AN OPERATIONAL MODEL FOR CAPTURING GRAPE RIPENING DYNAMICS TO SUPPORT HARVEST DECISIONS

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Introduction

Grape ripening is a critical phenophase during which many metabolites driving wine quality are accumulated in berries. Major changes in berry composition include a rapid increase in sugar and a decrease in malic acid content and concentration. Its duration is highly variable depending on grapevine variety, climatic parameters, soil type and management practices. Together with the timing of mid-veraison, this duration determines when grapes can be harvested. Grapevine sugar accumulation was previously studied from a physiological perspective (among others, see Dai et al., 2009; Suter *et al.,* 2021). Shahood *et al.* (2020) investigated sugar accumulation and malic acid degradation from a single berry perspective. Bigard *et al.* (2017) developed an original method to study ripening by sorting berries according to their density. In another study, the dynamics of organic acids and cations was considered together, to assess the effect on titratable acidity (Bigard *et al.,* 2020). Although these studies deepen our understanding of the physiological mechanisms involved in grape ripening, they do not provide an operational tool for growers to support harvest decisions, as the models developed and/or the sampling protocols associated with these studies cannot be deployed in a production setting. Moreover, in physiological studies, grape sugar is expressed in sugar content (mg/berry), while winemakers are interested in concentration (g/L of grape must), as it allows the prediction of wine alcohol percentage.

Viticulturists and winemakers monitor sugar to total acidity ratio (S/TA) during grape ripening and start harvesting grapes when this ratio reaches the optimum value for the desired wine style intended. Duteau (1990) suggested that this ratio, when expressed as a function of thermal summation (i.e. degree days), evolves in a strictly linear way during the first four weeks after mid- veraison. Hence, it can be expressed as:

$$y = \alpha x + \beta$$

where y = S/TA ratio and x = thermal summation.

In this equation, the slope of the curve (α) represents the ripening speed and (-β/α) a proxy for the timing of mid-veraison.

Research Objectives

The objective of this study is to apply the berry ripening speed model proposed by Duteau, 1990 on two large databases and study how ripening speed is affected by year, variety, soil type and other parameters. One of these data bases (DB1) encompass 10 years across 53 grapevine varieties; the second database (DB2) encompass 13 years across two grapevine varieties and three soil types. Depending on the database many parameters were measured, including vine water status by means of δ^{13}C (Gaudillère *et al.,* 2002), and berry weight at mid-veraison and at harvest. The model allows the determination of the ripening speed for primary metabolites, assessed through the slope of the sugar to total acidity (S/TA) ratio as a function of thermal summation. In a second step, the hierarchy of the effect of climate and grapevine variety (DB1) and the effect of climate, grapevine variety and soil type (DB2) were established. Finally, the impacts of vine water status as measured by δ^{13}C, berry weight and other parameters on grape ripening dynamics were investigated.

Material and methods

Description of the data bases

Database 1 (DB1) is collected in the VitAdapt common garden vineyard (Destrac-Irvine and van Leeuwen, 2017), which is located at the ISVV campus in Villenave d'Ornon, Protected Denomination of Origin (PDO) Pessac-Léognan, Bordeaux. 53 varieties (21 white, 32 red) are planted with 5 replicates in a randomized block design. The parcel was planted in 2009 and data was collected from 2012 through 2022. Data collected in 2012 was discarded from this analysis, because the young vines suffered from excessive water deficits due to their shallow root system. Budbreak, flowering and veraison are scored (three observations each week) and vigour is estimated by measuring pruning weight. Berry sampling starts immediately after mid-veraison and lasts until full maturity with one sampling each week. Berry weight, grape sugar and total acidity are measured weekly on each replicate. Vine water status is assessed by measuring δ^{13}C on grape juice at full ripeness (Gaudillère *et al.,* 2002).

