THE ANALYSIS OF LONG-TERM PHENOLOGICAL DATA OF APRICOT TREE (PRUNUS ARMENIACA L.) IN SOUTHERN MORAVIA DURING 1927–2009


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Abstract


The relationship between apricot tree (Prunus armeniaca L., variety Velkopavlovická) phenophases first flower and full flowering was evaluated in south Moravia region (161 a.s.l., 48°48´22´´N, 16°46´32´´E). The phenological data originated from Phenological year books for period 1927–1960 and was collected at various sites in southern Moravia. During 1961–2009 the phenophases were observed by only one observer each year at one experimental site (Lednice). The computer tool PhenoClim was used for calculation of the best combinations of temperature sum (TS) and base temperature (Tbase) as a predictors for onset of phenophases. Two different method of calculation was set – first is the thermal time model (TTM) and second use the simple sine wave method (SW method) of calculation TS. With using the TS and Tbase values the onset of phenophases was calculated for future climate conditions (2050 and 2100). The results showed firstly the reaction of phenophases to the changing climate during the last decades. The onset of first flower has advanced by 11.2 days since 1961. In the next step the most likely combination of T_s and Tbase was set by PhenoClim. The relationship between observed and modeled phenophases was evaluated by statistical parameter RMSE (Root Mean Square Error) which moved between 1.8 to 6.9 days for two phenophases and different periods. In model the values of TS and Tbase were subsequently used for estimation of timing the phenophases of apricot tree in future climate conditions. The onset of first flower and full flowering of apricot tree could be advanced by 11–13 days in 2050 and by 22–25 in 2100.

phenology, apricot tree, PhenoClim, base temperature, temperature sum

The role of the temperature, in temperate regions, is often dominant as it affects the rates of the most biological and chemical processes within plant body. Accumulated degree-days, calculated as the sum of the ambient temperatures above a base temperature, provide a measure of biological or thermal time. The concept of growing degree-days is well established having been used for over 200 years (Clark and Thompson, 2010) and also the use of degree-days for calculating the temperature-dependent development of plants is widely accepted as a basis for building phenology and population dynamics models (Roltsch et al., 1999). The simplest form of models, the simple thermal time (STT) model, has three parameters: the day of the year after which temperature sums are accumulated; the base temperature threshold, above which temperature sums are calculated; and the critical thermal threshold, which represents the accumulated temperature sum at which given phenological phase
is triggered (Bennie et al., 2010). Method of thermal time model was used e.g. by Chmielewski et al. (2005) for estimating the impact of temperature rise on vegetation development in Germany. Bennie et al. (2010) use simple thermal time model for prediction of expected critical sum thresholds in locations or for genotypes where observations do not currently exist for Betula pubescens. Clark and Thompson (2010) developed a technique to model phenological records of first flowering using the growing degree-days concept. Karlsson et al. (2003) use the thermal time model for evaluating if there is any difference in requirements of birch budburst degree-days in two sites.

The fact that the phenological phases are getting earlier is well known (e.g. Rosenzweig et al., 2008). Also many papers deal with the fact that growing season is getting larger; an extend of growing season has been observed from satellite data in northern high latitudes (e.g. Myneni et al., 1997; Slayback et al., 2003; Karlsson et al., 2008) and also from ground based phenological observations (e.g. Menzel, 2000; Ahas et al., 2002; Schwartz et al., 2006; Nordli et al., 2008). Consequently the timing of spring phenophases is considered to be under opposing pressures; earlier bud-burst increases the available growing season but later bud-burst decrease the risk of frost damage to actively growing parts. Nevertheless the possible damage by last frost days still exists and rapid changes in climate, as predicted for this century, are likely to exceed the rate at which trees and shrubs can adapt through evolution or migration (Bennie et al., 2010).

