COMPARISON OF PREDICTING FULL FLOWERING DATES OF APPLE TREE (*Malus domestica Borkh*) AND PLUM TREE (*Prunus domestica L.*) IN LJUBLJANA

PRIMERJAVA NAPOVEDOVANJA SPLOŠNEGA CVETENJA BOBOVCA (*Malus domestica Borkh*) IN DOMAČE ČEŠPLJE (*Prunus domestica L.*) V LJUBLJANI

Lučka Kajfež-Bogataj[1] and Klemen Bergant[2]

POVZETEK

V članku so obravnavane podobnosti med napovedovanjem splošnega cvetenja pri jablani (cv. 'bobovec') in splošnega cvetenja pri domači češplji. Analize podatkov so bile narejene na Centru za biometeorologijo, Biotehniške fakultete, Univerze v Ljubljani in temeljijo na podatkih fenoloških in klimatoloških opazovanj Hidrometeorološkega zavoda Republike Slovenije. Zaradi povezave med klimatskimi razmerami ter rastjo in razvojem rastlin, smo kot prediktorje splošnega cvetenja domače češplje in bobovca uporabili maksimalne in minimalne dnevne temperature zraka za prve štiri mesece (januar, februar, marec in april) v letih med 1969 in 1991 ter povprečne mesečne temperature zraka in količine padavin za iste štiri mesece za obdobje med 1967 in 1996. Poleg klimatoloških parametrov smo kot prediktorje splošnega cvetenja pri obravnavanih sadnih drevesih uporabili podatke o pojavu nekateri zgodnejših fenofaz samoniklih rastlin: pojav prvih listov pri brezi, bukvi in lipi ter začetek cvetenja španskega bezga. Za izdelavo modelov napovedovanja splošnega cvetenja domače češplje in bobovca smo uporabili dve metodi: linearno multiplo regresijo ter metodo temperaturnih vsot. Rezultati linearne multiple regresije kažejo, da lahko za napoved splošnega cvetenja bobovca s pridom uporabimo podatke o pojavu prvih listov pri bukvi ($R^2 = 0,55$), pri lipi ($R^2 = 0,62$) ter pri brezi ($R^2 = 0,73$). Podatki o pojavu prvih listov pri brezi so uporabni tudi za napovedovanje splošnega cvetenja domače češplje ($R^2 = 0,61$). Poleg tega obstaja statistično značilna zveza med pojavom splošnega cvetenja tako pri bobovcu kot pri domači češplji s kombinacijo povprečne marčevske in aprilske temperature zraka. V primeru napovedovanja splošnega cvetenja bobovca lahko s takšnim modelom razložimo 76 % variabilnosti podatkov v primeru splošnega cvetenja domače češplje pa 55 %. Vendar je napovedovanje splošnega cvetenja bobovca na podlagi povprečne marčevske in

[1] Prof., Ph. D., M. Sc., B. Sc., Center of biometeorology, University of Ljubljana, Biotechnical Faculty, Jamnikarjeva 101, P. O. Box 2995, 1111 Ljubljana, Slovenia, lucka.kajfez.bogataj@bf.uni-lj.si

[2] assist., B. Sc., ibid., Center of biometeorology, University of Ljubljana, Biotechnical Faculty, Jamnikarjeva 101, 1111 Ljubljana, Slovenia, klemen.bergant@bf.uni-lj.si

