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Apple (*Malus Domestica* Borkh.) Phenology in Relation to Topoclimate in Central Macedonia, Greece

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Abstract

Plant phenological behavior is strongly dependent on climate conditions. In the current research, the apple (*Malus domestica* Borkh.) phenology response to topoclimate conditions, as mainly determined by air temperature, was investigated at two agricultural regions of the Region of Central Macedonia, Greece, Giannitsa Pellas and Rachi Pierias. In this regard, phenological observations were collected in order to evaluate the timing of appearance of the following phenophases: bud burst-green leaf tips (BBCH 53), flower bud visible-still closed (BBCH 55), pink bud stage-flower petals elongating-visible sepals slightly open (BBCH 57), and full flowering at least 50% (BBCH 65). Also, air temperature data were taken from agrometeorological stations which covered the study regions. Results showed that higher maximum and lower minimum air temperatures prevailed during almost the whole year at the plain of Giannitsa than those of Rachi. Earlier appearance of the examined apple phenophases was confirmed at Giannitsa, in comparison to Rachi, increasing the damage risk of vulnerable plant tissues during the bud development and flowering from the late spring frosts. It seems that the maximum and minimum air temperatures of March are decisive for the appearance o BBCH 53, 55 and 57 phenophases while those of April are considered as crucial factors for the onset of BBCH 65. The knowledge of relation between apple tree phenology and topoclimate, in terms of air temperature, may provide valuable information for farmers' decision-making regarding the rational planning of cultivation techniques.

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Introduction

Plant phenology makes an important contribution to practical agriculture since many farmers decisions regarding the planning of field techniques are based on the timing of appearance and the duration of phenophases.[1] The growth of plants and therefore

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the occurrence of the plant phenophases are heavily depended on air temperature (T) changes.[2-8] Therefore, during late winter and early spring, higher T values accelerate the plant development which leads to an earlier onset of the phenophases that appear this period.[9] However, this fact could increase the late frost risk damages for fruit trees, especially those that occur after the first flowering.[1]

The complex terrain, the distribution of land and water (rivers, lakes, etc.), the geographical features such as altitude and aspect and, in general, the topography noticeably influence the local climate conditions which are expressed by the topoclimate.[10,11] The knowledge of topoclimate in a particular agricultural region is of great importance for the possible suitability of cultivated plant species intended to grow in this region.

The apple (*Malus domestica* Borkh.) tree is considered as the most cultivated species worldwide with great economic and agricultural value due to its edible fruits. In Greece, the average areas of apple orchards and the average fruit yield were approximately 11.1 thousand hectares and 268 thousand tons, respectively, during the period of 2010-2019.[12] Thus, this plant species constitutes an important part of agricultural production with a notable contribution to the national economy.

In this study, we hypothesize that the topoclimate influences the occurrence of apple phenophases, in particular their onsets, at representative cultivation regions in the northern part of Greece.

To test this hypothesis, we study the timing of appearance of this fruit tree phenophases at two cultivation regions characterized by different topography in Central Macedonia, Greece examining in parallel a major meteorological parameter, air temperature.

