# Triticum Aestivum *L. Phenological response to air temperature in Greece*

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**Abstract:** *In this research, the winter wheat (*Triticum aestivum *L.) response to air temperature was investigated in Greece. Phenological observations were taken in order to evaluate the emergence (C0), heading (C1), anthesis (C2), fruit development (C3), and ripening (C4) phenophases of* Triticum aestivum *L. cv. Yecora at the sites (from Northern to Southern Greece) of Xanthi, Kozani, Karditsa, Thives and Araxos, during the period 1985-1990. Also, sowing dates and air temperature data were recorded at the same period. The warmer temperature conditions at the sites of Karditsa, Thives and Araxos promoted the reproductive growth phenophases of wheat (C1, C2, C3 and C4) compared to the respective conditions in Xanthi and Kozani. The C1 phenophase was influenced by the air temperature of the spring months (April and May) at the sites of Xanthi and Araxos. Air temperature during April and May plays an important role, to a different degree, for the C2 phenophase at the sites of the Central (Karditsa) and Southern (Thives, Araxos) part of Greece.*
**Keywords:** *phenology, reproductive growth, winter wheat*

**Riassunto:** *In questa ricerca si è studiato il riscontro del frumento invernale alla temperatura dell'aria in Grecia. Sono state effettuate osservazioni fenologiche per valutare l'emergenza (C0), la spigatura (C1), la fioritura (C2), la formazione dei frutti (C3) e la maturazione dei frutti (C4) del Triticum aestivum L. cv. Yecora nelle regioni (dalla Grecia settentrionale a quella meridionale) di: Xanthi, Kozani, Karditsa, Tebe e Araxos nell'arco di tempo 1985-1990. Inoltre, sono state registrate le date della semina e della temperatura dell'aria durante lo stesso periodo. Le temperature più elevate nelle zone di Karditsa, Tebe e Araxos contribuiscono ad accelerare i tempi delle fasi fenologiche di crescita riproduttiva del frumento (C1, C2, C3, C4) in comparazione con le rispettive condizioni di Xanthi e Kozani. La data d'inizio della C1 fu influenzata dalla temperatura dell'aria dei mesi primaverili (aprile e maggio) nelle regioni di Xanthi e Araxos. La temperatura dell'aria durante i mesi di aprile e maggio ha un ruolo rilevante, a differenti gradi, per le date d'inizio della fase C2 nelle regioni della zona centrale della Grecia (Karditsa) ed in quelle meridionali (Tebe, Araxos).*
**Parole chiave:** *fenologia, crescita riproduttiva, frumento invernale*

## INTRODUCTION

Phenology, the sequence of plant life events in the various ecosystems, as expressed by the timing of various plant stages, is influenced by the environment, especially temperature (Schwartz, 2003).

Air temperature has been strongly correlated with the seasonal timing of plant phenophases, such as anthesis, in mid- and high- latitudes (Chmielewski, 2003; Menzel, 2003; Tao *et al.*, 2006; Estrella *et al.*, 2007; Pudas *et al.*, 2008). Higher values of temperature than a certain value, result in a greater rate of plant development and thus an earlier appearance of phenophases (Hu *et al.*, 2005). It has been reported that the rise of air temperature by 1 $^{0}$C led to an earlier onset of various phenophases of fruit trees and annual crops by 4-17 days (Sparks *et al.*, 2000; Chmielewski *et al.*, 2004; Doi, 2007). The knowledge of the onset of plant phenophases could provide valuable information for the evaluation of climate variation at a local scale (Aono and Kazui, 2008). Also, long series of phenological observations may be used for the detection of climate variability and can facilitate the understanding of climate changes (Ventura *et al.*, 2006; Bonamano, 2008).

Changes in the appearance of fruit trees and field crops phenophases have a great economic importance because of their impact on the quality of agricultural products and crop yield (Chmielewski *et al.*, 2004). Winter wheat (*Triticum aestivum* L.), one of the most important small-grain cereal crops for human nutrition (Lithourgidis *et al.*, 2006) is an important crop grown in many Mediterranean climate zones around the world (Schillinger *et al.*, 2008), playing a noticeable role in the development of civilization (Martin *et al.*, 1976). This crop is of major importance for the agricultural production in Greece (Lithourgidis *et al.*, 2006). The phenological behavior of winter wheat is strongly influenced by air temperature (Dalezios *et al.*,