Database 2 (DB2) was collected in a dry-farmed commercial winery in Saint-Emilion (van Leeuwen et al., 2004). Three soil types were investigated: a gravel soil, a heavy clay soil and a sandy soil with a water table within access of the roots. Soil water holding capacity is low on the gravel soil, hence vines meet frequently moderate to severe water deficits. The clay soil has a medium water holding capacity and water deficit is moderate in most vintages. On the sandy soil, due to the water table, water deficit is weak or non-existent, even in dry years. On each soil, four rows of Merlot, and Cabernet franc were grafted on vines with an established root system. Data was collected from 2004 through 2016. Budbreak, flowering and veraison were scored (two observations each week) and vigor was estimated by measuring pruning weight. Leaf area was estimated and fruit weight measured at full ripeness. Grapes were sampled weekly, starting at mid-veraison until maturity. Berry weight, grape sugar and total acidity were measured on each sampling date. Vine water status was assessed by measuring $\delta^{13}C$ on grape juice at full ripeness (Gaudillère et al., 2002).

Statistical analyses

Grape ripening dynamics were calculated using the function y = αx + β, where y = S/AT ratio and x = thermal summation, according to Duteau (1990). The S/TA ratio was calculated from the data as the ratio of reducing sugar (g/L) divided by the total acidity as tartaric acid (g/L), then multiplied by 100 for each of the first four weekly berry sampling points after mid-veraison. The thermal summation for each of those data points is then the sum of average daily temperatures (°C) between July 1st (DOY 182) and the day before the corresponding sampling date. A base temperature of 0°C was chosen according to Parker *et al*., 2011. In this equation, α represents the ripening speed and was calculated from a linear regression of S/TA ratios and corresponding thermal summations for each year, variety, and/or soil combination being considered. The ratio -β/α effectively becomes a proxy for the timing of mid-veraison. The effect of the year and grapevine variety were investigated for DB1 and DB2 and also the effect of soil type for DB2 using two-way ANOVA. The effects of $\delta^{13}C$, berry weight, mid-veraison date, yield and leaf area/fruit weight ratio on α were also investigated by stepwise multiple linear regression for DB2.

Results

Grape ripening speed is driven by climate, soil and cultivar.

The effects of climate, soil and cultivar on grape ripening dynamics were significant based on two-way ANOVA analysis. Because S/TA ratio was plotted against temperature summation to obtain ripening speed (α) and not the day of the year (DOY), the year effect did not account for differences in temperature. For both data sets year had the greatest effect on ripening speed. For DB1, the year accounted for 41.2% of total variance in ripening speed, while the variety accounted for 25.5%, with the remainder being residuals. In DB2 the year accounted for 45% of total variance in ripening speed, the soil accounted for 14.5%, and the variety for 5.5%, with the remainder being residuals. These results are consistent with van Leeuwen *et al.,* 2004 who also found that climate (year effect) was predominant in terroir expression.

Based on the DB1 dataset, ripening speed (α) was calculated and compared in a box plot for the 10 years studied (Figure 1a). Differences between the years were substantial. In rainy vintages, like 2021, 2014, 2017 and 2013 average grape ripening across all varieties investigated was slow, while it was quick in dry vintages. In 2015, ripening speed was almost double compared to 2021. Substantial differences in ripening speed were also observed across the 52 varieties (Figure 1b). Because ripening speed is based both on sugar accumulation and decrease in total acidity, the classification is somewhat different from the classification presented in Suter *et al.* (2021) where only sugar accumulation was taken into account. Grenache, Merlot and Sauvignon blanc are considered as a quickly ripening varieties in both classifications. Semillon stands out as a quick ripening variety here but not in Suter *et al.* (2021). A rapid decreased in total acidity in Semillon berries can explain these differences. Colombard, Sangiovese and Mourvèdre are among the slowest ripening varieties (Figure 1b), not only because they slowly accumulate sugar in their berries (as expressed in concentration, Suter *et al.,* 2021), but also because their total acidity decreases relatively slowly during grape ripening.