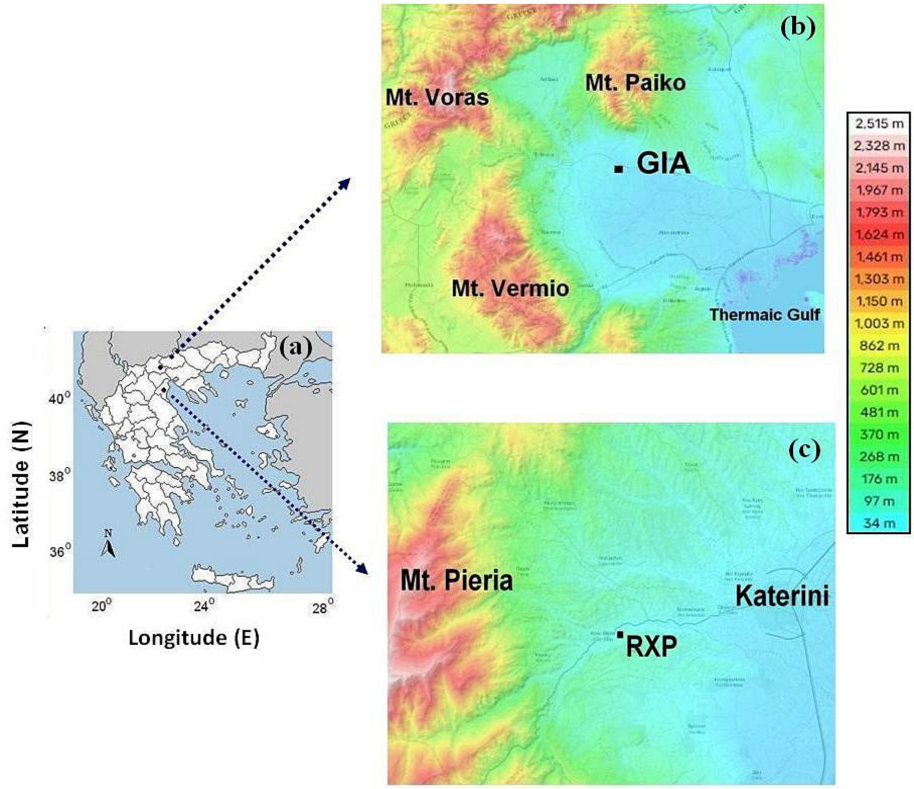


Fig. 1: Location (a) and terrain maps of apple (*Malus domestica* Borkh.) phenological observation regions of GIA (b) and RXP (c), in the Region of Central Macedonia, Greece, modified by Anonymous a[13] and b[14], respectively. The colors in the images indicate the altitude according to the legend on their right. GIA: Giannitsa Pellas, RXP: Rachi Pierias, Mt. mountain.

Materials and Methods

Study Regions

The present work was conducted at the two regions of Giannitsa Pellas (GIA) and Rachi Pierias (RXP) of the Region of Central Macedonia in Greece (Fig. 1a, b, c) which are characterized as favorable for apple (*M. domestica* Borkh.) growing. The plain of GIA is a part of the great valley that borders with the Thermaic Gulf to its east and with the Vermio (max. altitude 2,065 m) mountain (Mt.) to its west. In the northern and the northwestern parts of this plain the Mt. ranges of Paiko (max. altitude 1,649 m) and Voras (max. altitude 2, 524 m), respectively, are situated (Fig. 1b). These mountains are characterized by complex relief and are covered by dense forests with rich flora and fauna. The second region RXP (Fig. 1c) is situated in the western part of the Katerini city and is surrounded by hills with altitudes up to 350 m. In the western part of the wider areas of RXP the Pieria Mt. range (max. altitude. 2,525m) is situated.

Phenological and Meteorological Data Collection

Air temperature data were monitored from the two agrometeorological stations of the Peripheral Center of Plant Protection, Quality and Phytosanitary Control of Thessaloniki, the first at the region of GIA (40°46'45.87" N, 22°16'12.21" E, altitude 13.0 m), and the other at RXP (40°15'10.26" N, 22°21'50.19" E, altitude 131.0 m), from 2016 to 2021 (reference period). Also, to investigate the apple phenology response to the air temperature conditions, phenological observations were collected for the above period. The maximum distance between the phenological observations sites and the agrometeorological stations did not exceed 11.3 km. The following phenophases were monitored considering the standardized BBCH scale.[15,16] 1. Bud burst-green leaf tips (BBCH 53), 2. Flower bud visible, still closed (BBCH 55), 3. Pink bud stage-flower petals elongating-visible sepals slightly open (BBCH 57) and 4. Full flowering, at least 50% of flowers open and first petals falling (BBCH 65).The appearance timing of each phenophase was expressed by the relevant Julian day number.