Chmielewski et al. (2004) published results about phenology of annual crops and also about fruit trees. They mentioned that an earlier blossom of fruit trees holds the danger of damage by last frosts. Frosts before the beginning of blossom may cause masked injuries in flower buds and moreover the frost during the flowering period can harm the blossoms, so that total crop failures can occur. For the spring development of plants mainly the temperature changes in winter and early spring are important and also the terms of last frost days. Schwartz et al. (2006) published that phenological phases (first leaf of various trees) and last spring freeze are getting earlier but both in a different way. Scheifinger et al. (2003) studied 13 phenological phases and how they are in relation with last spring freeze events. Their results showed that the reaction of various phenophases differ and also that the phenophases and last freeze events reacted to the changing climate differently.

In this article we applied simple thermal time model – PhenoClim, for calculating temperature sums (\(T_d\)) and base temperatures (\(T_{base}\)) (Bartošová et al., 2010). The \(T_d\) and \(T_{base}\) were calculated by two different methods – simple thermal time model (TTM) and sine wave method (SW method). Our goals were: (1) to calculate the most likely combination of \(T_d\) and \(T_{base}\) for phenophases of fruit tree apricot and developed the tool for modeling the terms of phenophases; (2) with using the information about \(T_d\) and \(T_{base}\) to estimate the onset of phenological phases in future climate conditions (2050, 2100) and finally (3) to set the probability of percentage endangered by last frost days of phenophases in 2050 and 2100.

### METHODOLOGY

In this work the phenological data about apricot (Prunus armeniaca L.), variety Velkopavlovická, were used and three phenological phases were analyzed – flowering, first flower and full flowering. In order to obtain complex information about values of degree days and temperature sums as precisely as possible two different data sources were used. First part of data came from phenological year-book during period 1927–1960 while the second part of data were collected by co-author of the study (Z. Bauer) at one experimental site during 1961–2008. Phenological data (about one phenophase – flowering) from period 1927–1960 were collected at 7 experimental sites – Lednice, Podivín, Valtice, Mikulov, Velké Pavlovice, Bolednice and Horní Bojanovice. Since 1961 the information about phenology (two phenophases – first flower and full flowering were collected at only one experimental site – Lednice. More detailed information about phenological and meteorological input data were described by Černá (2011).

Meteorological and phenological data were elaborated using computer tool PhenoClim. This software allowed to carry out quality control of observed dataset and estimate phenological terms for sites where only meteorological data are available and also under future climate conditions (Bartošová et al., 2010). Phenological data for PhenoClim was required for primary calibration of phenological model and consisted of the date of analyzed phenological phase (e.g. first flower) or its duration (e.g. time from the first till full flowering) in each years. Meteorological parameters have to be prepared for PhenoClim in daily time step and for complex analysis required maximum and minimum air temperature (°C), global solar radiation (MJ.m⁻².day⁻¹), amount of precipitation (mm), water vapor pressure (hPa) and wind speed (m.s⁻¹). PhenClim worked with two basic variables – base temperature (\(T_{base}\)) and temperature sum (\(T_d\)). \(T_{base}\) is defined as the lowest temperature where metabolic processes result in a net substance gain in aboveground biomass (Sitte et al., 1999) and \(T_d\) is described as the sum of the positive differences between diurnal mean temperatures and given \(T_{base}\) (Solantie, 2004).

To set up model the phenological and meteorological database were divided into two parts prior to the analysis. First part of the data was used for calibration of the phenological model and the second one for model validation. User selected e. g. even years for calibration and odd years for verification data or assessed different time period (e. g. period 1961–1981 for calibration and
PhenoClim allowed calculation of the base temperature \( T_{\text{base}} \) and temperature sums \( T_S \) by two different methods. First method was the thermal time model. \( T_S \) and \( T_{\text{base}} \) were determined for each year in the calibration dataset and then mean \( T_s \) was calculated for all tested \( T_{\text{base}} \) values. Using this mean \( T_S \) and \( T_{\text{base}} \) (value/values) the phenological stage onset/duration was estimated at first for calibration years. PhenoClim enables based on the calibration dataset to select most likely combination of \( T_S \) and \( T_{\text{base}} \) for any particular species. This was done through set of statistical variables namely mean bias error (MBE), root mean square error (RMSE) and coefficient of determination \( R^2 \). The construction of MBE and RMSE is described by equation:

\[
\text{MBE} = \frac{\sum_{i=1}^{n} (\theta_{\text{obs}} - \theta_{\text{sim}})}{n},
\]

\[
\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} (\theta_{\text{obs}} - \theta_{\text{sim}})^2}{n}}.
\]

