The tolerance of durum wheat to high temperatures during grain filling

B. Maçãs, M.C. Gomes, A.S. Dias and J. Coutinho
Cereals Dept., National Plant Breeding Station, P.O. Box 6, 7351-951 Elvas, Portugal

SUMMARY – In South Portugal, rising temperatures during spring can be considered an important factor limiting wheat yields. Heat stress assumes particular importance when the wheat crop is under irrigation, where high yield potential is needed. The main objective of this study is to evaluate, under field conditions, the response of some wheat genotypes facing high temperatures during and after anthesis. Nine durum and eight bread wheat genotypes were exposed to two different sowing dates: normal and late sowing, to assure high temperatures during and after anthesis, in 1997-1998 and 1998-1999. Grain yield and individual grain weight were significantly affected by temperature increase in 1997-1998 season. Genotype x sowing date interaction was not observed indicating that selection pressure must be applied to identify genotypes with better resistance/tolerance to heat stress.

Key words: Durum wheat, heat stress, yield potential, grain filling.

***RESUME –** “Tolérance du blé dur aux hautes températures pendant le remplissage du grain”. Au Sud du Portugal, la montée de la température pendant le printemps peut être considérée un important facteur limitant de la production. Le stress causé par la chaleur est important surtout quand on fait le blé sous irrigation et quand le potentiel de production doit être maximisé. Le principal objectif de cette étude est l’évaluation, en conditions de champ, du comportement du blé sous conditions de températures élevées pendant et après l’anthèse. En 1997-1998 et 1998-1999, neuf génotypes de blé dur et huit génotypes de blé tendre ont été soumis à deux différentes dates de semis : une normale et une autre tardive, pour être sûrs d’avoir des hautes températures pendant et après l’anthèse. La production et le poids du grain ont été significativement affectés par la montée de température pendant l’année 1997-1998. L’interaction génotype x date de semis n’a pas été observée, indiquant que la pression de sélection doit être appliquée pour identifier les génotypes avec une meilleure résistance/tolérance au stress causé par la température.*

***Mots-clés :** Blé dur, stress thermique, potentiel productif, remplissage du grain.*

Introduction

In South Portugal, as well as in other Mediterranean environments, the rising temperatures of Spring, during the late phases of wheat development and, particularly, since the beginning of heading and after anthesis, should be considered as an important factor limiting yield. High temperatures, above 30ºC, affect final grain weight by reducing the duration of grain filling, due to the suppression of current photosynthesis (Al-Khatib and Paulsen, 1984) and by inhibition of starch synthesis in the endosperm (Jenner, 1994). Most of the available information is centred on the post-anthesis effects of temperature, there is ample evidence that temperature during pre-anthesis can modify, not only final grain weight, but also grain number (Wardlaw *et al.,* 1989). Pre-anthesis effects may be related with reduction on grain number due to problems during meiosis and the growth of the ovaries which may, in turn, impose an upper limit for potential grain weight (Calderini *et al.,* 1999). The optimum temperature range for reaching maximum kernel weight is 15-18ºC; higher temperatures reduce the duration of grain filling and this reduction is not balanced by the increase in rate of assimilates accumulation (Wardlaw *et al.,* 1980, 1989; Stone *et al.,* 1995). In South Portugal temperatures above this range are extremely common, even during the beginning of spring, when cereals are at the booting stage. Short periods of very high temperatures (30-37ºC) are also frequent in some years. The recognition of the importance of short periods with very high temperatures have stimulated many studies (Stone *et al.,* 1995; Calderini *et al.,* 1999), where it can be pointed out that these heat shocks reduce more individual kernel weight than progressively increasing temperatures.

The problem of high temperature becomes more relevant if irrigation is used. This practice allows the farmer to avoid another important limitation in Mediterranean regions but, if suitable varieties are not used, significant crop failures might occur.

The National Plant Breeding Station at Elvas-Portugal has the responsibility to carry out the cereals breeding program for all the country. Traditionally, the program was more focused on the selection for rainfed conditions, where the stability is the most important attribute to face environmental variability. With irrigation, farmers demand varieties with high yielding potential, which is, in some cases, not very well correlated with stability traits.

The tolerance of wheat yield to very high temperatures is known to vary with genotype (Sun and Quick, 1991). So, the main objective of this study is to evaluate, under field conditions, the response of some wheat genotypes facing rising temperatures during and after anthesis. For this purpose, in order to examine the genotypic response of wheat yield to high temperatures, nine durum and eight bread wheat genotypes were exposed to two different sowing dates: a normal sowing date and a late sowing, to assure high temperatures during and after anthesis.

The results coming out of this study are of extreme importance, once they are introduced in the durum wheat breeding program, in order to have more analytical information on the selection process.