Data Analysis

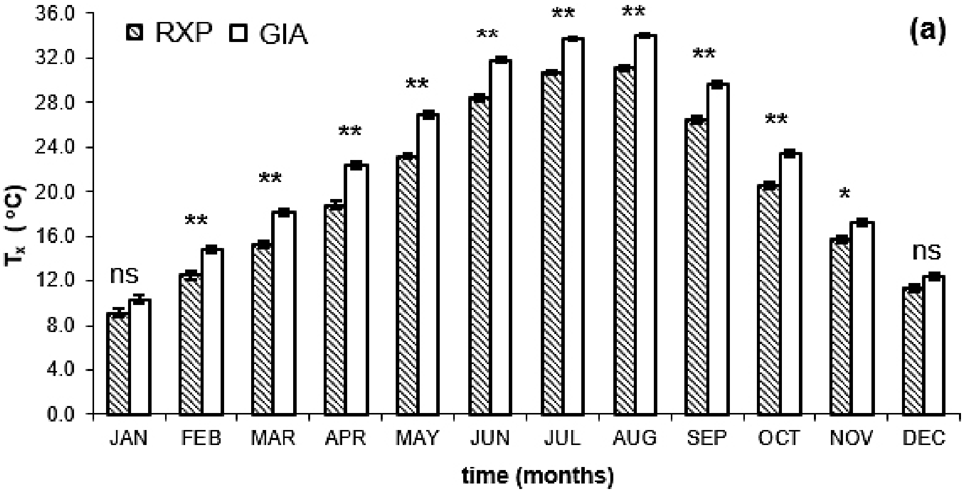
For the air temperature data, the daily values of mean (T_a), maximum (T_x) and minimum (T_n) air temperature were taken from the agrometeorological stations located at the two study regions. Then, the average monthly values of T_a, T_x and T_n in each year for the whole reference period were calculated.

To detect possible differences in timing appearance of apple phenophases for the study regions, independent t- tests[17] were used. In addition, regarding the comparison of the average monthly values of air temperature between the study regions, the two-sample t test[18] technique was applied. The relationship between the onset of the examined apple phenophases and each of the respective T_x and T_n during their appearance, was conducted using Pearson's correlation analysis.[4] For the air temperature and phenological data analysis the IBM SPSS Statistics 23.0 and MS Excel software packages were used. Results were considered significant at $p \leq 0.05$.

Results and Discussion

The average annual T_a at GIA was 15.9 °C while at RXP it was lower by 0.8 °C during the reference period. The annual course of this parameter at both regions showed simple seasonality during the year with the warmest and coldest months obtained in July and January, respectively. The T_a was significantly higher in GIA than in RXP from April to August ($p<0.05$). A fluctuation similar to that of T_a was observed in the cases of T_x and T_n throughout the year (Fig. 2a, b).

Significantly higher values of T_x at GIA than those at RXP almost throughout the year (Fig. 2a) were observed as the result of altitude and topography. Specifically, heating by the sun on the mountainous slopes and the floor of the valley at GIA, causes a closed circulation of air flow across the plain.[10,19] This results in the warmer conditions that prevail in the bottom of the plain at GIA in relation to those of RXP during the daytime hours. Additionally, significantly lower values of T_n (Fig. 2b) were obtained at GIA compared to those of RXP throughout the year. This fact could be attributed to local topography since the plain of GIA receives, during the night-time hours, the cold air masses coming from the steep slopes through the passes of the mountainous areas located in the northern and northwestern parts.[15,20] On the other hand, the mountains and hills located in the northern part of RXP are the physical barriers to the movement of cold air masses[21] from the GIA plain areas.



