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Ripening curves estimated for 'Cabernet Sauvignon' grape in the northwest region of the state of São Paulo, Brazil

Abstract – The objective of this work was to determine and evaluate the performance of regression models, to estimate the ripening curves of 'Cabernet Sauvignon' grape for the winter harvest in the northwestern region of the state of São Paulo, Brazil. 'Cabernet Sauvignon' plants were grafted onto the 'IAC 766 Campinas' rootstock. The ripening curves were fitted to linear, quadratic, power, logarithmic, and exponential regression models using 2017 data, while the performance of the models was evaluated using 2018 data. As a function of accumulated degree days, the quadratic model for soluble solid content allows to determine the ripening curve of 'Cabernet Sauvignon' grape in the studied region.

Index terms: *Vitis vinifera*, ripeness index, winter wines.

Estimativa das curvas de maturação de uvas 'Cabernet Sauvignon' na região noroeste do estado de São Paulo, Brasil

Resumo – O objetivo deste trabalho foi determinar e avaliar o desempenho de modelos de regressão, para estimar curvas de maturação de uvas 'Cabernet Sauvignon' para a colheita de inverno na região noroeste do estado de São Paulo, Brasil. As plantas de 'Cabernet Sauvignon' foram enxertadas sobre o porta-enxerto 'IAC 766 Campinas'. As curvas de maturação foram ajustadas a modelos de regressão linear, quadrática, potencial, logarítmica e exponencial, tendo-se utilizado dados de 2017, enquanto o desempenho dos modelos foi avaliado com dados de 2018. Em função dos graus-dia acumulados, o modelo quadrático do conteúdo de sólidos solúveis permite determinar a curva de maturação de uvas 'Cabernet Sauvignon' na região estudada.

Termos para indexação: *Vitis vinifera*, índice de maturação, vinhos de inverno.

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The northwest of São Paulo state has been an important region for table grape (*Vitis vinifera* L.) production since the 1980s. In this region, the double pruning system is adopted. Pruning to form branches is normally carried out between October and November, and production pruning takes place in the beginning of the year, which allows of harvesting to occur during winter, a period of mild temperatures and low rainfall (Conceição, 2020). This system was later adopted in other tropical regions of the country, to produce wine grapes for the winter harvest (Tonietto et al., 2020). As these wines have shown high oenological quality, some table grape growers in the northwest São Paulo have also been interested to produce wine grapes for the winter harvest.

In this region, 'Cabernet Sauvignon' (*V. vinifera*) has been one of the most important varieties used, due to its adaptability to different climate conditions (Würz et al., 2019; Leão et al., 2021).

The use of models to predict grape ripeness evolution can help to determine the most appropriate time for fruit ripening and harvesting, making it possible the efficient planning of different cultural practices (Clemente et al., 2022; van Leeuwen et al., 2023). Furthermore, these models can also help with the prediction of the grapevine behavior as a result of global climate change (Parker et al., 2020).

Regression models have been used to describe the maturation evolution of 'Cabernet Sauvignon' (CS) grape in different growing regions of Brazil.

Exponential models correlated the soluble solid content (SS) and the total titratable acidity (TA) with the accumulated degree days (DD) values, after flowering, in the municipality of São Roque, in the state of São Paulo, Brazil (Pedro Júnior et al., 2014).

Quadratic and potential models described the evolution of SS and TA for the CS cultivar on fifteen different rootstocks, in the Serra Gaúcha region, RS, Brazil (Miele & Rizzon, 2019). However, there are no adjusted models for the cultivar under the conditions of northwestern São Paulo state.

The objective of this work was to determine and evaluate the performance of regression models, to estimate the ripening curves of 'Cabernet Sauvignon' grapes for winter harvesting, in the northwest region of São Paulo state, Brazil.

The study was carried out in a two-year-old commercial vineyard of 'Cabernet Sauvignon' grafted onto 'IAC 766 Campinas' rootstock, in the municipality of Jales (20º10'S, 50º36'W, at 436 m altitude), in the state of São Paulo, Brazil.

The vines were grown in a Y-shaped system, spaced at 2.2 m between rows 1.0 m between vines, and covered with black polyethylene screen with 18% shading, aiming to protect the plants against the attack by birds and bats. The soil in the experimental area is classified as an Argissolo Vermelho-Amarelo (Ultisol) (Santos et al., 2013).

