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Article

Rootstock and potassium fertilization, in terms of phenology, thermal demand and chemical evolution, of berries on Niagara Rosada grapevine under subtropical conditions

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ABSTRACT: This study aimed to assess the effect of rootstocks (IAC 572 and IAC 766) and potassium fertilization at different concentrations (0, 75, 150 and 300 kg·ha^{-1} K_2O) on the phenology and thermal demand of the Niagara Rosada grapevine, and to evaluate the development of chemical traits during maturation stage. The length of the main phenological stages was recorded within two production seasons. Total thermal demand was calculated using the degree-day concept. The berries' titratable acidity and soluble solids contents were determined during maturation. Results indicated that IAC 572 and IAC 766 rootstocks along with potassium fertilization had no influence on the phenological cycle or thermal demand of the Niagara Rosada grapevine. The production cycle lasted 144 to 148 days with thermal demands ranging from 1,465.2 to 1,615.1 degree-days. For better grape quality, i.e., with a balance between soluble solids and acidity levels, it is estimated that the grape harvest is carried out around 21 to 24 days after the veraison.

Key words: table grapes, grafting, chemical characteristics, degrees-day, potassium fertilization.

INTRODUCTION

Niagara Rosada is one of the most grown table grapes in Brazil. This cultivar is widely accepted among producers and consumers due to its agronomic traits, that is, great yield, foxy-flavoured grapes, wide climate adaptation and low production cost (Tecchio et al. 2018). The production cycle of this cultivar takes about 109 and 123 days during summer season, according to previous studies under tropical conditions (Ribeiro et al. 2009; Tecchio et al. 2011; Tofanelli et al. 2011). On the other hand, the thermal demands ranges from 1,420 to 1,671 degree-days, which is 120 to 160 days under subtropical conditions (Hernandes et al. 2010; Anzanello et al. 2012; Tecchio et al. 2013; Bruna and Back 2015). However, some variables such as rootstocks and climate patterns can influence the length of phenological cycles and thermal demand (Sato et al. 2008; Tecchio et al. 2019).

Several studies have assessed the influence of rootstocks on the phenology and thermal demand of the cv. Niagara Rosada (Tecchio et al. 2011; Anzanello et al. 2012; Tecchio et al. 2013; Bruna and Back 2015). These studies indicated a highly unique outcome with regards to the interaction and affinity between rootstocks and scion, in addition to climate adaptations (Silva et al. 2018; Tecchio et al. 2020). Moreover, specific analyses based on the growing area are required to select the appropriate rootstock.

Potassium fertilization is a critical component for grapevines. Potassium (K) is the cation with the highest concentration in grape berries (Rogiers et al. 2006) and, therefore, can influence vine development and grape quality because it plays numerous roles in the physiological processes in plants, including protein and starch synthesis, osmotic control, anion neutralization, enzymatic activation, and assimilate translocation (Wang and Wu 2013; Ahmad and Maathuis 2014; Shabala and Pottosin 2014). Nonetheless, the effectiveness of K fertilization is influenced by several factors, including soil quality, fertilizer formulations and concentrations, treatment interval, climate conditions, scion, and rootstock genotypes (Mpelasoka et al. 2003).