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2002; Sadras and Monzon, 2006; Wang *et al.*, 2008). The analysis of the phenological data of a particular wheat cultivar in several locations could provide a measure for their temperature changes (Hu *et al.*, 2005). Global warming is expected to cause shorter growing seasons for wheat in the Mediterranean basin (Rosenzweig and Tubiello, 1997; Harrison *et al.*, 2000; Ferrara *et al.*, 2010). This would lead to an earlier occurrence of the spring phenophases of wheat, resulting in a shorter grain-filling period and consequently in the reduction of yields (Harrison and Butterfield, 1996). According to the climate change scenarios, an increase of 2 $^{o}$C during the period of 2031-2060 is expected to cause a crop growing cycle reduction of cereals by 9.0 days on average, in the European Mediterranean countries (Bindi and Moriondo, 2005; Moriondo and Bindi, 2007). The purpose of this study is to investigate the response of winter wheat (*Triticum aestivum* L. cv. Yecora) phenophases to air temperature at representative cultivated sites in Greece.

## MATERIALS AND METHODS

Research was conducted at five representative wheat cultivation sites in Greece (Tab. 1), based mainly on the latitude, altitude and distance from the sea during a 5-year cultivation period from 1985/86 to 1989/90.

Phenological observation data for winter wheat (*Triticum aestivum* L. cv. Yecora) were collected weekly, from a cultivated area of about 4000 m$^2$ in each site, in order to evaluate the starting dates of wheat stages (named 'phenophases') based on a recommended scale (BBCH) for phenological observations according to Meier (2003): emergence - coleoptile breaks through soil surface – BBCH 09 - appearance of the planting lines (C0), heading of about 10% of plants - BBCH 51 (C1), anthesis when 10% of the flowers has opened - BBCH 61 (C2), fruit development when the caryopsis is watery ripe and 10% of the grains has reached final size - BBCH 71 (C3) and ripening or fruit coloration - BBCH - 81 (C4). In addition, the dates of sowing (D2) were recorded. At the same time, air temperature data were provided by the meteorological stations of the Hellenic National Meteorological Service which covered the study sites. The mean distance between the phenological observation sites and the meteorological stations was 10.4 km and the maximum distance did not exceed 12.3 km.

From the air temperature data, average values were calculated during each cultivation period (November – July) at each study site. A Pearson's correlation analysis was conducted between the examined wheat phenophases and the average air temperature during the period of their appearance. For the statistical analysis, SPSS 11.0 and MS Excel were used with a significance level ($p$) ≤ 0.05.

## RESULTS AND DISCUSSION

The *Triticum aestivum* L. phenophases at the study sites in Greece from 1985 to 1990 are presented in Tab. 2. During the reproductive growth phenophases of wheat from April to June, the average temperature for the years 1986-1990, was higher by 2.3 $^{o}$C, 3.1 $^{o}$C and 3.4 $^{o}$C, at the sites of Araxos, Thives and Karditsa,

| Site | Region | Latitude | Longitude | Altitude (m) | Distance from the sea (km) | AvgT ($^{o}$C) | MAT ($^{o}$C) | base period |
|---|---|---|---|---|---|---|---|---|
| Xanthi (Xa) | East Macedonia and Thrace | 40° 54' N | 24$^{o}$ 36' E | 5 | 3 | 18.9 | 14.9 | 1984-97 |
| Kozani (Kz) | West Macedonia | 40° 17' N | 21$^{o}$ 46' E | 627 | 42 | 17.1 | 12.9 | 1955-97 |
| Karditsa (Kard) | Thessaly | 39° 33' N | 21$^{o}$ 46' E | 109 | 70 | 20.5 | 16.1 | 1973-97 |
| Thives (Th) | Central Greece | 38° 19' N | 23$^{o}$ 31' E | 140 | 19 | 20.2 | 16.8 | 1957-97 |
| Araxos (Arx) | West Greece (Peloponnese Peninsula) | 38° 08' N | 21$^{o}$ 25' E | 15 | 4 | 19.4 | 17.8 | 1955-97 |

**Tab. 1** - Phenological observation sites of *Triticum aestivum* L. cv. Yecora in Greece and respective average temperature values (AvgT) from April to June during the period 1986-90 in these sites. MAT: Climatic values of mean annual temperature (Source: Hellenic National Meteorological Service, 1999).