According to the Köppen-Geiger's classification, the climate of the region is Aw, humid tropical with dry winters (Alvares et al., 2013). The meteorological data were obtained from the tropical viticulture experimental station of Embrapa Uva e Vinho, located in the municipality of Jales, in the state of São Paulo. Irrigation was performed using micro sprinklers, and the control of fungal diseases was carried out preventively based on a fixed spraying schedule (practiced by the winegrower) which consists of three weekly applications of fungicides. For organic fertilization, cattle manure was used, and chemical fertilization was carried out based on the results of soil analysis.

Assessments for fruit ripening evolution were carried out weekly, during the crop production cycle, considering four pruning seasons for production, as follows: on April 13 and 21, 2017, used to fit the models; and on March 19 and 26, 2018, used to validate the regression models. On each evaluation date, six berries were collected from ten bunches (total of 60 berries per sampling), in a completely randomized design, with two berries being sampled from the bottom part of each bunch, two from the central part and two from the top part. In 2017, the producer harvested the grapes on the same date (09/15) in the two seasons, while in 2018, the harvest dates were 08/24 (pruning 1) and 08/30 (pruning 2).

The ripening curves were obtained by evaluating the SS with a portable reflectometer; the pH, with a table pH meter; and TA, by titration using phenolphthalein as an indicator. The ripening ratio (RR) represents the ratio between SS and TA (expressed in %). The DD between pruning and harvesting were calculated by the daily sum between the difference of the average air temperature (Tmed) and the base temperature of the crop that is considered to be equal to 10°C (Ortega-Farias & Riveros-Burgos, 2019). The curves correlating the independent variable DD and the dependent variables SS, pH, TA, and RR were performed using linear ($Y = a + bx$), quadratic ($Y = a + bx + cx^2$), power ($Y = ax^b$), logarithmic ($Y = aLn(x) + b$), and exponential ($Y = ae^{bx}$) regression models.

The comparison between measured and estimated values was carried out using the coefficients of determination (R^2), the standard errors of the linear regression models (SE), and the performance index (c) – proposed by Camargo & Sentelhas (1997) – and corresponds to the multiplication of the correlation coefficient (r) by the Willmott's agreement index (d). The performance was classified as excellent, for "c" greater than 0.85; as very good, for values between 0.76 and 0.85; as good, for values between 0.66 and 0.75; as regular, for values between 0.51 and 0.65; as bad, for values between 0.41 and 0.50; and as poor for values below 0.40. All the regression models were subjected to the F test, at 1% probability, to assess their significance.

The mean values in the present study were 20.1 °Brix (SS), 3.2 (pH), 106 meq L^{-1} (TA), and 25.7 (RR), in 151 days average cycle, and 1,887°C average DD value, between pruning and harvest.

In the Submédio São Francisco Valley, in the state of Pernambuco, Brazil, 'Cabernet Sauvignon' showed a shorter cycle (between 117 and 120 days), a lower solid soluble content (18.8 ºBrix), and the same value for total titratable acidity (106 meq L^{-1}) (Leão et al., 2021).

In Jundiaí, in the state of São Paulo, 'Cabernet Sauvignon' showed a lower sugar accumulation and higher acidity than those determined in Jales, SP (Tecchio et al., 2022).

In Lages, in the state of Santa Catarina, Brazil, Würz et al. (2019) obtained SS and pH values close to those obtained in the northwest of São Paulo.

In São Joaquim, also in the state of Santa Catarina, Marcon Filho et al. (2019) observed higher levels of acidity than those found in the Jales, in São Paulo.

The best fit was attained for the highest coefficient of determination (R^2) by the quadratic SS model, while the lowest one was displayed by the power TA model. All regressions were significant at 1% probability (Figure 1). Miele & Rizzon (2019) also adjusted quadratic models to describe SS and pH evolution, and a power model for TA evolution for 'Cabernet Sauvignon' grapes in the conditions of Serra Gaúcha, in the state of Rio Grande do Sul, Brazil.

The best performance indices (c) were achieved for the SS and the pH models, classified as excellent (Table 1). The estimation models for TA and RR showed performances classified as regular and very