Based on the DB2 dataset, ripening speed (α) was calculated and compared in a box plot for the 13 years studied (Figure 2a). Many statistically significant differences between years were observed. To obtain a deeper insight in the drivers of climate on ripening speed, a stepwise regression was then attempted on the DB2 dataset with the independent variables 50% veraison date (DOY), $\delta^{13}C$, berry weight, leaf area to fruit weight ratio and yield. In the best-fit model based on all variety and soil type data grouped together, berry weight explained 11.6% of the total variance in ripening speed, with greater berry weight associated with slower ripening. When the two varieties were considered separately, the effect of berry weight on ripening speed is more pronounced for Merlot (R^2 = 0.323) when compared to Cabernet franc (R^2 = 0.095; Figure 2b). Whether for all data together, or grouped by variety, none of the other variables considered in the stepwise regression explained a significant portion of the variance in ripening speed.

The use of grape ripening speed as a tool for harvest decisions

On a given vineyard block, the timing of full ripeness depends on the date of mid-veraison and the length of the ripening period. The date of mid-veraison can either be observed with great precision in field conditions, or estimated by means of the GFV model (Parker *et al.,* 2011). Here we present an operational model to calculate the ripening speed of primary metabolites as early as four weeks after mid-veraison. Input variables of the model are limited to mean daily temperatures, as well as grape sugar and grape total acidity sampled at weekly intervals. This data can easily be made available in a production setting. Hence, timing of harvest can be estimated several weeks in advance. Beyond S/TA ratio, grape harvest date also depends on phenolic ripeness, aromatic ripeness and sanitary status of the grapes. Such complementary information needs to be gathered in the last two or three weeks prior to harvest to fine-tune the exact date of harvest. Slow ripening varieties are better adapted to warm climates. The classification of a large set of varieties according to their grape ripening speed published herein can be used to select varieties in a context of climate change.

Conclusion

Great progress has been made in the understanding of the physiological mechanisms involved in grape ripening. The models published in the scientific literature and the associated sampling protocols are, however, too complex to be deployed in a production setting. With the data presented here, we validate a simple model to estimate grape ripening speed, based on the evolution of the S/TA ratio as a function of thermal summation during the first four weeks after mid-veraison. The robustness of the model was validated on two large data sets covering multiple years, varieties and soil types and provides a classification of 53 varieties based on ripening speed. This ripening speed was found to be highly dependent on year, soil type and variety and tends to be faster when berries are smaller. These results can be used by winemakers, viticulturists and consultants to fine-tune harvest decisions.

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Literature Cited

Bigard, A., Romieu, C., Sire, Y., Veyret, M., Ojeda, H., & Torregrosa, L. (2019). The kinetics of grape ripening revisited through berry density sorting. *OENO One*, *53*(4), 1-16

Bigard, A., Romieu, C., Sire, Y., & Torregrosa, L. (2020). *Vitis vinifera* L. diversity for cations and acidity is suitable for breeding fruits coping with climate warming. *Frontiers in Plant Science*, *11*, 01175.

Dai, Z. W., Vivin, P., Robert, T., Milin, S., Li, S. H., & Génard, M. (2009). Model-based analysis of sugar accumulation in response to source–sink ratio and water supply in grape (*Vitis vinifera*) berries. *Functional Plant Biology*, *36*(6), 527-540.

Destrac-Irvine A. and van Leeuwen C., 2017. *VitAdapt : an experimental program to study the behavior of a wide range of Vitis vinifera varieties in a context of climate change in the Bordeaux vineyards.* Climwine, sustainable grape and wine production in the context of climate change, 11-13 April 2016, Bordeaux. *Poster. Full text proceedings paper,* 165-171.

Duteau, J. (1990). Relations entre l'état de maturité des raisins (Merlot noir) et un indice climatique. Utilisation pour fixer la date des vendanges en année faiblement humide dans les crus de Bordelais. *Actualités Œnologiques 89*, 7-12.