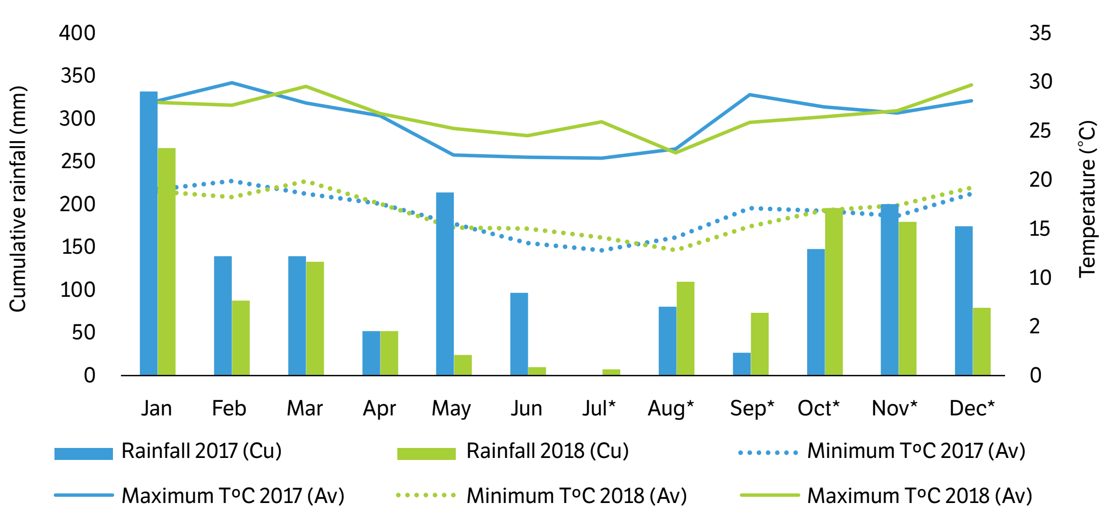
K fertilization has a direct impact on grapevine outcome, according to Tecchio et al. (2006) and Pushpavathi et al. (2021). Some other studies have already demonstrated that K is intrinsically linked to chemical traits of grape must (Fogaça et al. 2007; Walker and Blackmore 2012). So far, no research has assessed the effects of K fertilization on phenological cycle and thermal demands of grapevines.

It is worth mentioning that the characterization of phenological stages and the measurement of thermal demands are used to identify the climatic potential of a specific region for grapevine production. Furthermore, grape growers will be able to plan harvest dates, agricultural methods, and phytosanitary control, as well as periods when there is a high demand for labour work, if they know the length of each phenological subperiod. Therefore, it is crucial to understand how chemical components in berries change as they ripen, but it is also effective to establish the best time to harvest them, that is, when there is a balance between soluble solids and acidity levels. In viticulture, phenology, temperature demands, and grape maturation development are all essential.

This study aimed to assess the effects of rootstocks and K concentrations on grapevine phenology and thermal demand, as well as to analyse the quality attributes of the Niagara Rosada grapes produced under subtropical conditions.

MATERIAL AND METHODS

The study took place in an experimental vineyard in the city of Botucatu, Sao Paulo, Brazil (at the following GPS coordinates 22°50'S, 48°26'W and at an altitude of 790 m above sea level) across two production seasons (2017 and 2018). According to Köppen's classification, the climate is *Cfa* (subtropical with hot summers). From July to December, the experiment's minimum average temperature was 15.9 °C in 2017 and 15.8 °C in 2018. Also, the maximum average temperatures were 26.1 and 26.3 °C in 2017 and 2018, respectively. The annual precipitation was 729 mm in 2017, while 648 mm in 2018, being the summer the responsible for most of the precipitation (Fig. 1).



*Productive period. The bars represent the total amount of rain, while the lines represent the minimum and highest temperatures; Av: average; Cu: cumulative.
Figure 1. Climate data (temperature and cumulative rainfall) from the experimental site in 2017 and 2018. Botucatu, state of São Paulo, Brazil.

In the area, the soil is classified as red latosol (Embrapa 2018), and the soil chemical analysis was performed prior to the beginning of the experiment (Table 1).

Table 1. Results of soil analysis performed prior to treatments applications.

Soil depth (cm)	OM ($g \cdot kg^{-1}$)	pH	P* ($Mg \cdot dm^{-3}$)	K* ($mmol_c \cdot dm^{-3}$)	Ca* ($mmol_c \cdot dm^{-3}$)	Mg* ($mmol_c \cdot dm^{-3}$)	H+Al ($mmol_c \cdot dm^{-3}$)	V (%)
0-20	20.1 (2.9)	5.5 (0.1)	67.6 (14.2)	4.2 (0.5)	37.6 (3.5)	13.6 (0.1)	21.6 (3.3)	71.8 (5.2)
20-40	12.3 (1.5)	5.6 (0.1)	25.3 (7.7)	2.5 (0.4)	31.0 (3.0)	13.8 (0.6)	20.5 (3.4)	70.1 (4.4)

OM: organic matter; *extracted using ion exchange resin; V: base saturation. Values in parentheses: standard deviation (n = 4).