*Tab. 1 - Regioni di osservazioni fenologiche del Triticum aestivum L. cv. Yecora in Grecia e rispettivi valori medi della temperatura (AvgT) per il periodo aprile-giungo nell' arco di tempo 1986-90 nelle zone in oggetto. MAT: Valori climatici della temperatura annuale media. (Sorgente: Hellenico Nationale Servicio Meteorologico, 1999).*

| | $X_{Xa}$ | $SE_{Xa}$ | $X_{Kz}$ | $SE_{Kz}$ | $X_{Kard}$ | $SE_{Kard}$ | $X_{Th}$ | $SE_{Th}$ | $X_{Arx}$ | $SE_{Arx}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **D2** | 321.2 | 3.7 | 304.4 | 3.0 | 321.0 | 0.9 | 319.2 | 6.2 | 312.8 | 3.0 |
| **C0** | 353.4 | 5.8 | 335.2 | 4.8 | 338.2 | 2.9 | 333.0 | 3.3 | 322.0 | 3.6 |
| **C1** | 118.2 | 3.8 | 118.4 | 5.8 | 107.2 | 4.8 | 103.0 | 4.0 | 111.6 | 3.6 |
| **C2** | 135.2 | 1.1 | 142.2 | 2.0 | 123.0 | 9.0 | 117.0 | 2.7 | 118.2 | 3.7 |
| **C3** | 149.2 | 3.4 | 152.0 | 3.2 | 135.2 | 5.8 | 129.6 | 3.4 | 142.0 | 2.9 |
| **C4** | 169.6 | 5.5 | 170.2 | 2.9 | 165.8 | 4.0 | 164.0 | 4.9 | 161.8 | 4.8 |

**Tab. 2 -** Mean values in Julian days (X) and Standard error (SE) of the mean of the sowing dates and of the studied phenophases of *Triticum aestivum* L. cv. Yecora at the sites of Xanthi, Kozani, Karditsa, Thives and Araxos during the period 1985-90.

*Tab. 2 - Valori medi, in giorni giuliani (X) ed Errore standard (SE) della media delle date della semina e delle fasi fenologiche studiate del Triticum aestivum L. cv. Yecora nelle zone di Xanthi, Kozani, Karditsa, Tebe e Araxos durante il periodo 1985-90.*

respectively, than in Kozani. Similarly, the site of Xanthi was warmer than Kozani by 1.8 $^0$C (Tab. 1). Thus, during the study period, in the northern part of Greece (Kozani, Xanthi) cooler temperature conditions dominated, compared to the sites of Karditsa, Thives and Araxos (Central and Southern part of Greece). We can assume that the warmer temperature conditions in the sites of Karditsa, Thives and Araxos promoted the reproductive growth phenophases (C1, C2, C3 and C4) compared to the respective ones in Xanthi and Kozani (Tab. 2).
The results of the correlation analysis (Tab. 3) between air temperature and the reproductive growth phenophases indicated that the C1 phenophase correlated negatively with the average air temperature in April in Xanthi and Araxos. Also, at this site, a negative correlation was observed at a higher degree between C1 and air temperature for the period April-May, compared to the temperature in both April and May. These findings showed that the C1 phenophase was influenced by the air temperature in April and May in the coastal sites of Araxos and Xanthi which are characterized by lower altitudes (Tab. 1).
A negative correlation (Pearson) between the C2 phenophase and the average air temperature in April-May was observed at the sites of Karditsa, Thives and Araxos (Tab. 3). In addition, a higher correlation between the above mentioned phenophase and the air temperature in April compared to the April-May period was observed in Thives. On the other hand, a lower correlation between C2 and the air temperature in both April and May, compared to the April-May period was observed in Araxos. These findings indicated that the temperature during the above months is a crucial factor, to a different degree, for the C2 phenophase at the sites of the Central and Southern part of Greece. The correlation between the air temperature of the April-May period and C2 gets slightly stronger from Central (Karditsa) to Southern Greece (Thives, Araxos).
The C3 phenophase correlated negatively with the average air temperature of the April-June period in Karditsa and of May in Kozani (Tab. 3). Thus, this phenophase is influenced by the air temperature in spring and early summer months at the continental sites of Central (Karditsa) and Northern Greece (Kozani), depending on the latitude. Generally, higher air temperatures in spring accelerate the developmental process and consequently lead to an advanced timing (Chmielewski and Rötzer, 2001; Chmielewski *et al.*, 2004) of the reproductive growth phenophases. The results of our work are at accordance with those of Tao *et al.* (2006) on winter wheat in China as well as with those of Estrella *et al.* (2007) on winter wheat, barley and rye in Germany. An earlier heading or flowering of wheat at the Great Plains of the United States indicated warmer spring season temperature conditions (Hu *et al.*, 2005). A negative correlation between the milk stage-ripening time period of wheat and air temperature was found by Wang *et al.* (2008) in China. Similarly, a negative correlation between the air temperature and vegetative or reproductive growth phenophases has been observed recently on other crops like cotton, maize, rice and sugar beet (Chmielewki *et al.*, 2004; Tao *et al.*, 2006; Estrella *et al.*, 2007; Wang *et al.*, 2008).On the contrary, the C0 phenophase of vegetative growth did not correlate with air temperature (data not shown), in the vast majority of the cases at the study sites, due to a weaker response of the vegetative growth phenophases of wheat than of the reproductive ones (Porter and Gawith, 1999), in accordance to Estrella *et al.* (2007)