Gaudillère, J. P., van Leeuwen, C., & Ollat, N. (2002). Carbon isotope composition of sugars in grapevine, an integrated indicator of vineyard water status. *Journal of experimental Botany*, *53*(369), 757-763.

Parker, A. K., de Cortázar-Atauri, I. G., Van Leeuwen, C., & Chuine, I. (2011). General phenological model to characterise the timing of flowering and veraison of Vitis vinifera L. *Australian Journal of Grape and Wine Research*, *17*(2), 206-216.

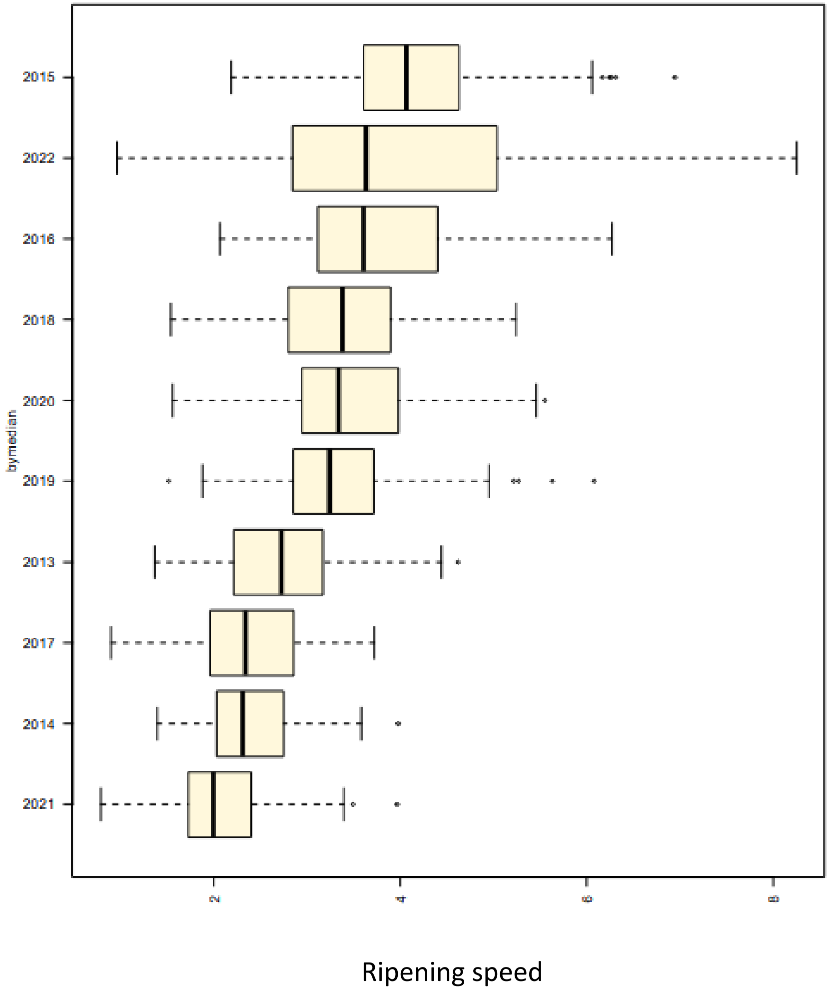
Shahood, R., Torregrosa, L., Savoi, S., & Romieu, C. (2020). First quantitative assessment of growth, sugar accumulation and malate breakdown in a single ripening berry. *OENO One*, *54*(4), 1077-1092.

Suter, B., Destrac Irvine, A., Gowdy, M., Dai, Z., & van Leeuwen, C. (2021). Adapting wine grape ripening to global change requires a multi-trait approach. *Frontiers in plant science*, *12*, 624867.

van Leeuwen, C., Friant, P., Chone, X., Tregoat, O., Koundouras, S., & Dubourdieu, D. (2004). Influence of climate, soil, and cultivar on terroir. *American Journal of Enology and Viticulture*, *55*(3), 207-217.