The same set of statistical variables were calculated for the verification dataset and model user was able to select the best predictor(s) of a given phenophase and its values of effective \( T_S \) and \( T_{\text{base}} \). When using the TTM base temperature and sums were calculated not only for mean temperature but also for maximum and minimum temperature, global solar radiation and precipitation. So the best predictor of phenophases could be defined.

Second method is based on construction of simple sine wave between maximum and minimum temperature during one day (24 hours). According to the position of sine wave between lower and upper threshold (set by model user) the particular equation for calculation of \( T_S \) was used. Final calculation of \( T_{\text{base}} \) and \( T_S \) was done just as described in the previous step (with using of RMSE, MBE and \( R^2 \)).

Model user was free to select the parameters of the calculation. First is the specification of the date of summation. It was possible to choose from three possibilities – given date in phenological data file (when the sums between two phenological phases are calculated); arbitrary date set in the interface (e.g. January 20, March 1 etc.); finally calculation could start in the date according to the climate conditions in each year based on combination (or just one indicator) of mean, maximum and minimum temperature and snow cover presence or absence (modelled by SnowMAUS model according to Trnka et al., 2010).

For this study range of \( T_{\text{base}} \) were set between 0 °C and 10 °C in step 0.1 °C for thermal time model. For sine wave method only the lower threshold of temperature \( T_{\text{base}} \) were set (in the same range as for TTM). The start of summation was set by temperature conditions, calculation of \( T_S \) started when mean temperature 2.5 °C, maximum temperature 5 °C and minimum temperature 0 °C values were reached. Calibration of data was done for even years and data for odd years was used for validation.

Statistical variables RMSE and \( R^2 \) were finally used as indicators for determination of the best combination of \( T_{\text{base}} \) and \( T_S \). These values of \( T_{\text{base}} \) and \( T_S \) were used for estimation of phenological onset in future climate conditions. Estimated terms of phenophases were specified by AgriClim computation of last frost days in each year in future climate conditions.

In the first step the \( T_S \) and \( T_{\text{base}} \) were calculated by PhenoClim for period 1927–1960. For this period only data about one phenological phases – flowering – of apricot and information about average temperature were available. Therefore only TTM method were elaborated because it allowed us to calculate \( T_S \) and \( T_{\text{base}} \) with only average temperature.

Next the \( T_S \) and \( T_{\text{base}} \) were calculated using data from 1961–2008. During this period the values of first flowering and full flowering have been observed, also all relevant meteorological data were available (average, maximum, minimum temperature, precipitation and global solar radiation). The TTM method were used and the best predictor for onset of phenophases and for modeling the phenological phases had been looked for. The SW method were used also.

The long term phenological data were firstly divided into two parts and the \( T_S \) and \( T_{\text{base}} \) were calculated for period 1927–1960 and 1961–2009. In the next step the values were elaborated for the whole time of observations (1927–2009). For this long time period the phenophases flowering (for period 1927–1960) and full flowering (for period 1961–2009) were linked and TTM method was used. These two phenophases were linked together because of the fact that phenophase flowering from Phenological year book was defined as a phase when 90% of blossoms are opened what agreed with the definition of full flowering.

