A general phenological model for characterising grapevine flowering and veraison
Un modèle phénologique pour caractériser la floraison et la véraison

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ABSTRACT
The timing of phenology is critical if grape quality potential is to be optimized. Phenological process based models are used to predict phenology. In this study, three different models were tested to predict flowering and veraison of grapevine (*Vitis vinifera* L.) using a new extensive phenological database. The Spring Warming model was found optimal in its trade-off between parsimony (number of parameters) and efficiency. The optimal parameter combination found for this model to calculate the degree-days was 0°C for the base temperature and the 60th day of the year for the starting day of accumulation (northern hemisphere). This model was validated at the varietal level, performed better than the classic Spring Warming model with Tb of 10°C and t_0 of 1st January (northern hemisphere) and remains easy to use.

Keywords : grapevine, modelling, phenology, veraison, flowering, temperature.
Mots-clés : vigne, modélisation, phénologie, véraison, floraison, température.

1 INTRODUCTION

Process-based phenological models work on the assumption that the process of phenological development is mainly regulated by temperature [1, 2, 3, 4]. Classically, the Spring Warming (SW) model (also known as Growing Degrees Days (GDD)) is the simplest model used to estimate grapevine phenology (bud break, flowering and veraison stages). This linear model uses a minimum base temperature (usually 10°C for grapevine) above which the average daily temperature summation is calculated and from a given date. More complex phenological models also take into account chill requirements necessary to break dormancy (for a review see [5]).

Process based modelling techniques, aiming to achieve temporal and spatial robustness, have not been fully explored for grapevine flowering and veraison. Furthermore, the parameter estimates defining existing indices have not been considered with respect to current modelling capabilities and the availability of new databases. For example, the relevance of the widely accepted base temperature parameter of 10°C, which was defined by Winkler et al. [6] for grapevines in California, has not been further explored on larger databases (covering large areas and time periods) using more modern and efficient optimisation algorithms for model parameterization.

The aim of this study was to develop a simple process-based phenological model to predict two important stages of development of *V. vinifera* L., flowering and veraison. The best model was selected in terms of efficiency relative to its complexity. The model can be further parameterized to describe the timing of flowering and veraison for individual varieties.

2 MATERIALS AND METHODS

2.1 Phenological data and temperature data

Historical data for 50% flowering and 50% veraison was collected from scientific research institutes, extension services ("Chambres d'Agriculture"), and private companies in France, Italy, Switzerland and Greece. The phenological observations collected for this study spanned from 1960 to 2007, from 123 different locations (predominantly in France). The observations corresponded to 81 varieties, 2278 flowering observations and 2088 veraison observations (combined total of parametrization and validation datasets) [7].

Daily average temperatures ((Tmin + Tmax)/2) were collected from meteorological stations situated within the limits of a 5 kilometre distance and 100 metre range (higher or lower in altitude) from each phenological data site.

2.2 Phenological models

Three different process-based models were tested: (1) SW with two different forms, (2) UniFORC and (3) UniCHILL [5]. SW and UniFORC consider only the action of forcing temperatures, while UniCHILL considers in addition the action of chilling temperatures involved during the dormancy period. The SW model contains 3 parameters, UniFORC 4 and UniCHILL 7. For more details see Chuine et al. [5].

2.3 Model parameterisation, selection and validation

All data for flowering and veraison across all varieties from the parameterization dataset was used to fit the most accurate model of the timing of flowering and veraison at the species level. The best model was selected based on model efficiency (EF)[8], error of prediction (Root Mean Squared Error, RMSE), and the Akaike Information Criterion (AIC) value [9] which rates models based on parsimony and efficiency where the best model is represented by the lowest value. The selected model was validated for 11 varieties on an independent validation data set, of which two (Chardonnay and Merlot) are presented here.

3 RESULTS

3.1 Model selection

The 4 model types (2 versions of SW, UniFORC, UniCHILL) were compared for flowering and veraison. Overall, there was very little difference between UniFORC, UniCHILL and SW in terms of efficiency (Table 1). The SW model with unfixed parameters for both flowering and veraison had the lowest AIC value indicating that SW was the best model with regard to the trade-off between parsimony and efficiency. The SW model with unfixed parameters for t_0 and Tb was subsequently chosen for our study.

Table 1. Statistical analysis of the four tested models for flowering and veraison using the same dataset. SW refers to the model Spring Warming, EF is the efficiency of the model, RMSE is the root mean squared error, AIC is the Akaike Information Criterion.