| | 4 | $T_5$ | $T_6$ | $T_7$ | $T_{45}$ | $T_{46}$ | $T_{56}$ | $T_{67}$ |
|---|---|---|---|---|---|---|---|---|
| | | | | XANTHI | | | | |
| C1 | -0.869* | 0.821 | | | 0.486 | | | |
| C2 | | 0.613 | | | | | | |
| C3 | | 0.759 | 0.786 | | | | 0.831 | |
| C4 | | | 0.277 | 0.317 | | | | 0.351 |
| | | | | KOZANI | | | | |
| C1 | -0.211 | 0.214 | | | -0.182 | | | |
| C2 | | 0.820 | | | | | | |
| C3 | | -0.964* | 0.666 | | | | 0.824 | |
| C4 | | | 0.163 | | | | | |
| | | | | KARDITSA | | | | |
| C1 | -0.668 | | | | | | | |
| C2 | -0.792 | -0.334 | | | -0.923* | | | |
| C3 | -0.435 | -0.620 | -0.430 | | -0.722 | -0.931* | -0.577 | |
| C4 | | -0.524 | -0.174 | | | | -0.387 | |
| | | | | THIVES | | | | |
| C1 | -0.386 | | | | | | | |
| C2 | -0.957* | -0.373 | | | -0.930* | | | |
| C3 | -0.569 | -0.241 | | | -0.563 | | | |
| C4 | | -0.651 | -0.587 | | | | -0.693 | |
| | | | | ARAXOS | | | | |
| C1 | -0.872* | -0.900* | | | -0.960** | | | |
| C2 | -0.890* | -0.895* | | | -0.966* | | | |
| C3 | | -0.779 | 0.547 | | | | 0.807 | |
| C4 | | -0.367 | -0.736 | | | | -0.608 | |

*, **, ***: significant at $p \leq 0.05$, 0.01 and 0.001, respectively.
**, **, ***:significativo $p \leq 0.05$, 0.01 e 0.001, rispettivamente.*

**Tab. 3 -** Pearson's correlation coefficients between air temperature (from April to July) and reproductive growth phenophases of wheat (*Triticum aestivum* L. cv. Yecora) in the sites of Xanthi, Kozani, Karditsa, Thives and Araxos, in Greece from 1985/86 to 1989/90. $T_4$, $T_5$, $T_6$ $T_7$: average monthly air temperature for April, May, June and July, respectively. $T_{45}$, $T_{56}$, $T_{46}$ $T_{67}$: average air temperature from April to May, May to June, April to June and June to July, respectively.
*Tab. 3 - Coefficienti di correlazione di Pearson fra la temperatura d' aria (da aprile fino a luglio) e le date d'inizio delle fasi feonologiche della crescita riproduttiva delle coltivazioni di grano nelle zone di Xanthi, Kozani, Karditsa, Tebe e Araxos in Grecia dal 1985/86 fino al 1989/90. $T_4$, $T_5$, $T_6$ $T_7$: temperatura mensile media dell'aria nei mesi di aprile, maggio, giugno e luglio, rispettivamente. $T_{45}$, $T_{56}$, $T_{46}$ $T_{67}$: temperatura media dell'aria da aprile fino a maggio, da maggio fino a giugno, da aprile fino a giugno e da giugno fino a luglio, rispettivamente.*

who reported that the phenophase 'emergence' (C0) of *Triticum aestivum* L. was much less influenced by air temperature than the subsequent phenophases.

## CONCLUSIONS

The most important results of this study can be summed up as follows:
The warmer temperature conditions at the sites of Karditsa, Thives and Araxos promoted the reproductive growth phenophases of wheat (C1, C2, C3 and C4) compared to the respective ones in Xanthi and Kozani.
The heading was influenced by air temperature in the spring months (April and May) at the coastal sites of Xanthi (Northern Greece) and Araxos (Southern Greece).
Air temperature during April and May plays an important role, to a different degree, in anthesis at the studied sites of the Central (Karditsa) and

Southern (Thives, Araxos) parts of Greece.
The fruit development correlated with the air temperature in May and in the April-June period at the continental sites of the Northern (Kozani) and Central (Karditsa) parts of Greece, respectively. This work is one of the first steps of a research concerning the effect of meteorological parameters on the phenological behavior of winter wheat in Greece. In the future, the research will focus on other cultivated plants for better understanding of the interaction between weather and phenology in Greece.

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