aprilske temperature zraka možno v povprečju le dva dni vnaprej, v primeru domače češplje pa še manj. Povezave pojava splošnega cvetenja bobovca in domače češplje s količino padavin v spomladanskem času niso statistično značilne. To lahko razložimo s tem, da v pomladanskem času količina padavin zadostuje potrebam rastlin. V drugem primeru smo s prirejeno metodo pravokotnika skušali oceniti efektivne temperaturne vsote nad različnimi temperaturnimi pragovi. Temperaturne vsote od prestopa praga do pojava splošnega cvetenja bobovca in domače češplje so bile izračunane za pragove med 0 in 10 °C s korakom 0,5 °C. Izmed uporabljenih temperaturnih pragov smo za napovedovanje fenofaze splošnega cvetenja pri obravnavanih sadnih drevesih po kriteriju minimalne relativne variabilnosti temperaturnih vsot med obravnavanimi leti izbrali: za bobovec temperaturni prag 6 °C ter za domačo češpljo 5,5 °C. Efektivna temperaturna vsota za pojav splošnega cvetenja bobovca tako v povprečju znaša 217 °C in je v dosežena 44 dni po prestopu temperaturnega praga 6 °C. V primeru domače češplje pa fenofaza splošnega cvetenja nastopi, ko je dosežena efektivna temperaturna vsota 233 °C, do česar v povprečju pride 45 dni po prestopu temperaturnega praga 5,5 °C. Tako v primeru uporabe linearne multiple regresijske metode kot metode temperaturnih vsot so podobnosti med modeli napovedovanja splošnega cvetenja bobovca in domače češplje očitne. Vzrok je najbrž v tem, da se sam fenološki razvoj pred splošnim cvetenjem pri obravnavanih sadnih drevesih, navkljub temu da pripadata različni rastlinski vrsti, ne razlikuje toliko kot fenološki razvoj po splošnem cvetenju. Razvoj plodu, ki se začne po koncu cvetenja, pri pečkarjih, kamor spada bobovec, poteka drugače kot pri koščičarjih, kamor spada domača češplja. Zato je pričakovati večje razlike med modeli v primeru napovedovanja pojava kasnejših fenofaz bobovca in domače češplje. Analize fenoloških podatkov, ki so predstavljene v članku, kažejo na to, da lahko za napovedovanje pojava fenofaz sadnega drevja uporabimo različne klimatološke podatke ter fenološke podatke samoniklih rastlin. Vendar pa moramo pri uporabi regresijskih modelov, kot tudi modelov s temperaturnimi vsotami, upoštevati da se, tako kot temperaturne razmere od pomladi do pomladi, tudi dolžina intervala, ko je dosežena ustrezna temperaturna vsota, iz leta v leto močno razlikuje.

Ključne besede: fenologija, statistični modeli, temperaturne vsote

ABSTRACT

Paper discusses the similarities in predicting the full flowering of apple tree and plum tree in Ljubljana. The study was conducted on University of Ljubljana, based on climatological and phenological observations of Hidrometeorological institute of Slovenia during the time period 1967-1996. Two different approaches were employed for predicting of full flowering of apple tree and plum tree. In first case the linear multiple regression technique was used. Input data for models were climatological data (average monthly air temperatures and average monthly amount of precipitation) and phenological data of autochthon plants. The date of flowering for both species is strongly correlated with first leaves unfolding of birch and in case of apple tree also with first leaves unfolding of linden and beech. Also strong correlation with combination of average March and April air temperature was found. In second case the modified rectangular method was used for calculating the accumulated degree-days. Input data were daily maximum and minimum temperature, and threshold temperature for calculating the degree-days totals. The threshold temperature was estimated by using different temperatures between 0 and 10 °C and choosing the one, which produce the lowest relative variability in accumulated degree-days. The estimated value for threshold temperature for apple tree is 6 °C and for plum tree 5.5 °C. The analyze shows that different climatological data and phenological data of autochthon plants could be successfully used for prediction of phenophases of different fruit trees.

Key words: phenology, statistical models, degree-days

1 INTRODUCTION

Climate conditions have great impact on plant growth and development. The most obvious indicator of relationship between climate variation and plant development is time of appearance of different phenophases. Phenological observations are the basis to study: the timing of recurring biological events, the causes of their timing with regard to biotic and abiotic forces, and the interrelation among phases of the same or different species (Lieth, 1974).

There are two main approaches to phenological data analyses: descriptive and quantified. The procedures of descriptive statistics are fairly straightforward, but in practice interpretations of results vary greatly between national agrometeorological services and also among scientists (Scharrer et al., 1998) On the other hand, modern phenological approaches base on quantifying the relations between phenological processes and environmental parameters or different biological processes. This comprises mainly phenological models, which are primarily designed to predict or understand the relationship between occurrence of biological event and another event or process (Hodges, 1991).

