CLIMATE CHANGE IMPACT STUDY BASED ON GRAPEVINE PHENOLOGY MODELLING

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ABSTRACT
In this work we present a joint model of calculation the budbreak and full bloom starting dates which considers the heat sums and allows reliable estimations for five white wine grape varieties (Chardonnay, Szürkebarát (Pinot gris), Pinot blanc, Riesling, Hárslevelű) and their clone varieties in Hungary (Chardonnay 75 and 96, Riesling 239, 378, 391 and 49, Hárslevelű P.41 and K.9., Pinot blanc 54, 55 and D55, Szürkebarát 34 and 52). The base lower and upper temperatures have been determined by optimization, above which (threshold temperature) the accumulation of daily means is most active, or alternatively, below which the daily means are most sensitively expressed in the phenology. The model has been extended to the calculation of the end of the rest period (endodormancy), by optimization as well. We determined the lower and upper base temperatures separately for the budbreak and full bloom starting dates such that the lowest (normalized) sum of squares error, the lowest average absolute and the lowest maximum error of predictions can be achieved. We determined the optimal (lower) base temperature as 6 °C and the optimal starting date as the 41st Julian day of the year for the budbreak. Moreover, we set 10,45 °C and 26 °C as lower and upper optimal base temperatures for full bloom. The joint model was then applied to study the impact of climate change on budbreak and full bloom starting dates based on RegCM3.1 (regional) climate model. We calculated the expected shifts of budbreak and full bloom and proved that the changes are significant.

KEYWORDS
budbreak – vegetation period – phenology model – biologically effective day degrees – full bloom – starting dates of phenological stages – *Vitis vinifera* L.

INTRODUCTION
The success of viticultural production depends highly on weather parameters. The effects of climate change are already visible in the phenology of several varieties. Modelling the starting dates of budbreak and full bloom is very important because the success of plant protection and technology techniques scheduling is depending mainly on phenological information. Moreover, several risk factors can be traced back to the connection of weather and phenological timing. This kind of research is of even greater importance nowadays when usual phenological timing is changing.

The budbreak date is the first phase of vegetation period. It depends on weather parameters (like soil and air temperatures, thermo parameters of winter and spring), variety, physiological stage of the vine-stock, maturity of buds, etc. The budbreak starts off, when the necessary (critical) biologically effective heat sum is reached. The beginning of budbreak was recorded, when the broken buds reach the proportion of 50 %.

The blooming of grapevine usually occurs in Hungary between end of May and middle of June. However, climate change and weather anomalies in the last decades and in the future may cause the change of phenology timing. First of all, temperature and relative air humidity define the beginning of blooming. There are appreciable deviations between blooming periods of *Vitis vinifera* L., North-American or East-Asian species, and between the early and late ripening varieties. The ideal temperature for grapevine blooming is between 20°C and 26°C. During bloom dry weather with low air humidity is unfavourable as well as heavy rainfall is disadvantageous. We set the beginning of bloom when 4-5 % of grapevine flowers opened. The full bloom is defined by 60-70 % of flowers opened.

The starting dates of budbreak and full bloom are investigated with a biologically effective day degreee joint model which depends on lower and upper base temperatures and also on the starting date of heat accumulation.With the help of the phenology model as well as of the RegCM3.1 regional climate model the expected shifts of budbreak and full bloom are calculated.

MATERIALS AND METHODS

The phenology data of Central Agricultural Office (CAO) we used were recorded between 2000 and 2004 in Helvécia (South Great Hungarian Plain Region, Hungary), when budbreak and full bloom periods started. Five white wine grape varieties (Chardonnay, Szürkebarát (Pinot gris), Pinot blanc, Riesling, Hárslevelű) and their clone varieties (Chardonnay 75 and 96, Riesling 239, 378, 391 and 49, Hárslevelű P.41 and K.9., Pinot blanc 54, 55 and D55, Szürkebarát 34 and 52) were investigated**.** In this region the soil is sandy with very low humus content (Pernesz, 2004).The number of yearly sunny hours is between 2000-2500 hours and the vegetation period is highly variable (Fig. 1). The main risk factors are frost and drought.