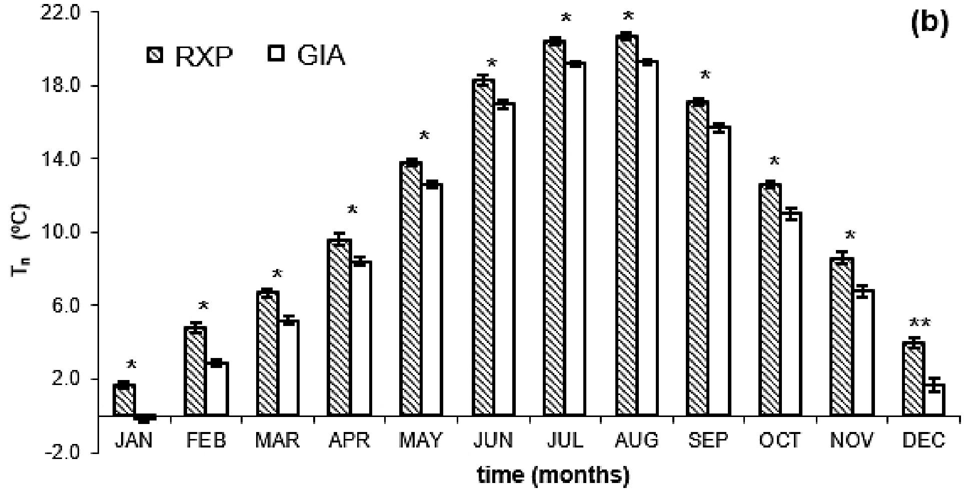


Fig. 2: Annual course of average monthly T_x (a) and T_n (b) at the regions of Giannitsa Pellas (GIA) and Rachi Pierias (RXP) in Central Macedonia, Greece.

In each column the vertical bar on it indicates the standard error of the mean. **, *: significant at p≤0.01 and p≤0.05, respectively. ns: not significant. T_x, T_n: maximum and minimum air temperature, respectively.

The results of the application of t-tests revealed significant changes in the onset of the same apple phenophases in spring between RXP and GIA. These phenophases appeared earlier by approximately 13 days at GIA than RXP during late winter and early spring (Fig. 3). Thus, the timing of the appearance of the examined apple phenophases seems to be affected by the significantly higher T_x values as mentioned above. The advanced onset of these phenophases with increased T_x values was reported at other regions of Central Greece.[3] Also, in many previous studies the advanced timing of tree phenophases by higher air temperatures in late winter and spring has been reported.[2, 4, 7, 9, 22]

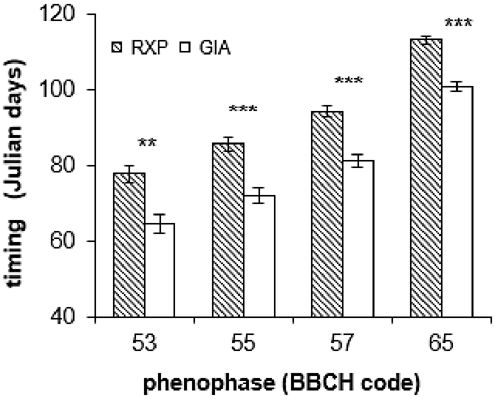


Fig. 3: Average timing (Julian days) of the studied phenophases of apple *Malus domestica* Borkh., at the regions of Giannitsa Pellas (GIA) and Rachi Pierias (RXP) in Central Macedonia, Greece.

The vertical line on each bar indicates the standard error of the mean. **, ***: significant at p≤ 0.01 and p≤ 0.001, respectively. BBCH 53: bud burst, 55: flower bud visible, 57: pink bud stage, 65: full flowering.

The earlier onset of the leaf development, of the pre-flowering and flowering phenophases of apple trees holds the risk of damages by late frosts during early spring. Frosts cause permanent or temporary damage to plant tissues leading to their partial or total injuries.[15]

The average timing of apple phenophases at both study regions was correlated negatively with the extreme temperatures. The timing of appearance of the BBCH 53 and 55 was correlated with T_x and T_n of March at RXP (Tab. 1, 2). Notably, at this region, higher correlation coefficients were confirmed in relation to the above extreme temperatures in the case of BBCH 53. In addition, the timing of BBCH 53 at GIA was correlated with T_n from February to March while a significant relationship between appearance of BBCH 55 and T_x of March, was found.