Materials and methods

A field study was carried out in 1997-1998 and 1998-1999 seasons, at the experimental fields of the National Plant Breeding Station at Elvas (38º54´N, 7º09´W, 208 m asl) on a loamy soil. Trials involved nine durum and eight bread wheat genotypes and two sowing dates each season: normal sowing – 5 December 1997 and 20 November 1998, and late sowing – 16 February 1998 and 28 January 1999. The latest sowing in each season was used to expose the crop to extreme, but realistic, field combinations of pre and post-anthesis temperatures. Durum wheat genotypes were chosen by their selection history and are mostly based on CIMMYT germplasm. Plot size of 12 m^2 consisted of six rows, 20 cm apart and 10 m long, distributed on a randomised complete block design for each sowing date. Irrigation, fungicide and herbicide treatments were applied when necessary to avoid drought and biotic stresses.

Sowing rate ranged from 400 viable kernels/m^2 for the first sowing dates and 500 viable kernels/m^2 for the latest, in order to minimise differences in biomass production. Plots were fertilised at sowing with 24 kg N, 48 kg P_2O_5 and 16 kg K_2O/ha and top-dressed with 100 kg N/ha during tillering.

Throughout the crop cycle the dates of heading, anthesis and physiological maturity were recorded according to the Zadoks scale. Measurements of biomass at anthesis and maturity and yield components were made for each plot.

Data were subject to analysis of variance using the MSTAT-C software.

Results and discussion

Average values for the grain filling period and the number of days with maximum temperatures above 20, 30 and 35ºC, for each situation and season are reported in Table 1, while maximum daily temperatures, recorded in the two seasons during grain filling, are reported in Fig. 1.

Table 1. Grain filling period (days from anthesis to physiological maturity) and number of days with maximum temperatures above 20ºC, 30ºC and 35ºC calculated for each sowing date and season during grain filling

	Normal sowing		Late sowing	
	1997-1998	1998-1999	1997-1998	1998-1999
Grain filling period (days)	80	63	50	49
Temperatures above 20ºC (days)	54	52	48	40
Temperatures above 30ºC (days)	6	12	19	15
Temperatures above 35ºC (days)	1	1	9	2

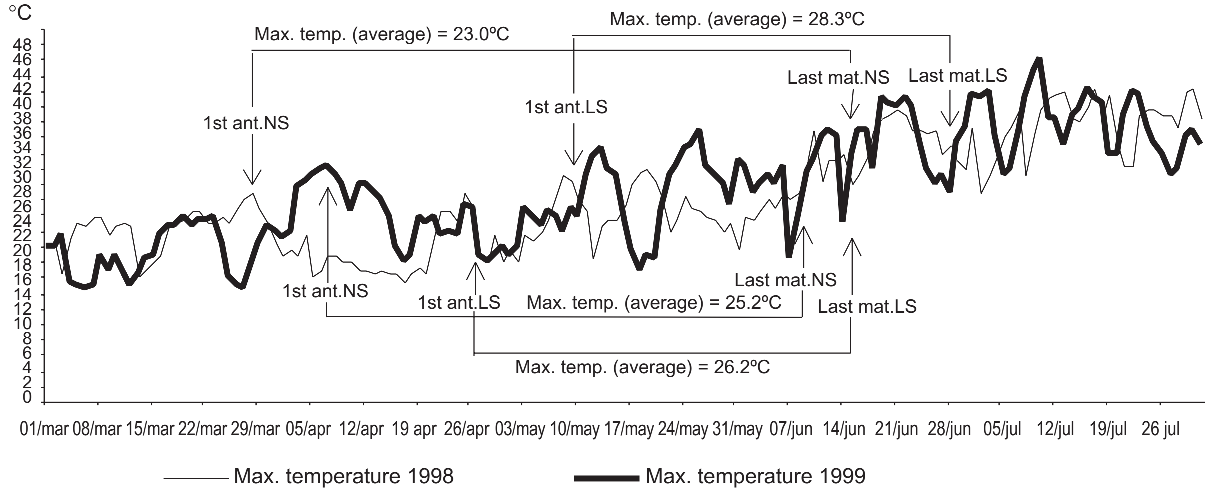

Fig. 1. Maximum daily air temperatures (ºC) during heading and grain growth. NS = normal sowing date and LS = late sowing date. Arrows indicate the beginning and ending of grain filling period for each situation and season.

It was found that in March of 1998 the maximum temperature was 4ºC higher, which, therefore, when compared with 1998-1999 season, anticipated the heading and anthesis on the normal sowing treatment. On the reverse, after anthesis, temperatures were higher in 1998-1999. For this reason, the first phases of grain filling took place under lower temperatures in 1997-1998, which might be interpreted as being the main factor responsible for the delayed period of grain growth. As a result the crop were submitted to higher temperatures during 1997-1998 at the end of the cycle (Fig. 2).

