat tolerance in temperate cereals: An overview. Aust. J. Plant Physiol. **21**:695–703.
Wardlaw, I.F., Blumenthal, C., Larroque, O., Wrigley, C.W. 2002. Contrasting effects of chronic heat stress and heat shock on kernel weight and flour quality in wheat. Funct. Plant Biol. **29**:25–34.
Zhong-hu, H., Rajaram, S. 1994. Differential responses of bread wheat characters to high temperature. Euphytica **72**:197–203.