In September 2013, grapevine nurseries grafted on rootstocks were planted at a spacing of 2 m between rows and 0.8 m between vines (density of 6,250 vines per hectare). The support system consisted of a three-wire espalier suspended at 1, 1.3, and 1.6 m above ground. For irrigation, inverted micro-sprinklers were placed every 2.5 m and 50 cm above the ground. A polyethylene screen with 18% shading was installed to keep birds at bay. Other agricultural and phytosanitary managements were done in accordance with regional agricultural practices.

Winter pruning and harvesting occurred in the months of July and December, respectively, in 2017 and 2018. One or two buds per spur were retained during winter pruning, and 2.5% hydrogen cyanamide was sprayed to stimulate consistent budburst. To standardize the grapevines, 10 to 12 bearing canes per vine were chosen once sprouting began.

A 4 × 2-factorial scheme (eight treatments) with four blocks and five vines per plot was used to place 160 plants in randomized blocks, that is, four K concentrations (0, 75, 150, and 300 $kg \cdot ha^{-1}$ K_2O) and two rootstocks (IAC 572 Jales and IAC 766 Campinas) were used as variables.

In this study, the chosen scion was cv. Niagara Rosada, a mutant of cv. Niagara Branca that is the product of a cross between the cvs. Concord × Cassady, with 75% *Vitis labrusca* and 25% *Vitis vinifera* in their genealogy. Moreover, the rootstocks were obtained by the Agronomic Institute of Campinas (IAC) and were derived from the following crosses: IAC 572 Jales (*Vitis caribaea* × [*Vitis riparia* × *Vitis rupestris* 101-14]) and IAC 766 Campinas (Riparia do Traviú × *Vitis caribaea*).

With regards to K concentrations, the grape fertilization guideline of the studied area was considered (Terra et al. 1997), that is, no fertilization (0 $kg \cdot ha^{-1}$ K_2O), half of the recommended dose (75 $kg \cdot ha^{-1}$ K_2O), recommended dose (150 $kg \cdot ha^{-1}$ K_2O), and double the recommended dose (300 $kg \cdot ha^{-1}$ K_2O).

In accordance to the plot size (8 m^2), fertiliser treatments were weighted and applied along 40-cm line in a top-dressing pattern next to the grapevines. In all the production seasons (2017 and 2018), fertilization was divided into two application times within each production season, i.e., half of the dose was delivered one week after production pruning and the remaining amount administered at veraison.

The phenological stages were assessed through the Coombe's recommended criteria (1995). The length of each phenological stage was calculated in days after pruning (DAP) by using visual observations. All the subperiods between pruning and budburst, full bloom, setting, veraison, and harvest were measured. The grape harvest was determined via maturity curve, that is, when soluble solids and titratable acidity levels stabilized between two samples.

To determine the thermal demand in degree-days (DD), the sum of pruning to harvest was computed using the following Winkler's equation (1965) (Eq. 1):

$$DD = \Sigma \text{ (mean temperature - 10 °C)} \times \text{days after pruning} \quad (1)$$

The grape maturation curves were calculated through the development of the titratable acidity (TA) and soluble solids (SS). TA was obtained by titration with 0.1 N NaOH to the equivalence point of pH of 8.2, which was expressed as a percentage of tartaric acid. The SS was determined using a digital refractometer and direct refractometry of grape must (Model: r2i300, Reichert®, United States of America), and the findings were reported in °Brix.

Ten bunches per experimental plot were randomly selected and marked at veraison to be monitored from the time of marking until the grapes were fully ripe. The berries were harvested every six days in the 2017 season, at 0, 6, 12, 18, and 24 days after veraison (coinciding with 124, 130, 136, 142 and 148 DAP). In the 2018 season, berry harvests were carried out every seven days, on days 0, 7, 14, 21, and 28 after veraison (coinciding with 116, 123, 130, 137 and 144 DAP).