Model:	**SW**	**SW t_0 = 1 January**	**UniFORC**	**UniCHILL**
		Flowering		
EF	0.80	0.75	0.76	0.79
RMSE	5.4	6.1	6.0	5.6
AIC	3481	3740	3709	3559
		Veraison		
EF	0.74	0.57	0.72	0.69
RMSE	8.0	10.2	8.2	8.7
AIC	3845	4299	3909	4018

3.2 Optimisation of a single model for flowering and veraison

The best estimates of parameters t_0 and Tb for the SW model fitted on flowering dates were 56.4 days and 2.98°C respectively (Table 2). For the sake of simplicity for users, these values were rounded to 60 days and 3°C. When applied to veraison, the parameter estimates of 60 days and 3°C reduced slightly the model efficiency (0.70 vs. 0.72) compared to the parameter estimates fitted on veraison dates. Further fitting of veraison maintaining t_0 at 60 days yielded a Tb estimate of 0°C, increasing the efficiency of the veraison model slightly (0.72 vs. 0.70) and reducing slightly the efficiency of the flowering model (0.76 compared vs. 0.79).

Table 2. Efficiency of the SW model to predict flowering and veraison for different sets of parameter estimates of t_0 and Tb (F^* is adjusted for each stage).

Parameters	**t_0 (d)**	***Tb* (°C)**	**Flowering**	**Veraison**
t_0 and *Tb* fitted on flowering dates	56	3	0.79	0.69
t_0 and *Tb* fitted on veraison dates	92	4	0.71	0.72
t_0 and *Tb* fixed	60	3	0.79	0.70
t_0 and *Tb* fixed	60	0	0.76	0.72

A greater range of values for parameters t_0 and Tb were then investigated to further confirm the choice of initial parameter estimates that were optimized for the veraison model (t_0 value of 60 days, Tb value of 0°C). The efficiency of the model increased as t_0 increased from 0 to 60 days (Tb at 0°C), after which the efficiency remained stable (data not shown); a decrease in the efficiency of the model occurred when Tb

increased from 0°C to 15°C (t_0 at 60 days) (Table 3). This confirmed the choice of estimates for parameters t_0 and *Tb* following the optimization procedure.

Table 3. Change in the error of prediction (RMSE) and efficiency (EF) of veraison model (Spring Warming, t_0 = DOY 60) in response to changes of *Tb*.

	Base temperature (°C)						
	0	**3**	**5**	**7**	**10**	**12**	**15**
EF	0.72	0.70	0.66	0.58	0.26	-0.55	-2.17
RMSE	8.14	8.4	9.00	9.90	13.17	19.09	27.35

Table 4. Comparison of efficiency (EF) and quality of prediction (roots mean squared error, RMSE) of flowering and veraison between the new Spring Warming (SW) model parameters (t_0 at 60 days, *Tb* of 0°C) and the classical SW model parameters (t_0 at 1 day, *Tb* of 10°C). 1092 observations were used for flowering, 980 observations were used for veraison.

	Flowering		**Veraison**	
	New SW	**Classical SW**	**New SW**	**Classical SW**
t_0	60	1	60	1
Tb	0°C	10°C	0°C	10°C
EF	0.76	0.73	0.72	0.14
RMSE	5.9	6.3	7.7	14.3

The new model SW using the new parameter estimates of 60 days for t_0 and a *Tb* value of 0°C, was more efficient than the classical model of SW (GDD) with the parameters t_0 at 1 day and a *Tb* value of 10°C, particularly so for veraison (Table 4).The new model was termed the Grapevine flowering veraison model (GFV) herein.

3.3 Model validation

For both flowering and veraison, overall it was observed that the dispersion of data and model efficiency was similar for parametrization and validation at the varietal level (examples for veraison for Chardonnay and Merlot in Figure 1).