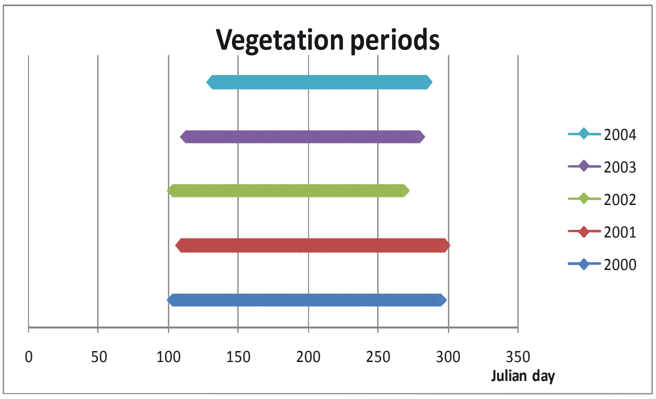

Figure 1 The lengths of the vegetation periods of the years 2000-2004 in Helvécia

A phenology model for the estimation of budbreak and full bloom dates

The method of calculating the sum of daily mean temperatures as "degree days", is based on the observation that the plants are able to utilise cumulatively - in growth and development - the temperature above a lower and under an upper base temperature (Tomasi et al., 2005).

For grapevines (Vitis vinifera L.), 10 °C is widely accepted as (lower) base temperature (Jones, 2003, Jones et al., 2005). However, we decided to calculate the base temperatures of grapevine with optimization method for budbreak and flowering starting dates separately. The optimization was based on the least standard deviation in days as well as on the least average absolute deviation in days and on the least maximum deviation in days. The thermal time was accumulated from the average daily temperature above the lower base temperature and, in case of flowering starting date estimation, with a ceiling of the upper base temperature if the average exceeded it. Though the most widely used starting date of thermal accumulation for budbreak date models is the 1st of January (Riou, 1994, Bindi et al., 1997 a,b,), after optimization we have chosen a later starting date which has improved our budbreak date estimation. The optimized starting date can be considered as the *statistical* end of endodormancy (the period when buds are dormant due to physiological conditions) and the starting date of ecodormancy (when buds remain dormant just because of unfavourable environmental conditions (Lang, 1987, Cesaraccio, 2004). Judging by the quantity and quality of the available data we decided to use a daily scaled linear model.

The joint model was then applied to study the impact of climate change on budbreak and full bloom starting dates. To this we took the RegCM3.1 (regional) climate model with 10 km resolution referring to 2021-2050 and with reference period 1961-90, supposed the SRES scenario A1B. The original climate change model was developed by Giorgi al. (1993) and was downscaled at Eötvös Loránd University, Department of Meteorology, Budapest, Hungary (Bartholy et. al., 2009, Torma et. al., 2008). We calculated the expected shifts of budbreak and full bloom and proved that the changes are significant.

RESULTS AND DISCUSSION

We determined the optimal (lower) base temperature as 6 °C and the optimal starting date as the 41st Julian day of the year for the budbreak. (It means that the statistically calculated date of the end of the endodormancy is the 10th of February.) The optima, however, has not changed when the upper base temperature was built in the model. The reason of it is that there were no such high average daily temperature between 10th of February and budbreak in these years which could significantly change the value of degree days. It means that between the end of endodormancy and budbreak the heat was as high as the plant could almost totally benefit it.

The optima are corresponding to the ones in the literature based on physiological reasons (Gladstones, 2000). Table 1 represents the accumulated heat sums (°C) of the different varieties in the time period 2000-2004. The critical values of heat sums (°C) for the budbreak of the fifteen white wine varieties during the five years 2000-2004 are also summarized in Table 1 where the average values for the certain varieties can be seen below, in separate lines. We can see that the varieties needed the less heat sum in 2003, the most heat sum in 2004 for their budbreak.

Table 1 The accumulated observed heat sums (°C) above the (lower) base temperature of 6 °C for different varieties in the time period 2000-2004 together with their averages (called critical heat sums)

Varieties Years	Ch	Ch_75	Ch_96	Szb	Szb_34	Szb_52	Pb_54	Pb_55	Pb_D55	Rr_239	Rr_378	Rr_391	Rr_49	Hl_P41	Hl_K9	Average
2000	160,75	160,75	188,75	238,25	238,25	238,25	188,75	238,25	238,25	238,25	238,25	238,25	238,25	238,25	238,25	**221,32**
2001	204,25	216,75	204,25	234,50	224,75	246,00	195,25	204,25	204,25	234,50	246,00	246,00	246,00	234,50	234,50	**225,05**
2002	202,00	202,00	208,00	245,50	245,50	256,50	202,00	208,00	193,00	214,50	221,50	208,00	230,00	221,50	221,50	**218,63**
2003	160,50	160,50	160,50	182,00	199,50	182,00	182,00	182,00	171,00	182,00	182,00	182,00	182,00	182,00	171,00	**177,40**
2004	215,00	223,50	223,50	201,00	223,50	215,00	207,00	234,50	223,50	278,00	266,50	266,50	223,50	244,00	215,00	**230,67**
Average	**188,50**	**192,70**	**197,00**	**220,25**	**226,30**	**227,55**	**195,00**	**213,40**	**206,00**	**229,45**	**230,85**	**228,15**	**223,95**	**224,05**	**216,05**	