Finally by means of \( T_S \) and \( T_{\text{base}} \) of particular phenophases Phenoclim calculated onset of phases in future climate conditions. Climate-change scenarios for this study were developed by means of a “pattern-scaling” technique (Santer et al., 1990; Dubrovský et al., 2005) from the outputs of the Global Climate Models (GCMs) and were then used to modify the parameters of the weather generator M&Rfi , which is follower of the Met&Roll weather generator (Dubrovský et al., 2000, 2004). Both generators have been used in many agricultural climate change impact studies (e.g. Žalud and Dubrovský, 2002; Trnka et al., 2004, 2011; Rötter et al., 2011). The standardize climate change scenarios were derived from three global climate models (GCMs) – ECHAM5, HadCM3, NCARPCM (available
from the IPCC-AR4 database and referred to as ECHAM, HadCM and NCAR in the text), and then scaled by the changes in global mean temperature for 2050 and 2100 calculated via a simple climate model, MAGICC (Harvey et al., 1997; Hulme et al., 2000), assuming the A1B emission scenario and medium climate sensitivity (Tab. I).

In addition for modeled onset of phenological phases in future climate conditions the percentage probability of endangered by last frost days (the lowest temperature was −0.1 °C) was calculated by model AgriClim (Trnka et al., 2011).

RESULTS

The possible distribution of apricot tree in southern Moravia and the average temperature during vegetation season in study region is depicted on Fig. 1. Blažek et al. (1998) mentioned that the best growing areas are with average year temperature above 8.5 °C with altitude 200–250 a.s.l., which is correspond to the area of southern Moravia.

Phenological phases of apricot from locality Lednice showed changes in onset of phenological phases during the long time period (Tab. II). Since the 1927 to 1960 (phenological data originated in Phenological year-book and from various sites in southern Moravia) the phenophases had expressed delayed in onset (nevertheless the trend was not significant). But since 1961 till 2009 (pheno data was obtained by only one observer and from one experimental site in Lednice) the reaction of phenophases has changed. Timing has advanced to the earlier time by 11.2 days during the whole period. Finally two periods of phenological data were linked and the trend to the earlier onset was also significant.

For period 1927–1960 and 1961–2009 the T_s and T_base were calculated (Tab. III). The statistical indicators (RMSE and explain variability) calculated for phenophases from period 1927–1960 were worse (value RMSE is to high) than for the next period. For the TTM method and period 1961–2008 only the results for mean and maximum temperature were presented because of the fact that the rest of meteorological parameters (minimum temperature, global radiation and precipitation) showed weak or no linkage with phenophases terms (values

<table>
<thead>
<tr>
<th>Year</th>
<th>First flower</th>
<th>Full flowering</th>
</tr>
</thead>
<tbody>
<tr>
<td>1961–2009</td>
<td>−2.6*</td>
<td>−11.2*</td>
</tr>
<tr>
<td>1927–2009</td>
<td>−1.4*</td>
<td>−11.1*</td>
</tr>
<tr>
<td>1927–1960</td>
<td>0.7</td>
<td>2</td>
</tr>
</tbody>
</table>

I: Assumed change (with respect to 1990) in mean global temperature (°C) for given SRES scenario and middle climate sensitivity (3K)

<table>
<thead>
<tr>
<th>Year</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
<th>2060</th>
<th>2070</th>
<th>2080</th>
<th>2090</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1B/middle sensitivity</td>
<td>0.34</td>
<td>0.56</td>
<td>0.87</td>
<td>1.25</td>
<td>1.58</td>
<td>1.94</td>
<td>2.27</td>
<td>2.54</td>
<td>2.77</td>
<td>2.96</td>
</tr>
</tbody>
</table>

II: Phenological linear trends per decade and per the whole period for apricot tree. The linear trends for decades are significant at level α = 95%.
The analysis of long-term phenological data of apricot tree (*Prunus armeniaca* L.) in southern Moravia

III: Values of $T_s$ and $T_{sw}$ and statistical parameters for each phenological phases and for three different periods. (RMSE = Root Mean Square Error).