Statistical analyses were carried out in the two production seasons of 2017 and 2018. All data was submitted to analysis of variance (two-way ANOVA) to investigate the influence of rootstocks and K concentration along with their interactions. The Tukey's test compared the means of rootstocks at 5% of probability. A regression analysis was performed to quantify the effects of K concentrations by using the SISVAR® statistical program, version 5.6 (Lavras, MG, Brazil).

RESULTS AND DISCUSSION

There was no significant interaction ($p > 0.05$) in all assessed variables between rootstocks and K concentrations. Subsequently, the variables were examined independently.

In the first production season, the rootstocks had no effect ($p > 0.05$) on any phenological stages. In the second cycle, the rootstocks had an influence ($p > 0.05$) on the setting and veraison, since IAC 766 provided two and three days of precocity, respectively (Table 2).

Table 2. Phenological stages (DAP) and thermal demands (DD) of Niagara Rosada grapevine grafted on IAC 572 Jales and IAC 766 Campinas rootstocks in two production seasons*.

DAP and DD	Seasons	Rootstocks		
		IAC 572 Jales	IAC 766 Campinas	*p*-value
Budburst	I	21.5 ± 0.66	21.4 ± 0.51	0.34
	II	27.5 ± 1.43	28.0 ± 1.49	0.28
Full-bloom	I	50.3 ± 0.43	50.3 ± 0.53	0.93
	II	59.2 ± 3.30	58.1 ± 1.54	0.18
Setting	I	55.3 ± 0.67	55.4 ± 0.64	0.46
	II	66.5 ± 2.95 a	64.2 ± 1.80 b	< 0.01
Veraison	I	125.9 ± 1.93	124.9 ± 2.52	0.18
	II	119.2 ± 2.69 a	116.1 ± 3.24 b	< 0.01
Harvest date (DAP)	I	148.8 ± 2.12	147.2 ± 4.37	0.18
	II	144.5 ± 2.00	144.0 ± 5.01	0.73
Full cycle requirement	I	1,622.3 ± 29.63	1,608.0 ± 37.93	0.25
	II	1,458.3 ± 31.36	1,472.1 ± 34.00	0.24

*Mean ± standard deviation (n = 16) is used to express the data. On the same line, values preceded by various letters differ substantially (Tukey's test, $p > 0.05$).

The whole phenological cycle of the cv. Niagara Rosada lasted on average 148 days among rootstocks in the first production cycle and 144.2 days in the second one. Other studies have showed that the length was shorter in cv. Niagara Rosada under tropical conditions, such as 115.8 days under an Aw climate (high temperatures) (Ribeiro et al. 2009); and from 109 to 113 days under Aw climate (Tofanelli et al. 2011).

Although there were no significant differences between rootstocks in this study, previous studies have reported that the IAC 572 and IAC 766 showed different effects on the length of the phenological cycle of cv. Niagara Rosada. Alvarenga et al. (2002), Tecchio et al. (2011), and Tecchio et al. (2013) found that the IAC 766 induced higher precocity in the Niagara Rosada grapevine when compared to the IAC 572.

Through a literature search, it was found an influence of IAC 766 and IAC 572 on the phenology of several types of grapevines, but the findings differed from each other. Nonetheless, Borges et al. (2014) reported that IAC 572 promotes an extension of the phenological cycle of cv. Concord. Sato et al. (2008) observed that IAC 572 increased six days of precocity in cv. Isabel when compared to IAC 766 under subtropical conditions. Besides that, any rootstock affected the entire period of the Rubea phenological cycle in this respective study. The discrepancies between these outcomes are most likely due to factors such as interaction affinity between rootstock and scion, as well as their adaptation to edaphoclimatic conditions, genetic and agronomic characteristics, such as vigour and capacity for solute and nutrient absorption and translocation.

There was no significant effect of rootstocks on thermal demands in this study, but some authors claim that rootstocks can affect grapevines' thermal demands (Miele 2019; Tecchio et al. 2019). Thus, grapevines required an average of 1,615.1 DD and 1,465.2 DD to complete the first and second production cycles, respectively (Table 2).