Table 2 The errors of the estimations of budbreak

	Ch	Ch_75	Ch_96	Szb	Szb_34	Szb_52	Pb_54	Pb_55	Pb_D55	Rr_239	Rr_378	Rr_391	Rr_49	Hl_P41	Hl_K9	Yearly average of the absolute values
2000	2	3	1	-1	0	0	1	-1	-2	0	0	0	0	0	-1	**0,80**
2001	-2	-3	0	-1	1	-1	0	2	1	0	-1	-1	-2	-1	-2	**1,20**
2002	-1	-1	-1	-3	-2	-3	0	1	2	2	1	3	0	1	0	**1,40**
2003	3	3	3	3	2	3	1	3	3	3	4	3	3	3	4	**2,93**
2004	-3	-4	-3	3	1	2	-1	-2	-2	-4	-3	-3	1	-1	1	**2,27**
Average of the absolute values	**2,20**	**2,80**	**1,60**	**2,20**	**1,20**	**1,80**	**0,60**	**1,80**	**2,00**	**1,80**	**1,80**	**2,00**	**1,20**	**1,20**	**1,60**	**1,72**

The (normalized) sum of squares error, the average (absolute) error and the maximal error are 2,09, 1,72 and 4 days for budbreak. Considering Table 2 we can see that the budbreak dates of variety Chardonnay_75 (Ch_75) can be predicted with the largest average absolute error (2,8 days). The model estimations gave the smallest errors for the clone variety Pinot blanc 54 (Pb_54), its average absolute error was 0,6 day. The less predictable year was 2003 with an average absolute error of 2,93 days. The averages of the absolute errors of the years 2000-2002 were all under 2 days.

Moreover, we set 10,5 °C and 26,5 °C as lower and upper optimal base temperatures for full bloom. The (normalized) sum of squares error, the average (absolute) error and the maximal error are 2,22, 1,76 and 6 days for full bloom.

Table 3 represents the accumulated heat sums (°C) of the different varieties in the time period 2000-2004 while Table 4 shows the errors of the estimations (days).

Table 3 The accumulated observed heat sums (°C) of the different varieties between budbreak and bloom in the time period 2000-2004 together with their averages (called critical heat sums)

Varieties Years	Ch	Ch_75	Ch_96	Szb	Szb_34	Szb_52	Pb_54	Pb_55	Pb_D55	Rr_239	Rr_378	Rr_391	Rr_49	Hl_P41	Hl_K9	Average
2000	273,20	262,60	262,60	253,50	245,90	240,80	262,60	253,50	256,00	245,90	247,50	245,90	245,90	298,50	306,10	**260,03**
2001	247,05	247,05	240,45	248,55	248,05	244,95	254,75	250,15	252,25	244,95	248,05	244,95	251,65	302,15	291,15	**254,41**
2002	209,70	285,90	252,50	292,40	267,90	267,90	284,90	278,70	267,60	274,00	263,80	267,90	274,00	285,70	288,30	**270,75**
2003	248,78	248,78	248,78	219,35	227,58	227,58	248,78	227,58	235,68	227,58	213,98	227,58	227,58	219,35	219,35	**231,22**
2004	268,60	268,60	267,00	235,00	220,30	208,20	242,30	250,70	240,20	255,60	255,60	270,80	255,60	279,90	247,10	**251,03**
Average	**249,47**	**262,59**	**254,27**	**249,76**	**241,95**	**237,89**	**258,67**	**252,13**	**250,35**	**249,61**	**245,79**	**251,43**	**250,95**	**277,12**	**270,40**	