<table>
<thead>
<tr>
<th>Period</th>
<th>Phenophase</th>
<th>Method</th>
<th>$T_{avg}$ (°C)</th>
<th>$T_{base}$ (°C)</th>
<th>RMSE/ days</th>
<th>Expl. Variability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1927–1960</strong></td>
<td>FIRST FLOWER</td>
<td>TTM method</td>
<td>116.8</td>
<td>3.1</td>
<td>6.9</td>
<td>69</td>
</tr>
<tr>
<td><strong>1961–2009</strong></td>
<td>FIRST FLOWER</td>
<td>TTM method</td>
<td>121.2</td>
<td>3.9</td>
<td>2.9</td>
<td>92</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TTM method</td>
<td>174.8</td>
<td>7.5</td>
<td>1.9</td>
<td>96</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SW method</td>
<td>92.6</td>
<td>6</td>
<td>1.8</td>
<td>97</td>
</tr>
<tr>
<td></td>
<td>FULL FLOWERING</td>
<td>TTM method</td>
<td>192.9</td>
<td>2.9</td>
<td>4.4</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SW method</td>
<td>261.2</td>
<td>6.4</td>
<td>3.4</td>
<td>89</td>
</tr>
<tr>
<td><strong>1927–2009</strong></td>
<td>FIRST FLOWER</td>
<td>TTM method</td>
<td>113.5</td>
<td>3.7</td>
<td>6.5</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TTM method</td>
<td>121.2</td>
<td>3.9</td>
<td>2.9</td>
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<td>89</td>
</tr>
</tbody>
</table>

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RMSE were high and vice versa the explain variability were low). As the best predictor for onset of phenophases the average temperature (using SW method) was finally set as the combination of RMSE and R² showed the best values. SW method was subsequently used for calculating the terms of phenophases with using values Tₛ (92.6 °C) and Tₘₐₓₙ (6.0 °C) for first flower and Tₛ (192.7 °C) and Tₘₐₓₙ (3.6 °C) for full flowering because it gave the lowest values of RMSE (1.79 days). The values of Tₛ for first flower and two different methods (SW and TTM) showed differences. This was caused by different values of Tₘₐₓₙ which were set by PhenoClim. For period 1927–1960 and 1927–2009 only the TTM method was used. For SW method the maximum and minimum temperature are necessary but only average temperature was available for this historical period.

For periods 1927–1960 and 1927–2009 the statistical indicator RMSE were high and conversely the explain variability were low. Nevertheless the values of Tₛ and Tₘₐₓₙ were used for modeling the onset of phenophases. The relationship between observed and modeled terms of phenological phases is described on Fig. 2 a, b. Statistical indicators for Tₛ and Tₘₐₓₙ, which were calculated for data from period 1961–2009 show better results. Modeled terms of phenological phases were in a good correlation with observed terms. The results from two different methods show almost the same values of statistical indicators, finally the SW method was defined as a best and the Tₛ and Tₘₐₓₙ were used for modeling (Fig. 2 c, d). The results for first flower (Fig. 2 c) showed two outliers in 1980 and 1998 and for full flowering (Fig. 2 d) three outliers in 1980, 1998, 2007. After removal of this data (year 1998, 1980 and 2007) from the computation the results showed clearly better correlation (Fig. 2 e, f).

Finally we decided to use SW method for modeling the terms of phenological phases in future climate conditions. The phenological database where the outliers (years 1980, 1998 and 2007) were excluded was used because of the fact that the robust and compact database improve the modelling. The terms of phenophases were calculated for 2050 and 2100 with climate data generated using climate change scenarios based on the three different global circulation model [Fig. 3]. In 2050 the terms of first flower phase could be advanced in the range of 12 days (NCAR) to 15 days (HadCM). In 2100 the shifting of phenophase (first flower) to the earlier time was stronger. Average terms of phenophases could be advanced by almost 26 days. The situation for phenophase full flowering was almost similar. Full flowering could be advanced by 11–13 days in 2050 and by 22–25 days in 2100. The probability of endangered of the phenophase first flower was expressed by percentages values (Fig. 3) for minimum onset of phenophase (5th percentile) and for average terms of modeled phenophase (50th percentile). The danger was high not only for future climate conditions but also for the present situation. For the average terms of phenophases the danger was weaker but the values still achieve more than 50% of probability of endangered.