The aim of this paper is to compare the multiple regression models for prediction of flowering dates of apple tree (*Malus domestica* Borkh), which belongs to pome fruit trees and plum tree (*Prunus domestica* L.) which belongs to stone fruit trees. The multiple regression models used in this study base on climatological data (average monthly air temperature and precipitation) and phenological data of autochthon plants (birch–*Betula pendula* Roth, linden–*Tilia platyphyllos* Scop., beech–*Fagus sylvatica* L. and Spanish elder – *Syringa vulgaris* L.) for location Ljubljana. The possibility of estimation the threshold temperature (LTh) for calculating accumulated degree–days and using it for prediction of flowering days is also discussed in this paper.

2 MATERIAL AND METHODS

Climatological and phenological data for Ljubljana for time period 1967-1996 were used as input data. The used climatological data comprise the daily maximum (*Max*) and minimum (*Min*) air temperature for time period 1969-1991, average monthly air temperature (T_{month}) and average monthly amount of precipitation (RR_{month}) for time period 1967-1996, for months from January till April. From phenological data, dates of full flowering ($p_{F,specie}$) of apple tree (*Malus domestica* Borkh) and plum tree (*Prunus domestica* L.), unfolding of first leaves ($p_{L,specie}$) of birch (*Betula pendula* Roth), linden (*Tilia platyphyllos* Scop.) and beech (*Fagus sylvatica* L.), and beginning of flowering ($p_{B,specie}$) of Spanish elder (*Syringa vulgaris* L.) were used in our study. Hidrometeorological institute of Slovenia did the collection and quality check of data. Studied plant species are widely spread in Slovenia and some similar analyzes were already done also for other sites around country (Kajfež-Bogataj, 1997).

In first case the stepwise multiple regression technique (Zar, 1996) was employed to build phenological models for predicting $p_{F,apple}$ and $p_{F,plum}$ from earlier phenophases of autochthon species, and from average monthly air temperature and precipitation data. All calculations were performed using statistical package STATGRAPHICS Plus 2.1.

Plants require a certain amount of heat to develop from one point in their life–cycle to another (Wilson et al., Barnett, 1983). Accumulated degree-days (*DD*) are often used as heat measure in phenological modeling. The degree-day (*DD*) calculation methods differ somewhat in complexity (Wilson et al., 1983). Three methods are common: rectangular, triangular, and sin wave. All use *Max* and *Min* to try to estimate the *DD* total. Triangular and sine wave methods use curve fitting at half-day intervals. They are more accurate and done using a computer program. The rectangular method employs simple averaging, is less accurate, but usually provides adequate results; it can be done by hand, using data provided by maximum and minimum thermometers (Baskerville et al., 1969). In our case the modified rectangular method was used (Table 1).

Table 1: Relationship defining modified rectangular method for estimating of DD totals.

Modified rectangular method using only LTh	
IF	
$Min > Lth$	$DD = \frac{Max + Min}{2} - LTh$
$Max > LTh$ $Min < LTh$	$DD = \frac{(Max - LTh)^2}{2(Max - Min)} - LTh$
$Max < LTh$	$DD = 0$

Max and *Min* data were used to determine the *LTh* for calculating *DD* for apple tree and plum tree. *DD* were calculated for *LTh* from 0 to 10 °C with step 0.5 °C and the threshold temperature, which produced minimum relative variability (Zag, 1996) in *DD* for 22 years (1969-1991), was chosen as the best.

3 RESULTS AND DISCUSION

The values of climatological parameters in Ljubljana vary from spring to spring and, therefore, the dates of different phenophases of fruit trees vary accordingly. Descriptive statistics about full flowering of apple tree and plum tree in years between 1967 and 1996 are presented in Table 2.

In average, the appearance of full flowering of plum tree is 4 days ahead of full flowering of apple tree. The expected day for full flowering of plum tree is 28th April and for full flowering of apple tree is 2nd May. The variability of full flowering date for plum tree is higher than for apple tree, which can bee seen from values of standard deviation in Table 2. The range for flowering date is in case of plum tree is also longer than in case of apple tree for about 43 %.

Table 2: Descriptive statistics of full flowering date of apple tree and plum tree in Ljubljana in years from 1967 to 1996.

	plum tree	apple tree
average p_F	118th day 28. April	122th day 2. May
latest p_F	132th day 12. May	134th day 14. May
earliest p_F	92th day 2. April	106th day 16. April
variation range	40 days	28 days
standard deviation	9.5 days	6.6 days

The correlation analyzes were performed to find the relationships between the full flowering of plum and apple tree and climatological parameters and also between full flowering and appearance of some phenophases of autochthon plant species. The correlation coefficients for individual predictor are presented in Table 3 and Table 4.