The differences in climate conditions also affect the accumulation in degree-days of grapevines between areas (Pedro Júnior et al. 1993) and seasons (Ahmed et al. 2019), as shown in this current study. The DD concept is, therefore, predicated on the difference between mean and baseline temperature (10°C), with no development taking place below it (Miranda et al. 2013; Tecchio et al. 2013). It is worth mentioning that this concept is beneficial for forecasting plant development in various environments, and it is also a valuable indicator for analysing grapevine behaviour in a specific growing area.

With regards to K fertilization, a significant effect was only observed at veraison in the second production season, when a quadratic polynomial model was adjusted (Table 3).

Table 3. Phenological stages (DAP) and thermal demands (DD) of Niagara Rosada grapevine subjected to potassium fertilization with different concentrations of K in two production seasons#.

DAP and DD	Seasons	Doses of K (kg·ha^{-1} K_2O)				
		0	75	150	300	*p*-value
Budburst	I	21.7 ± 0.56	21.4 ± 0.55	21.5 ± 0.49	21.2 ± 0.70	0.81
	II	28.2 ± 1.46	26.9 ± 0.54	28.0 ± 1.20	27.9 ± 2.11	0.38
Full-bloom	I	50.5 ± 0.45	50.1 ± 0.56	50.4 ± 0.48	50.1 ± 0.35	0.96
	II	58.1 ± 3.81	58.2 ± 1.68	59.4 ± 2.72	59.1 ± 1.89	0.57
Setting	I	55.7 ± 0.84	55.2 ± 0.37	55.6 ± 0.80	55.0 ± 0.14	0.96
	II	65.3 ± 2.74	64.9 ± 1.59	66.1 ± 3.69	65.2 ± 2.55	0.54
Veraison	I	125.8 ± 2.81	125.3 ± 1.55	125.3 ± 3.20	125.2 ± 1.44	0.76
	II	118.7 ± 3.20*	115.1 ± 2.64	117.5 ± 3.32	119.3 ± 3.02	< 0.05
Harvest	I	148.7 ± 3.03	148.3 ± 1.52	149.0 ± 2.82	146.2 ± 5.36	0.37
	II	146.0 ± 1.85	144.3 ± 2.23	144.5 ± 2.07	142.3 ± 6.47	0.05
Full cycle requirement	I	1,619.0 ± 42.88	1,614.9 ± 22.93	1,623.5 ± 42.70	1,602.9 ± 27.11	0.50
	II	1,481.8 ± 29.03	1,457.0 ± 33.66	1,458.3 ± 32.46	1,463.6 ± 36.38	0.18

#Values are expressed as mean ± standard deviation (n = 8); *y = 0,0001x2 - 0,0282x + 118,13 (R^2 = 0,61).

The K doses had no effect on the other phenological stages and thermal demands of the grapevines, and the average lengths of the phenological periods from pruning to budburst, full bloom, setting, veraison, and harvest were 21.4, 50.2, 55.3, 125.4, and 148 days for the first production season and 27.7, 58.7, 65.3, 117.4, and 144.2 days for the second production cycle, respectively.

According to Mpelasoka et al. (2003), both biotic and abiotic factors influence K fertilization, including rootstock and scion genotypes, as well as microclimatic conditions and soil features. This study's non-significant effect of K concentrations is most likely related to soil conditions, as the amount of available K in the soil was higher at the beginning of the experiment, that is, 4.2 $mmol_c·dm^{-3}$ at the depth of 0-20 cm; and it was the average with 2.5 $mmol_c·dm^{-3}$ at the depth of 20-40 cm, according to Raij's criteria (1997) (Table 1). Currently, soils are performing huge quantities of K, exceeding 1.6 mmolc·dm^{-3}. This is due to overfertilization, which is widespread in the grapevine-growing areas of the state of São Paulo (Tecchio et al. 2006). Therefore, fertilizer is only necessary to keep the amount of K available in the soil constant with a suggested concentration of 150 kg·ha^{-1} K_2O (Terra et al. 1997). Moreover, excess K fertilization can cause an imbalance in calcium and magnesium levels, in addition to having no positive effects on the grapevines and raising the cost of production (Tecchio et al. 2006; Dalbó et al. 2015; Pushpavathi et al. 2021).