Tables and Figures

(a)



(b)

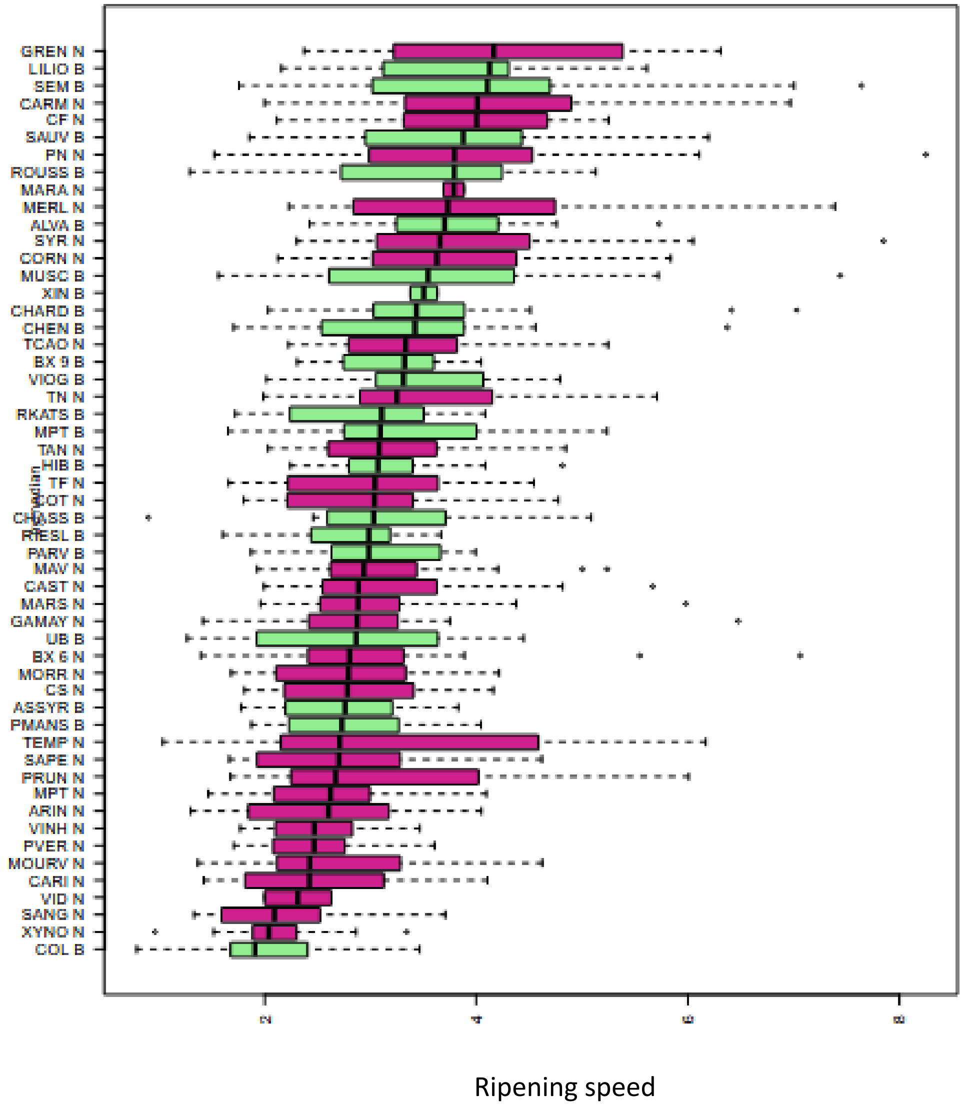
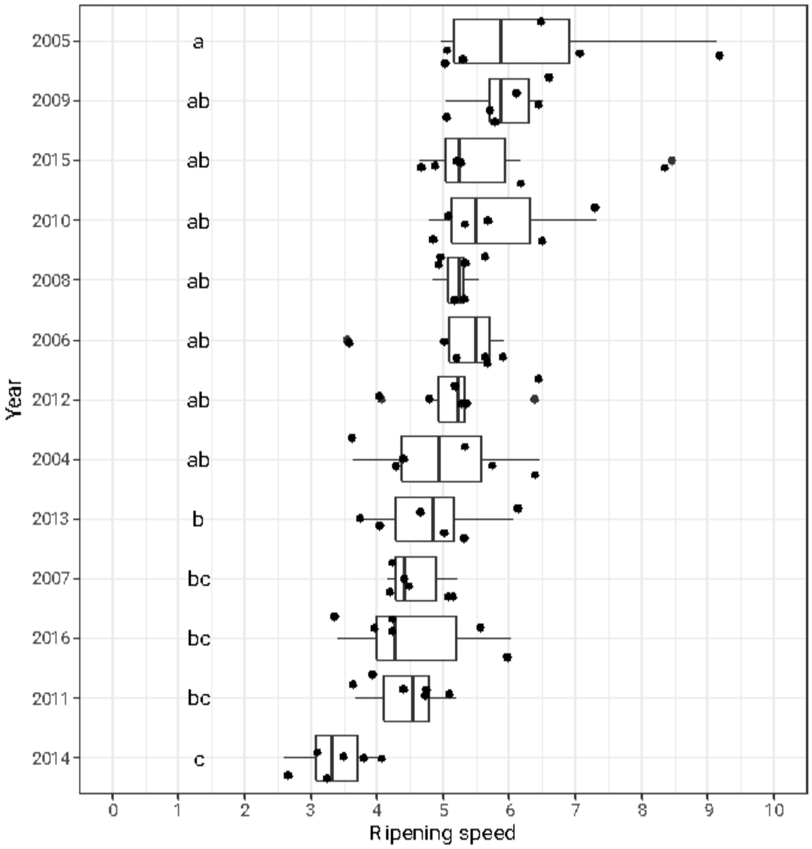