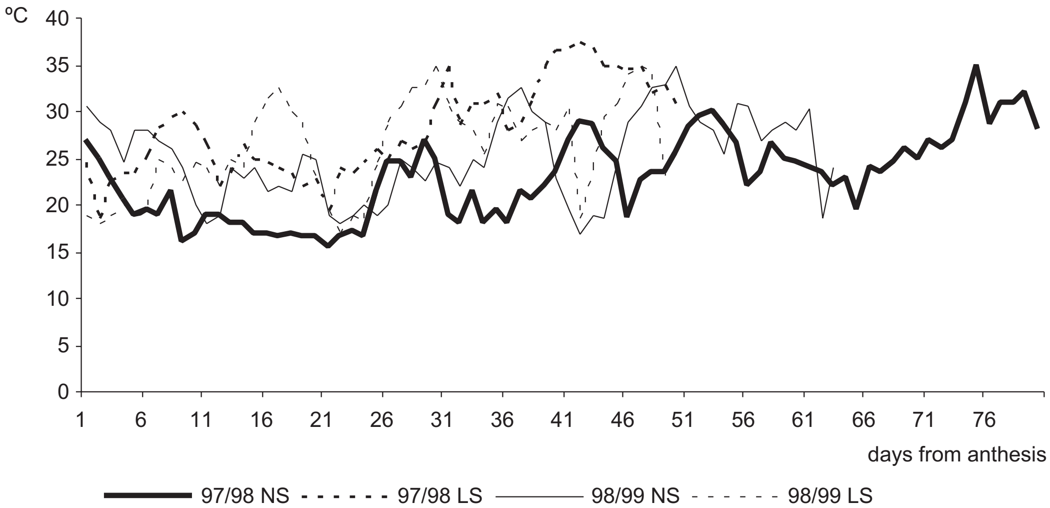

Fig. 2. Maximum daily temperature profiles during the grain filling period for 1997-1998 and 1998-1999 seasons. NS = normal sowing; LS = late sowing.

In 1997-1998 during the grain filling, the average values for the interval temperatures between treatments was bigger (about 6ºC) than this of 1998-1999 (about 1ºC).

Sowing date modified substantially the temperature during grain growth period in the first season of this study (Table 2). In 1998-1999, sowing date did not alter significantly.

The maximum temperature crop exposure in 1998-1999 season was higher than for the first season. Despite the higher values recorded in 1998-1999 (Table 3), the average grain weight is higher than in

1997-1998. A possible explanation for this situation is presented by Tashiro and Wardlaw (1990). They concluded that grains exposed to high temperature, early in grain filling, may become less sensitive (better adapted) to subsequent high temperatures. From Fig. 2, where it can be seen that relatively lower temperatures were recorded at the beginning of the first phases of grain growth during 1997-1998, we can support this interpretation. On the other hand, these results confirm the difficulty in interpreting field data on the Mediterranean regions, where the timing of stress occurrence is always unpredictable.

Table 2. Mean maximum temperature (ºC) during the anthesis-physiological maturity period in the normal and the late sowing for 1997-1998 and 1998-1999 seasons for nine durum wheat genotypes and eight bread wheat genotypes.

Genotypes	Mean maximum temperature (ºC)			
	1997-1998		1998-1999	
	Normal sowing	Late sowing	Normal sowing	Late sowing
Castiço	22.1	25.9	24.2	26.6
TE 9307	23.2	26.4	24.5	27.0
Celta	22.1	26.9	24.1	25.7
TE 9007	22.3	27.4	24.2	26.0
TE 9306	23.2	28.6	24.6	26.3
TE 9204	22.8	27.9	24.8	26.1
TE 9006	23.5	28.2	25.2	26.7
TE 9110	23.6	28.8	25.3	27.3
Acalou	24.7	28.1	25.2	27.3
BWM sg[†]	23.0	28.6	24.1	26.8
BWM lg[††]	22.0	28.0	24.3	26.7

[†]BWM sg = Bread wheat mean (small grain – 3 genotypes).
[††]BWM lg = Bread wheat mean (large grain – 5 genotypes).