There was no significant interaction between the chemical variables studied during maturation ($p > 0.05$). Consequently, the treatments means were calculated as a function of the number of days since veraison. During maturation, changes in soluble solids content and titratable acidity followed the expected pattern, with an increase in soluble solids content and a decrease in titratable acidity, and quadratic regression models for both crops were adjusted accordingly (Fig. 2).

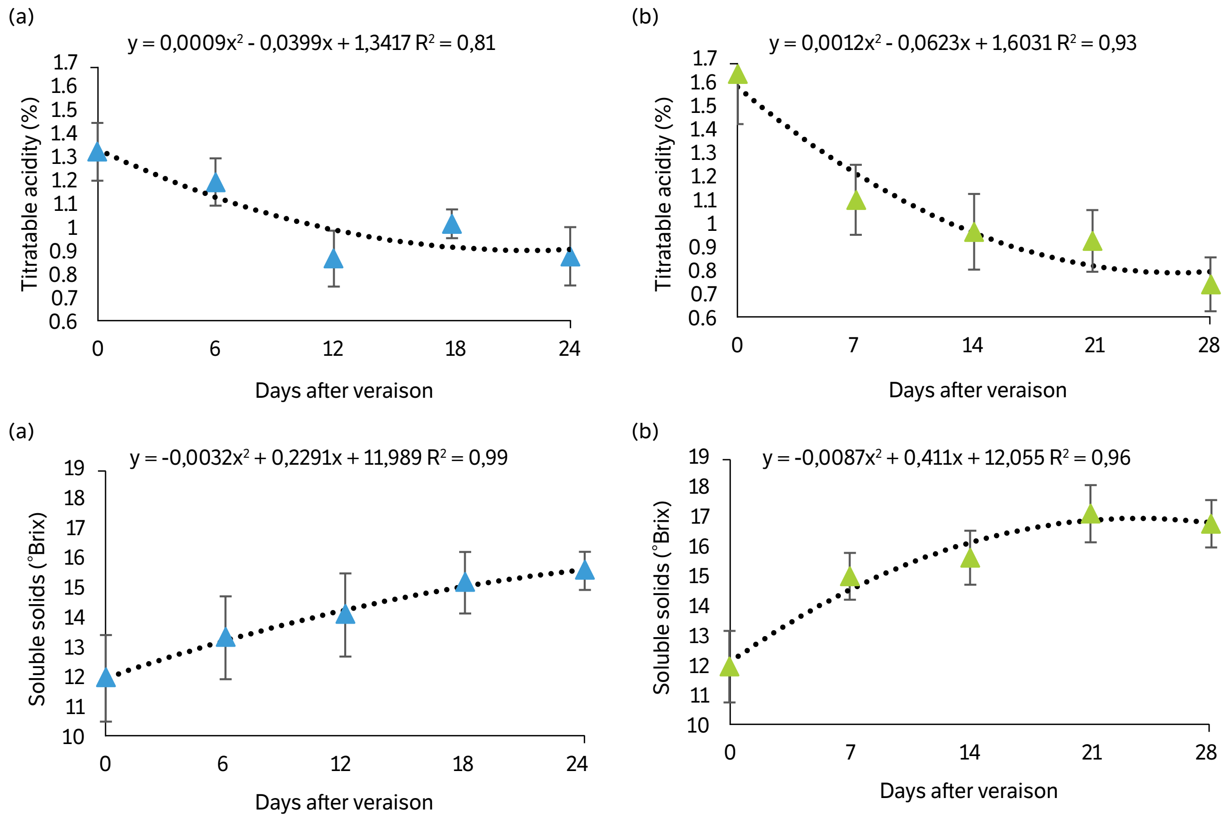


Figure 2. Development of titratable acidity and soluble solids content during the ripening of Niagara Rosada grape grown in subtropical conditions in (a) 2017 and (b) 2018 production seasons.