Table 3: Correlation coefficients for predicting the full flowering date of plum and apple tree on the base of climatological data.

	$T_{January}$	$T_{February}$	T_{March}	T_{April}	RR_{Januar}	$RR_{Februar}$	RR_{March}	RR_{April}
$p_{F,plum}$	- 0.28	- 0.52	- 0.59	- 0.40	0.22	- 0.05	0.30	0.02
$p_{F,apple}$	0.00	- 0.45	- 0.64	- 0.33	0.40	- 0.05	0.27	0.19

Table 4: Correlation coefficients for predicting the full flowering date of plum and apple tree on the base of autochthon plant species development indices.

	$p_{L,birch}$	$p_{L,beech}$	$p_{L,linden}$	$p_{B,elder}$	$p_{F,plum}$	$p_{F,plum}$
$p_{F,plum}$	0.78	0.62	0.65	0.54	1	0.65
$p_{F,apple}$	0.86	0.77	0.79	0.44	0.65	1

The results of correlation analyze show, that here is no significant correlation between p_F of studied fruit trees and individual T_{month}. The stepwise correlation method (Zar, 1996) was performed to check, if there are combinations of different climatological parameters that influence on appearance of full flowering of apple tree and plum tree. In both cases the combination of T_{March} and T_{April} was found to be important for predicting the p_F.

In case of RR_{month} the situation is even worse than in case of individual T_{month}. The p_F were not correlated to RR_{month} at all. This could be expected since in Slovenia, water availability in the spring is not a major problem and air temperature plays decisive role in determining phenological development (Kajfež-Bogataj et al., 1998).

For both studied fruit trees, the p_F is strongly correlated with $p_{L,birch}$ and in case of apple tree also with $p_{L,linden}$ and $p_{L,beech}$. The correlation coefficient in mentioned cases were higher than 0.7, which means, that more than half of variance, can be explained by linear model between p_F and mentioned phenophases of autochthon trees. Statistical models for predicting the $p_{F,apple}$ and p_{Fplum} on the base of T_{March}, T_{April}, $p_{L,birch}$, $p_{L,linden}$, and $p_{L,beech}$ are presented in Table 5 and Table 6.

Table 5: Linear simple regression models for predicting the $p_{F,apple}$ and $p_{F,plum}$ on the base of phenological data of some autochthon species.

MODELS BASED ON DIFFERENT PLANTS PHENOLOGY		
STATISTICAL MODEL	R^2	days ahead
$p_{F,plum} = 0{,}88 \times p_{L,birch} + 22.6$	0.61	15
$p_{F,apple} = 0{,}68 \times p_{L,birch} + 43.2$	0.73	13
$p_{F,apple} = 0{,}67 \times p_{L,linden} + 47.4$	0.62	11
$p_{F,apple} = 0{,}93 \times p_{L,beech} + 19.2$	0.55	11

Table 6: Linear multiple regression models for predicting the $p_{F,apple}$ and $p_{F,plum}$ on the base of climatological data.

MODELS BASED ON MEAN MONTHLY AIR TEMPERATURES		
STATISTICAL MODEL	R^2	days ahead
$p_{F,plum} = -2.86 \times T_{March} - 3.92 \times T_{April} + 173$	0.55	0
$p_{F,apple} = -2.46 \times T_{March} - 3.30 \times T_{April} + 168$	0.76	2

In case of using $p_{L,birch}$ data as a predictor for $p_{F,apple}$ and $p_{F,plum}$ the predictions can be made 13 and 15 days ahead and in case of using $p_{L,linden}$ and $p_{L,beech}$ as a predictor for $p_{F,apple}$ 11 days. The multiple regression model for predicting the p_F on the base of

T_{March} and T_{April} have great disadvantage, because the predictions can be made in case of apple tree only 2 day ahead and in case of plum tree not even that. On the other hand, the similarity of multiple regression models for both trees shows us, that they have similar *LTh*.