Regarding the timing of BBCH 57, significant negative correlation of this parameter and each of T_x and T_n of April and of March-April was found at RXP, while at GIA, negative correlation was found only in the case of T_x of March (Tab. 1, 2). In addition, significant correlations between the appearance of BBCH 65 and each of T_x and T_n of April were found and so these meteorological parameters are considered as crucial factors for the occurrence of the aforementioned phenophase.

Table 1: Pearson's correlation coefficients between maximum temperature (T_x) and appearance of the average timing of apple (*Malus domestica* Borkh.) phenophases in Central Macedonia, Greece.

BBCH	T_{x2}	T_{x3}	T_{x4}	T_{x23}	T_{x34}
			Giannitsa Pellas		
53	-0.211	-0.28		-0.482	
55		-0.884**			
57		-0.878*			
65			-0.882*		
			Rachi Pierias		
53		-0.949**			
55		-0.827*	-0.178		-0.675
57		-0.278	-0.849*		-0.835*
65			-0.840*		

T_{x2}, T_{x3}, T_{x4}: average maximum temperature for February, March, April, respectively. T_{x23}, T_{x34}: average maximum temperature from February to March and March to April, respectively. *, ** significant at p≤0.05 and p≤0.01, respectively. The empty cells indicate the absence of the respective phenophases. The absence of asterisks indicates non-significance. BBCH 53: bud burst, 55: flower bud visible, 57: pink bud stage, 65: full flowering.

Table 2: Pearson's correlation coefficients between minimum temperature (T_n) and appearance of the average timing of apple (*Malus domestica* Borkh.) phenophases in Central Macedonia, Greece.

BBCH	T_{n2}	T_{n3}	T_{n4}	Tn_{23}	T_{n34}
			Giannitsa Pellas		
53	-0.792	-0.763		-0.881*	
55		-0.654			
57		-0.408			
65			-0.842*		
			Rachi Pierias		
53		-0.943**			
55		-0.892*	-0.219		-0.616
57		-0.547	-0.899*		-0.927**
65			-0.872*		

T_{n2}, T_{n3}, T_{n4}: average minimum temperature for February, March, April, respectively. T_{n23}, T_{n34}: average minimum temperature from February to March and March to April, respectively. *, ** significant at $p \le 0.05$ and $p \le 0.01$, respectively. The empty cells indicate the absence of the respective phenophases. The absence of asterisks indicates non-significance. BBCH 53: bud burst, 55: flower bud visible, 57: pink bud stage, 65: full flowering.

From the correlation analysis about the BBCH 53, 55 and 57 phenophases it seems that T_x and/or T_n of March are decisive for their appearance depending on the region. Finally, the different topoclimate conditions that prevailed at both GIA and RXP depending on the relief and, in general, the complex topography affect the timing of appearance of the apple phenophases during the late winter and early spring. The evaluation of phenological behavior of apple (M. *domestica* Borkh. cv. Starking Delicious) has been studied at various regions in Thessaly, Greece.[3] Furthermore, the flowering stages of this tree in the eastern-central part of Italian Alps have been reported to be affected by local topography.[23]

Conclusions

In summary, the complex terrain influences the topoclimate conditions which prevail at Giannitsa Pellas and Rachi Pierias in Central Macedonia, Greece. It seems that the higher values of the maximum air temperature at Giannitsa caused an earlier appearance of the apple phenophases bud burst (BBCH 53), flower bud visible (BBCH 55), pink bud stage (BBCH 57) and full flowering (BBCH 65) compared to the respective ones at Rachi. Also, it was showed that the maximum and minimum air temperatures of March are considered as crucial factors for the appearance of the BBCH 53, 55, and 57 while those of April are decisive for the appearance of BBCH 65. However, the earlier onset of the phenophases during the early spring may cause damage attributed to frost risk with consequent great reductions in fruit yields. For this reason, it is necessary in the future to investigate the response of apple phenology to the higher air temperatures due to climate change for long reference periods in agricultural regions in Greece. This will lead to a more rational programming of cultivation techniques for the protection of apple cultivation in Greece and other countries.

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Conflict of Interest
The authors do not have any conflict of interest.

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