DISCUSSION

The fact that that the timing of phenophases is changing is widely accepted. Rosenzweig et al. (2008)
mentioned that 90–94% of significant changes are consistent with warming in physical and biological systems (e. g. leaf unfolding and blooming date) across Europe. Many authors published papers dealing with shifting of phenological phases to the earlier time (e. g. Sparks and Menzel, 2002; Walther, 2004; Schleip et al., 2009). Chmielewski et al. (2004) published that beginning of cherry tree and apple tree blossom started earlier by 2.0 and 2.2 days during decade since 1961 to 2000. Seguin et al. (2004) published advance of apricot and peach tree in flowering of 1–3 weeks (1970–2001). Our results for apricot tree are very similar to those; phenophases has advanced by 2.2 and 2.6 days per decade during 1961–2009. Menzel et al. (2006) used enormous data set of 542 plant species in 21 European countries (1971–2000). Most of the studied species showed advancing (78%) but some were also delayed (22%). The shifting to the later time showed more autumn plant species (e. g. Menzel, 2000; Chmielewski and Rötzer, 2001). Our data from period 1927–1960 also showed the later onset (but with no significant) and this situation could be explained also by the fact that data was averaged from 7 experimental sites where the high variability could occur. In order to estimated possible impacts of temperature rise on plant development the thermal time model and sine wave method were used. The goodness of fit of the model was defined by statistical indicators RMSE which were to high for period 1927–1960 and 1927–2009 (6.9 and 6.5 statistical indicators RMSE which were to high time model and sine wave method were used. The temperature rise on plant development the thermal variability could occur. This situation could be explained also by the fact that data was averaged from 7 experimental sites where the high variability could occur.

The analysis of long-term phenological data of apricot tree (Prunus armeniaca L.) in southern Moravia

Shifting of phenophases to the earlier time relate to danger of last frost days. These days with minimum temperature which can endangered or devastate the blossoms particularly of early spring species, such as apricot tree should be earlier for various species during the future 80 years. These papers also showed results for various plant species but in present situation, on our knowledge, there is no similar publications about apricot in accessible scientific letters.

Shifting of phenophases to the earlier time should be earlier by 37 days in 2050. These results by various investigators show high variability. Nevertheless it is clear that onset of phenological phases should be earlier for various species during the future 80 years. The study was set in North America, where although both are getting earlier, the relative rates of change of first leaf and last spring freeze date are spatially heterogeneous, so assessment of freeze damage risk variations are complex (Schwartz & Reiter, 2000). Scheifinger et al. (2003) did an extensive examination of the relative rates of change of last spring freeze events compared with 13 phenological phases (1951–1997). Their results showed that except for some of the earliest phenological events (these were progressing slightly faster or at the same rate as last freeze dates), last freeze dates were getting earlier at a faster rate than phenological events in that region. They also correctly caution that the timing difference between last freeze date and phenological event date will not be the same for all phenological events, so results from a single comparison need to be interpreted with caution. Our results showed that even if the term of the last frost day getting earlier the possible damage could be higher and higher.

Nevertheless our results also showed that not only last frost days could be the limiting factor for onset of phases but also the photoperiod. The good example of the photoperiod’s impact is the year 1998. In this year the onset of phase first flower was observed 95th days but the model calculated the terms of phenophases on 65th day because of the 15-day period with high minimum and also maximum temperature (average temperature in period from 1st day period with high minimum and also maximum temperature which can endangered in 63–68% in 2050, and in 64–73% in 2100. Seriously higher percentage endanger was calculated for the 25th percentile of modeled phases (90–100%). Chmielewski et al. (2004) pointed out also that an earlier blossom of fruit trees holds the danger of damage by late frosts. Schwartz et al. (2006) realized that usually, when the time between the onset of plant growth and subsequent last spring freeze grows larger, the potential for damage increases, as plants are in a more advanced stage of development. They study was set in North America, where although both are getting earlier, the relative rates of change of first leaf and last spring freeze date are spatially heterogeneous, so assessment of freeze damage risk variations are complex (Schwartz & Reiter, 2000).