Table 4 The deviations of the estimations from the observed dates of full bloom

Varieties Years	Ch	Ch_75	Ch_96	Szb	Szb_34	Szb_52	Pb_54	Pb_55	Pb_D55	Rr_239	Rr_378	Rr_391	Rr_49	Hl_P41	Hl_K9	Yearly average of the absolute values
2000	-2	0	-1	0	0	0	-1	0	-1	2	-1	2	2	-1	-2	**1,00**
2001	1	5	3	1	-2	-2	2	1	0	2	0	2	0	-1	-1	**1,53**
2002	4	-2	1	-6	-2	-3	-3	-3	-1	-3	-2	-1	-3	-1	-3	**2,53**
2003	1	2	1	3	2	1	1	3	2	2	3	3	3	6	5	**2,53**
2004	-1	0	-1	2	2	3	2	1	1	0	0	-2	0	0	3	**1,20**
Average of the absolute values	**1,8**	**1,8**	**1,4**	**2,4**	**1,6**	**1,8**	**1,8**	**1,6**	**1**	**1,8**	**1,2**	**2**	**1,6**	**1,8**	**2,8**	**1,76**

Analyzing the deviations of the estimations from the observed dates (Table 4) we can see that the starting date of full bloom of Hárslevelű K.9 clone was the most difficult to forecast. The most varieties however, have their absolute error near the average (1,76 days) which indicates the relative high stability of the model. The least average absolute error of the model was resulted for the clone variety Pinot blanc D55 (1 day).

Figure 2 The observed (_o) and the predicted (_p) bud break (left) and full blooming (right) starting dates of the five white vine varieties in the time period 2000-2004.

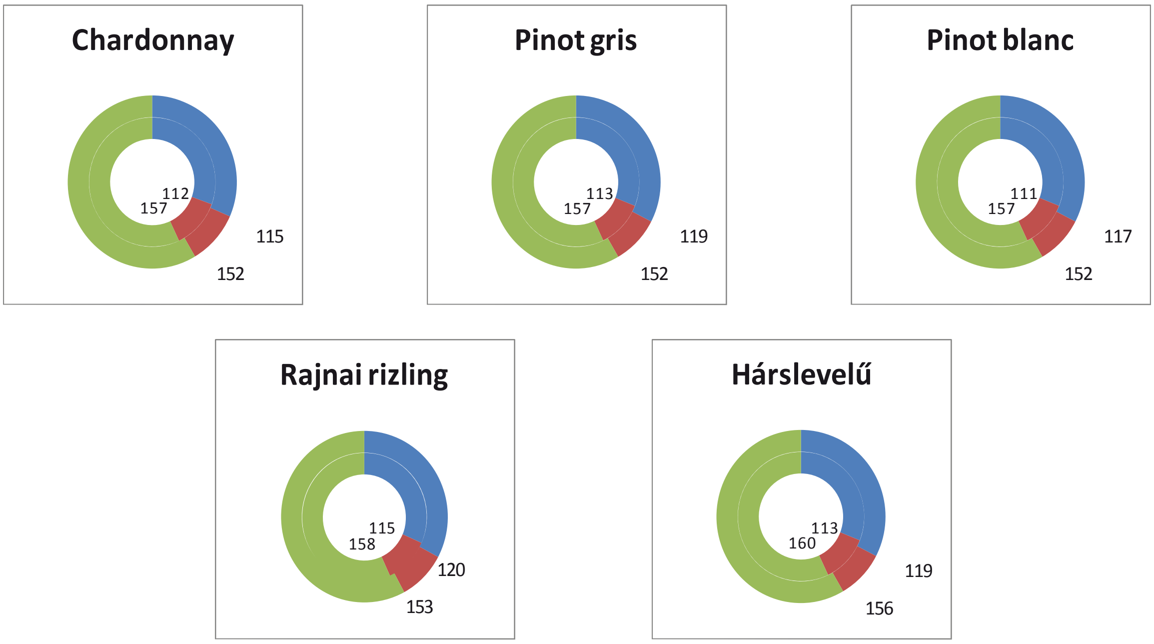

Figure 3 The results of the phenological model in the time period 2000-2004 (external circle), respectively by the RegCM3.1 regional climate model predicted dates in 2021-2050 (internal circle). The numbers mean the starting date of budburst and full boom (in Julian Day).

After having determined the parameters of the model, based on the regional climate model RegCM3.1 (Bartholy, et al. 2009, Torma, et al. 2008), we examined what the model predicts to the time period between 2021 and 2050. We illustrated our results on Figure 3. The model predicted the beginning of budbrake (red) about five days earlier, the starting date of full bloom (green) about five days later in the examined period compared to the observed data.

CONCLUSIONS

Phenology modelling is a useful tool to predict the expected changes in scheduling, caused by climate change. In case long-term phenology data together with weather records are available, the above introduced model can be improved. For this

1. Further spatial and temporal validity study is necessary. Other varieties should also be involved.
2. Other parameters as chilling sum during the dormancy as well as precipitation/humidity data should be inserted in the model to make it more accurate.

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