In the first production season, TA dropped from 1.33% at veraison to 0.88% during harvest (24 days after veraison), which was the lowest point of the quadratic regression model (Fig. 2a). The minimum point of the equation was obtained 28 days after veraison in the second cycle, when berries presented 0.74% (Fig. 2b), which is comparable to other table grape cultivars produced under subtropical regions of Brazil, such as BRS Vitória (Maia et al. 2016), BRS Ísis (Ahmed et al. 2019), and BRS Melodia (Koyama et al. 2020).

The TA of cv. Niagara Rosada is about 60 meq/L, according to Maia and Camargo (2012). However, it was clear that the different climate conditions that occurred throughout each harvest, as shown in Fig. 1, had a major effect on the chemical properties of the grapes (Fig. 2). The reduction in TA during ripening is caused by multiple physiological processes, including dilution of organic acids, increased berry size, synthesis suppression and transformation of organic acids into sugar. Furthermore, temperature, insolation, and rainfall have a huge effect on grape metabolism, which may promote or hinder the genetic potential of the grapes (Ribeiro et al. 2012).

In terms of soluble solids content, it was found that the highest value was reached 24 days after veraison (15.6 °Brix) in the first production cycle. The maximum value of soluble solids was validated 21 days after veraison in the second production cycle, with 17.0 °Brix (Fig. 2). According to Maia and Camargo (2012), the Niagara Rosada grape may achieve up to 16.3 °Brix under lower temperature, such as temperate and subtropical conditions. One of the primary features of the maturation development is the accumulation of sugars, which are glucose and fructose in grapes. This is the most significant commercial factor for growers when identifying the appropriate time to harvest. The second production cycle had greater amounts of soluble solids, presumably due to the higher temperature and reduced rainfall in November and

December (Fig. 1), which coincided with the end of the ripening season. Heat waves directly boost sugar imports for grape berries (Mori et al. 2007; Parker et al. 2011). Orduña (2010) also stated that sugar contents are greater in fruits under high temperatures. Furthermore, studies showed that high precipitation leads to reduced SS deposition in berries (Ribeiro et al. 2012), as happened in this study. This occurs when sugars are diluted in berries because of the increased water absorption.

It is worth mentioning that the SS content dropped around 25 days after veraison in the second production cycle (Fig. 2b), and some berries showed signs of wilting and deterioration. Therefore, it may be advised that grapes be harvested within 25 days after veraison. Nonetheless, this may vary based on the climate conditions at the production area.

CONCLUSION

The Niagara Rosada vine's full phenological cycle lasted 144 to 148 days, with thermal demands ranging from 1,465.2 to 1,615.1 DD.

The rootstocks IAC 572 Jales and IAC 766 Campinas had no effect on the overall length of the phenological cycle or the vines' thermal demand, indicating that they had similar climate adaptability and affinity with cv. Niagara Rosada.

K fertilization at varied concentrations had no effect on the phenology or thermal demand of cv. Niagara Rosada, when there was a high amount of K available in the soil.

The harvest is expected to take place at 21 to 24 days after veraison, i.e., when there is a better balance between soluble solids and acidity levels.

AUTHORS' CONTRIBUTION

Conceptualization: Tecchio, M. A. and Teixeira, L. A. J.; **Methodology:** Callili, D., Tecchio M. A. and Teixeira, L. A. J.; **Investigation:** Callili, D., Sanchez, C. A. P. C., Watanabe, C. Y., Macedo, B. M. P. and Domingues Neto, F. J; **Writing – Original Draft:** Callili, D.; **Writing – Review and Editing:** Callili, D. and Silva, M. J. R.; **Funding Acquisition:** Tecchio, M. A.; **Resources:** Callili, D., Silva, M. J. R., Tecchio, M. A. and Teixeira, L. A. J.; **Supervision:** Tecchio, M.A.

DATA AVAILABILITY STATEMENT

All dataset were generated and analyzed in the current study.

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