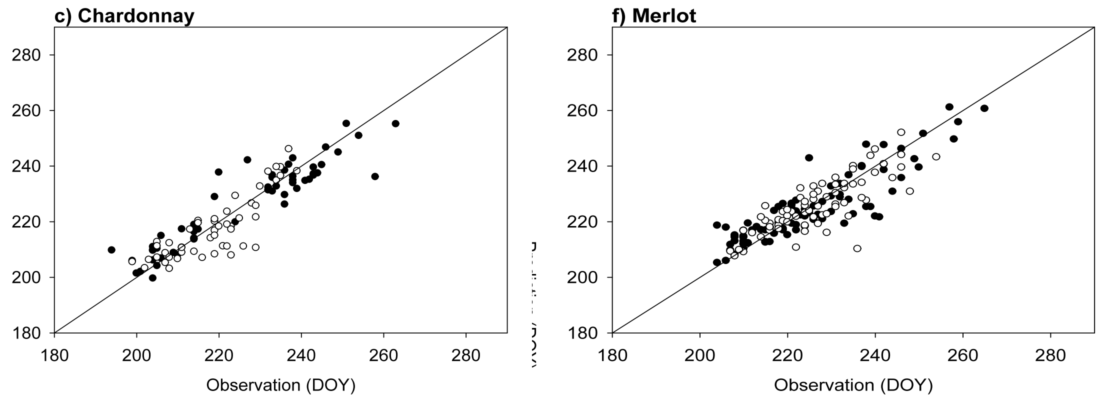

Figure 1. Observed and simulated dates of veraison of Chardonnay and Merlot using the Grapevine Flowering Veraison model. Closed circles (●) represent data used for the model parameterization; open circles (○) represent data used for the model validation. EF values (parametrization data, validation data): Chardonnay (0.78, 0.73), Merlot (0.78, 0.77).

4 DISCUSSION

We modelled flowering and veraison using process-based models [5] that had thus far been untested for the grapevine. With the aim of developing the most simple model possible at the species level, the proposed model GFV with a start date of the 60th day of the year (t_0) for application in the northern hemisphere; and a base temperature, *Tb*, of 0°C showed the best overall performance, representing the best balance between complexity and performance compared to the other possible model choices.

The GFV model proved more efficient than the current classic model of GDD using a base temperature of 10ºC from 1 January (in the northern hemisphere). The base temperature of 10ºC has been proposed to represent a threshold above which physiological processes are of importance for phenological development. Our results indicate that (i) either physiological processes influencing phenological development below 10ºC could be of more importance than currently thought and/or (ii) that the threshold temperature that is optimal for model prediction is not necessarily the temperature threshold for the underlying physiological processes of the developmental stage. The base temperature of 0ºC has the advantage for model users in that it is more simple to calculate during the growing season when minimum temperatures are less likely to drop below 0ºC. Therefore, in such cases its application represents a simple addition of accumulated daily average temperatures (from the 60^{th} day of the year).

5 CONCLUSIONS

We have shown that general process-based models can be successfully applied to and validated for the grapevine. A simple model, GFV corresponding to SW (t_0 at 60 days, *Tb* value of 0°C) has been selected, optimised and shown to be efficient to predict flowering and veraison at the species and varietal level. The model was validated and showed greater predictive power compared to existing models. Its simplicity makes it easy to use, and enables further adoption of the model to predict the varietal timing of flowering and veraison under a changing climate.

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Vine nitrogen status and the terroir effect: a study on cv. Doral in the Vaud vineyard (Switzerland)

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ABSTRACT

A 3-year study was conducted in the Vaud vineyard (Switzerland) to evaluate the effects of « terroir » on the ecophysiology and fruit compostion of *Vitis vinifera* L. cv. Doral and the characteristics of the wine made therefrom. The impact of soil on the vine-fruit-wine continuum was evaluated at 13 locations in the Vaud during the 2007-2009 seasons. Except for soil, the vineyards presented almost identical climatic characteristics and used similar cultivation techniques. The aim of this chapter was to assess whether soil might be a major environmental factor explaining the terroir effect through its effect on vine nitrogen status. We monitored the nitrogen status of the vines by measuring yeast assimilable nitrogen (YAN) in the must. The soil modulated vine nitrogen status by its fertility and rooting depth. Low vine nitrogen status induced a highly-soluble solids content, low malic acid content and high pH in fruits, resulting in small berries and low vine vigour. Wines were produced in a standardised manner from each location; then, they were subjected to sensory and chemical evaluation. YAN in musts was the parameter that best explained the variation in sensory characteristics of the wine made from grapes from the different locations. Wines made from grapes with low YAN values had negative sensory characteristics such as astringency and low aroma complexity scores. Therefore, vine nitrogen status was a key parameter contributing to the terroir effect. Furthermore, this work provides evidence of how geopedology can influence vine nitrogen status, fruit composition and sensory attributes of wines.

Keywords: soil categories, rooting depth, leaf and must nitrogen status, wine characteristics.

1 INTRODUCTION

In addition to climate, soil makes a major contribution to the terroir effect. However, the role of soil has not been studied widely and is still debated. For example, neither Noble [1] nor Bader and Wahl [2] found any relationship between soil and wine, whereas others authors have observed that soil affects both grape and wine composition. Most of the studies on this subject have described the effects of soil, but few have identified the contributing factors. The soil water holding capacity and its influence on vine water status may contribute to soil's effect [3,4]. However, except