The onset of phenophases in future climate conditions were calculated for two phenophases of apricot tree. The timing of phenophases should advance by 12–15 days in 2050 and by 22–26 days in 2100. Chmielewski et al. (2004) published that spring and summer tree species should advancved by 27 days in 2050. Črepinšek et al. (2009) published results for Juglans regia, the phenophases of this species should advanced by almost 4 weeks in 2060. Zahradnicek (2009) studied the terms of phenophases of Vitis vinifera in 2050 and 2100. The phases of wine should be earlier by 2–4 days in 2050 and by 10–20 days in 2100. The same species studied Webb et al. (2007) and their results showed stronger shifting, by 37 days in 2050. These results by various investigators show high variability. Nevertheless it is clear that onset of phenological phases should be earlier for various species during the future 80 years. These papers also showed results for various plant species but in present situation, on our knowledge, there is no similar publications about apricot in accessible scientific letters.

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to 95th day in the year is 5.2 °C; in the year 1998 the temperature during the same period was higher – 8.1 °C). It means that TS for phenophase first flower was already reached but the short day and shortage of light might not allowed the onset of opening the flowers. Caffarra and Donnelly (2011) mentioned that the release from dormancy is controlled by photoperiod and chilling but the degree to which the two triggers contributed to this process varied among species. For example, apple and pear trees are not influenced by day-length, but only by temperature (Heide and Prestrud, 2005); Fagus sylvatica has been reported to require a relatively long photoperiod in addition to chilling in order to resume growth in spring (Korner and Basler, 2010) and is influenced by photoperiod during the whole winter times (Caffarra and Donnelly, 2011). However, due to the various factors affecting the phenology, more studies about predictors and species should bring new insights.

**CONCLUSIONS**

The most likely combination of base temperature \( (T_{\text{base}}) \) and temperature sums \( (T_s) \) were evaluated for phenophases of apricot tree Using \( T_{\text{base}} \) and \( T_s \) the terms of phenophases were calculated and the relationship between observed and modeled terms of phenophases was evaluated by statistical indicator RMSE, it moved between 1.8–6.9 days. The sine wave method was set as a best method of calculation \( T_s \) and \( T_{\text{base}} \) with the lowest value of RMSE (1.8 day). The timing of phenophases was subsequently calculated for future climate conditions. In 2050 the terms of phenophases could be earlier by 12–15 days and in 2100 by almost 26 days. In these climate conditions the probability of damage by last frost days could be higher (63–73%).

**SUMMARY**

In presented work the phenological phases of apricot tree (Prunus armeniaca L.) was elaborated. Phenological data originated in two different time periods – 1927–1960 and 1961–2009 during which the phenophases first flower, flowering and full flower were observed and elaborated in region of south Moravia of the Czech Republic. Computer tool PhenoClim was used for calculation of the base temperature \( (T_{\text{base}}) \) and temperature sum \( (T_s) \) for particular phenophases. PhenoClim also allowed us to find the most likely combination of these two temperature parameters which can defined the onset of phenophases as good as possible. The goodness of fit of the model is defined by statistical indicators – RMSE [Root Mean Square Error], MBE [Mean Bias Error] and coefficient of determination \( (R^2) \). Finally, with using the \( T_{\text{base}} \) and \( T_s \) values the possible terms of the phenophases were defined also for future climate conditions (years 2050 and 2100). The best values of statistical parameters were set for data from period 1961–2009 (RMSE = 1.8 day, explain variability = 97%) when the \( T_{\text{base}} \) and \( T_s \) were calculated and subsequently used for modeling. The onset of phenological phases could be advanced in future climate conditions by 12–15 days in 2050 and by almost 26 days in 2100. Together with onset of phenophases the probability of endangered by last frost days of phenophases was calculated. The probability was expressed by percentages values for average terms of modeled phenophases (50th percentile). The possibility of endangered was 63–68% in 2050 and 64–73% in 2100.

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