Table 3. Yield (kg/ha) and yield components (number of grains/m^2 and thousand kernel weight – TKW – g) for nine durum wheat and eight bread wheat genotypes in two sowing dates in 1997-1998 and 1998-1999 seasons

Genotypes	1997-1998						1998-1999					
	Normal sowing			Late sowing			Normal sowing			Late sowing		
	Yield (kg/ha)	No. grains/m^2	TKW (g)	Yield (kg/ha)	No. grains/m^2	TKW (g)	Yield (kg/ha)	No. grains/m^2	TKW (g)	Yield (kg/ha)	No. grains/m^2	TKW (g)
Castiço	4143	9065	47.3	3579	9233	41.0	5677	12499	49.7	2683	8678	41.2
TE 9307	4731	11385	47.7	3072	6998	39.9	6460	13920	49.7	3416	8605	51.9
Celta	4807	12334	44.0	3296	10621	36.3	6153	16573	41.5	3936	11232	39.6
TE 9007	4256	12761	38.4	3055	8718	35.8	5779	13819	46.0	4239	9460	49.5
TE 9306	4662	13246	45.8	4075	9479	42.5	6367	13084	53.6	3634	7540	53.5
TE 9204	4098	10060	41.5	3730	8960	39.1	6448	13361	48.9	4891	10654	50.0
TE 9006	4805	12666	46.2	4542	10834	38.4	6729	15047	46.0	3930	10759	45.1
TE 9110	5217	13186	48.0	4262	9474	44.6	5121	11088	49.1	3196	7255	53.0
Acalou	4178	9567	51.4	3728	8514	42.5	5682	11123	55.4	2037	8359	50.6
BWM sg[†]	4734	16105	34.7	3457	11948	28.9	5777	16854	35.5	4578	14180	37.7
BWM lg[††]	4325	11587	41.2	3711	10211	37.1	5743	14119	43.6	4767	12675	42.4

[†]BWM sg = Bread wheat mean (small grain – 3 genotypes).
[††]BWM lg = Bread wheat mean (large grain – 5 genotypes).

In the season 1998-1999 the grain yield reductions observed in the late sowing are not related with increasing temperatures during grain growth, but in 1997-1998 an increase average of 6ºC in the maximum temperatures reduced grain weight 13% and 12% on bread and durum wheat respectively, with 18% average decrease in production. So, grain yield was significantly affected by temperature increase, but genotypes reacted similarly to the sowing date as indicated by the lack of significance for genotype x sowing date interaction. A similar behaviour was observed concerning grain weight. Table 4 shows average values of agronomic traits that are significantly different between treatments for 1997-1998 season.

Table 4. Average values of agronomic traits for durum and bread wheat at normal and late sowings. Data for 1997-1998 season

	Durum wheat		Bread wheat	
	Normal sowing	Late sowing	Normal sowing	Late sowing
Grain yield (kg/ha)	4544	3704	4478	3616
Number of grains/m^2	11586	9203	13281	10862
Thousand kernel weight (g)	46.00	40.00	38.77	34.02
Biomass at anthesis (kg/ha)	8568	6311	8045	6098
Biomass at maturity (kg/ha)	15929	11310	16090	11736
Test weight (kg/hl)	80.77	79.79	77.74	78.77
Harvest index (%)	0.33	0.32	0.33	0.32

Conclusions

Although grain yield is a main objective in the durum wheat breeding program at Elvas-Portugal, our results suggest that selection for heat tolerance would be useful mainly for irrigated conditions where the maximum expression of the genetic yield potential is very important.

The reduction in yield and grain weight observed in 1997-1998 and the absence of genotype x treatment interaction reveals that materials must be submitted to selection pressure to identify genotypes with better resistance to heat stress for South Portugal regions.

References

Al-Khatib, K. and Paulsen, G.M. (1984). Mode of high temperature injury to wheat during grain development. *Physiol. Plant.*, 61: 363-368.

Calderini, D.F., Abedelo, L.G., Savin, R. and Slafer, G.A. (1999). Final grain weight in wheat as affected by short periods of high temperatures during pre-and post-anthesis under field conditions. *Aust. J. Plant Physiol.*, 26: 452-458.

Jenner, C.F. (1994). Starch synthesis in the kernel of wheat under high temperatures conditions. *Aust. J. Plant Physiol.*, 21: 791-806.

Stone, P.J., Savin, R., Wardlaw, I.F. and Nicolas, M.E. (1995). The influence of recovery temperature on the effects of a brief heat shock on wheat. I. Grain growth. *Aust. J. Plant Physiol.*, 22: 945-954.

Sun, Q.X. and Quick, J.S. (1991). Chromosomal locations of genes for heat tolerance in tetraploid wheat. *Cereal Res. Comm.*, 19: 431-437.

Tashiro, T. and Wardlaw, I.F. (1990). The response to high temperature shock and humidity changes prior to and during the early stages of grain development in wheat. *Aust. J. Plant Physiol.*, 17: 551-561.

Wardlaw, I.F., Dawson, I.A., Munibi, P. and Fewster, R. (1989). The tolerance of wheat to high temperatures during reproductive growth. Survey procedures and general response patterns. *Aust. J. of Agric. Res.*, 40: 1-13.

Wardlaw, I.F., Sofield, I. and Cartwright, P.M. (1980). Factors limiting the rate of dry matter accumulation in the grain of wheat grown at high temperature. *Aust. J. Plant Physiol.*, 7: 387-400.