Regarding the correlation coefficients in Table 3, we have chosen for the target interval for *LTh* values between $T_{Februar}$ (1.4 °C) and T_{April} (9.9 °C). We were trying to find the *LTh*, which would produce the minimum interannual variability of *DD* on chosen interval. The interannual variability of *DD* for apple tree and plum tree by using *LTh* from 0 to 10 °C with step 0.5 °C is presented on Figure 1. For measure of *DD* variability the coefficient of variation (*CV*) was used. In case of apple tree it reaches its local minimum value (7.3 %) between T_{March} and T_{April} at *LTh* 6 °C and in case of plum tree (11.9 %) at *LTh* 5.5 °C. The final model parameters are so for apple tree *LTh* 6 °C and *DD* 217 °C and for plum tree *LTh* 5.5 °C and *DD* 233 °C. Accumulation of *DD* starts for apple tree after the average daily temperature 6 °C threshold interception and reaches the value of 217 °C in average after 44 days. For plum tree the *DD* accumulation starts after 5.5 °C threshold interception which appears in average 45 days ahead of full flowering of plum tree, when the DD reaches value of 233 °C.

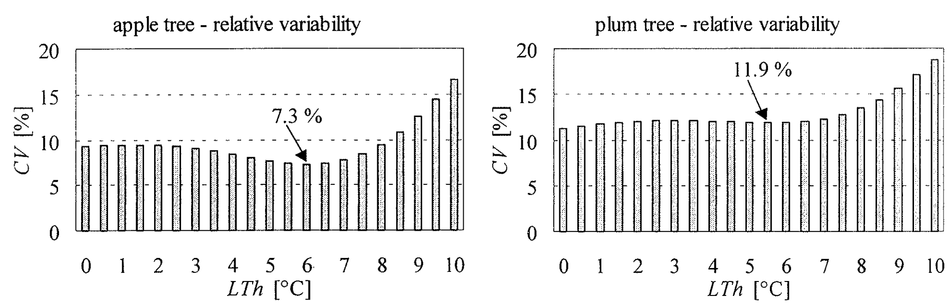

Figure 1: The interannual variability of *DD* for apple tree and plum tree for time period 1969-1991 by using different *LTh*.

In both types of models, the regression and *DD* models, we need to be aware that as the temperature conditions differ from spring to spring also the time interval for accumulation of *DD* and so the appearance of full flowering varies strongly from year to year.

4 CONCLUSIONS

The air temperature conditions in spring play decisive role in plant growth and development. Air temperature data and phenological data of earlier phenophases of autochthon plant species can be used to predict the appearance of full flowering of apple tree and plum tree in Ljubljana and also in other sites in Slovenia (Kajfež-

Bogataj, 1997 and Kajfež-Bogataj et al., 1998). The best predictor for full flowering of apple tree and plum tree was in our case the unfolding of first leaves of birch tree. In case of apple tree the full flowering date can be predicted also on the base of first leaves unfolding of linden and beech. Also strong correlation was found between full flowering of both studied fruit trees and combination of T_{March} and T_{April}. Unfortunately the models based on this correlation are practically useless for predicting the date of full flowering, because they can not be used more then 2 days ahead. Monthly amounts of precipitation in spring can not serve as a predictor for full flowering of apple tree and plum tree.

Beside climatological data and phenological data of autochthon plant species also models based on previous phenophases of studied fruit trees can be produced (for example Kajfež-Bogataj, 1997 and Kajfež-Bogataj et al. 1998). In general the appearance of full flowering of stone fruit trees is earlier than of pome fruit trees. So it is not surprising, that the full flowering date of plum (*Prunus domestica* L.), which belong to stone fruit trees, is in average 4 days ahead of full flowering date of apple tree (*Malus domestica* Borkh), which belong to pome fruit trees.

Multiple regression models and degree-days models are very similar for both studied fruit trees, although we are dealing with different species. The reason is probably, that the phenological development before the phenophase of full flowering is not so different for studied fruit trees as after it. More significant difference between stone fruit trees and pome fruit trees is in case of fruit development, so some differences in prediction models for later phenophases are not excluded.

In our case only statistical models were used. They are very simple to derive, but unfortunately they are site specific. Further work should be done in direction of developing the dynamical phenological models that are more sound and of more general use.

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