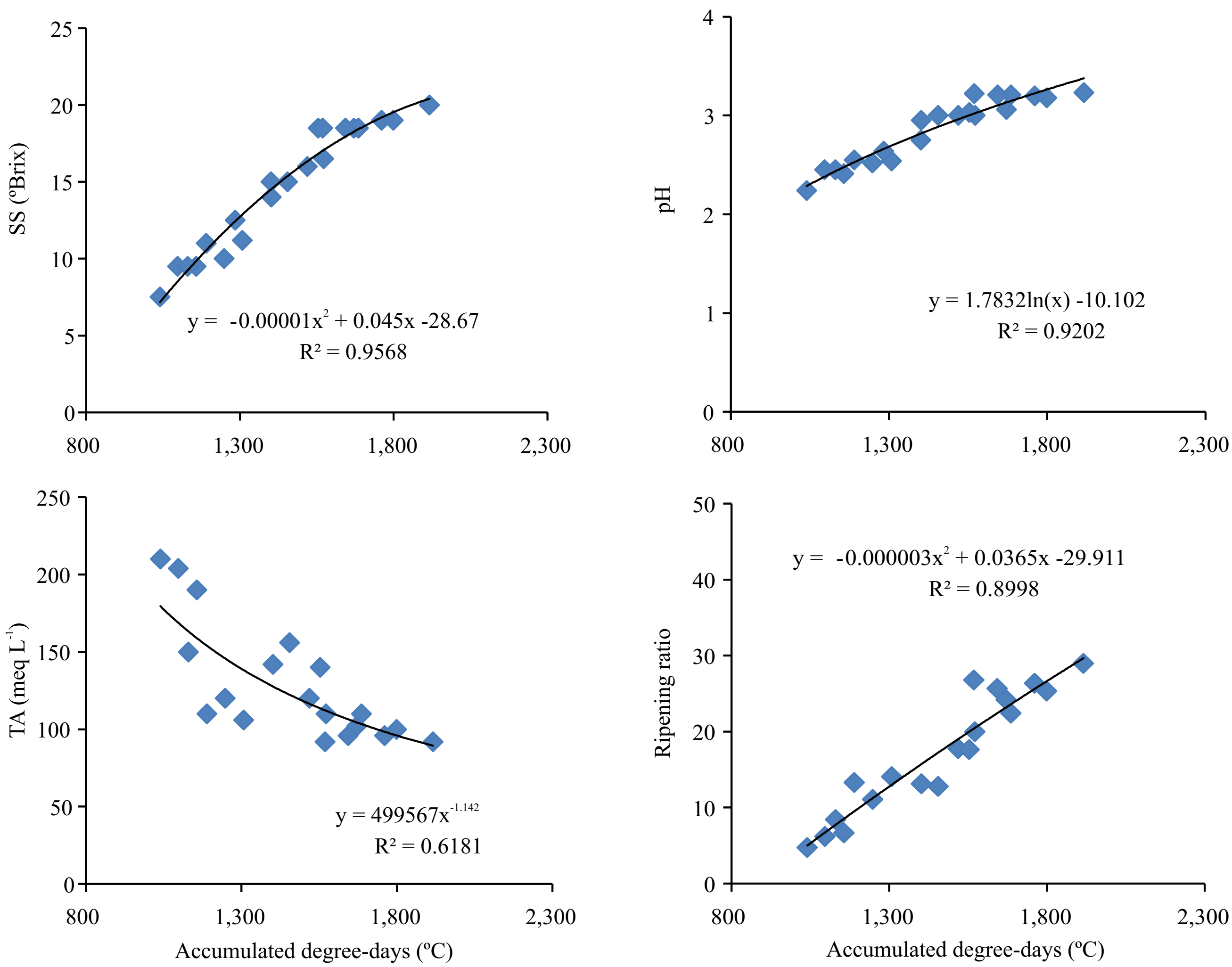

Figure 1. Fitted models for soluble solids content (SS), pH, total titratable acidity (TA), and ripening ratio (RR), as functions of accumulated degree-days (DD) for 'Cabernet Sauvignon' grapes (*Vitis vinifera*). Jales, SP, Brazil. 2017.

Table 1. Values of the regression standard error (SE), agreement index (d), correlation coefficient (r), performance index (c), and performance classification of the model for estimating the variables soluble solids content (SS), pH, total titratable acidity (TA), and ripening ratio (RR) of 'Cabernet Sauvignon' grapes (*Vitis vinifera*). Jales, SP, Brazil.

Variable	SE	d	r	c	Classification
SS (°Brix)	1.08	0.968	0.962	0.931	Excellent
pH	0.14	0.937	0.932	0.873	Excellent
TA (meq L^{-1})	9.30	0.592	0.930	0.551	Regular
RR	2.13	0.833	0.919	0.766	Very Good

good, respectively. However, these models cannot be employed if different training system or rootstock will be used, since these factors may alter the fruit quality and, consequently, their ripening curves (Würz et al., 2019; Tecchio et al., 2022). The use of plastic covering over the vineyard can also affect the ripening curves of the grapes, due to solar radiation reduction over the canopy (Schwerz et al., 2023).

The soluble solid content quadratic model, as a function of accumulated degree days, allows to determine the ripening curve of 'Cabernet Sauvignon' grapes in the northwest region of São Paulo state, Brazil.

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