Figure 1 - Box plots of ripening speed by year (a), and grapevine variety (b). Data from DB1 spanning over 10 years and 53 varieties.

(a)


Year
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Ripening speed

(b)

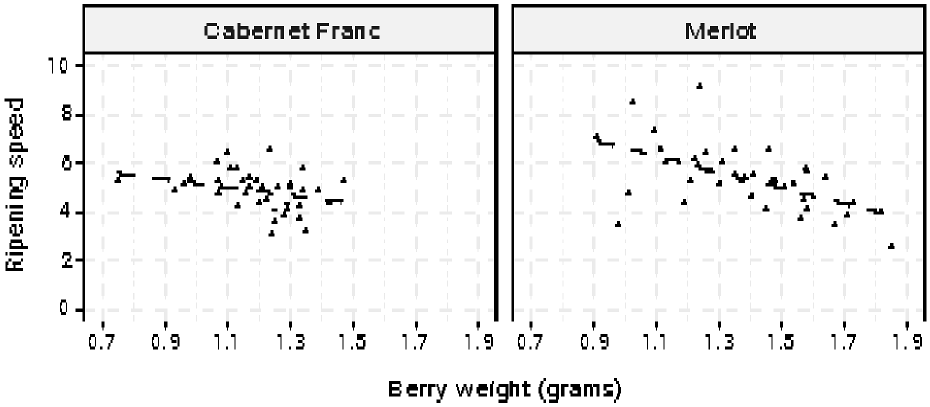

Figure 2 - Box plot of ripening speed by year with averages and Tukey significance classifications (a) and (b) plot of berry ripening speed as a function of berry weight for Cabernet franc ($R^2 = 0.095$) and Merlot ($R^2 = 0.323$). Data from DB2, Saint-Emilion, covering 13 vintages in three different soil types.