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Phenology, thermal requirement, and ripening of the 'BRS Isis' grape grafted on different rootstocks in a subtropical condition

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ABSTRACT: The replacement of traditional table grape cultivars with seedless genotypes has become common in Brazilian viticulture, especially in non-conventional regions under subtropical conditions. In the context of viticulture, it is crucial to highlight the pivotal role played by rootstocks, which exert a direct influence on phenological cycle, productivity, and grape quality. This study aimed to assess the duration of phenological stages, thermal demand, and maturation of the grape cultivar 'BRS Isis' grafted onto different rootstocks in a subtropical climate during three harvest seasons. The results indicated that the duration of phenological stages varied across harvest seasons, notably extending in the third harvest season due to adverse prevailing climatic conditions. Although no significant differences were observed in the rootstocks during the initial phases of the phenological cycle, they influenced the overall duration from pruning to harvest. Particularly noteworthy were the rootstocks 'IAC 572' and '1103P,' that had earlier maturation in one of the assessed seasons. Consequently, a variation in thermal requirement was higher in the third harvest season. The analysis leads to the conclusion that climatic conditions have impacted the duration of phenological stages, thermal requirements, and the maturation of 'BRS Isis' grape bunches in subtropical regions.

Key words: vitiviniculture, grafting, physicochemical characteristics, red grapes, white grapes.

INTRODUCTION

The substitution of traditional grape cultivars with seedless genotypes, characterized by enhanced production and quality, has become a growing practice in Brazilian viticulture, driven by high consumer market demand (Leão et al. 2020). However, in non-traditional regions for the cultivation of these cultivars, such as the state of São Paulo, Brazil, grape growers have sought to increase and diversify seedless grape production to meet this demand. This is particularly relevant as the state is traditionally known to produce 'Niagara Rosada,' the primary seeded table grape consumed in Brazil (Tecchio et al. 2018).

According to data from the Brazilian Institute of Geography and Statistics (IBGE 2023), grape production in the state of São Paulo increased from 146 thousand tons in 2017 to 166 thousand tons in 2023, representing a growth of over 13%. At the same time, the cultivated area, which was 8,158 ha in 2023, experienced only a 1% increase during the same period. This increase in production within a smaller area over the years was only possible due to the use of more productive seedless cultivars adapted to climatic conditions, coupled with the implementation of other technologies in the production system (Leão et al. 2020).

Among the seedless cultivars that are gaining prominence in Brazilian viticulture, 'BRS Isis' stands out as a contribution from the genetic improvement program conducted by the Brazilian Agricultural Research Corporation (Embrapa). This cultivar is characterized as a red seedless table grape, recognized for its resistance to downy mildew (*Plasmopara viticola*) and its adaptation to the tropical climatic conditions of Brazil (Ritschel et al. 2013). Studies have demonstrated the successful cultivation of the 'BRS Isis" cultivar in semi-arid regions such as the São Francisco Valley and the southern region of Brazil, especially in Paraná (Ahmed et al. 2019, Leão et al. 2020).

However, due to the climatic diversity in Brazilian territory, it is essential to assess the performance of the 'BRS Isis' cultivar in other regions with productive potential, such as the subtropical conditions of São Paulo state. In this context, it is crucial to consider that various factors, in addition to climate, influence the productive characteristics of grapevines and grape quality, with rootstocks being a key factor. Rootstocks play a fundamental role in viticulture, aiding in the control of soil pests and diseases, as well as overcoming abiotic stresses (Ibacache et al. 2016, Jin et al. 2016).

Studies have also shown that rootstocks affect the duration of phenological stages, canopy structure, growth, production, and fruit quality (Koundouras et al. 2008, Bascunán-Godoy et al. 2017, Silva et al. 2017). The proper selection of rootstocks depends on compatibility and affinity with the graft combination, adapting to soil and climate characteristics (Vrsic et al. 2015). Therefore, the careful choice of the ideal combination between scion and rootstock is of paramount importance in a grape production system (Silva et al. 2018).

Knowledge of the duration of grapevine phenological stages plays a crucial role in vineyard management, providing essential information to grape growers, such as periods of increased labour demand, assisting in phytosanitary control, fertilizer programs, and other management techniques, as well as probable harvest dates. Additionally, phenology allows the assessment of the regional climatic potential for grape cultivation and production (Ahmed et al. 2019). When introducing a new cultivar in a specific region, evaluating the duration of phenological stages becomes imperative, considering climatic variations, soil characteristics, and management practices, enabling the measurement of the impact of climate change on the crop. It is also important to understand the thermal demand of the cultivar, which allows for better adaptation of the plant to the environment and aids in predicting phenological events under different climatic conditions. The integration of these insights into phenology and thermal requirements is essential for promoting sustainable grapevine production, ensuring resource optimization and environmental preservation.

The thermal requirement (TR) concept is defined as the disparity between the mean temperature and the base temperature (10 °C), below which vegetative growth does not proceed (Miranda et al. 2013, Tecchio et al. 2013). A positive relationship exists between rising air temperatures and diminishing duration of the grapevine's productive cycle (Hall et al. 2016). This concept facilitates the prediction of plant development across diverse environments and serves as a valuable metric for evaluating plant performance within specific cultivation regions. This evaluation illustrates the requisite accumulation of growing degree-days necessary to complete the grapevine cycle, which varies from one area to another; in addition to climatic factors, it can be influenced by combinations of rootstock and canopy cultivars (Sato et al. 2008).

The study aimed at evaluating the duration of phenological stages, thermal requirements, and maturation curve of the 'BRS Isis' grape grafted onto 'IAC 572,' 'IAC 766,' and 'Paulsen 1103' rootstocks in a subtropical condition in the central-west region of São Paulo state, Brazil.

MATERIAL AND METHODS

The experimental design used was in subdivided plots, with the rootstocks 'IAC 766,' 'IAC 572,' and 'Paulsen 1103' being the main plots and the harvest seasons (2020, 2021 and 2022) being the subplots, with seven blocks and three wines per plot, thus totalling 63 vines in the experimental area.

The grape cultivar evaluated was 'BRS Isis,' developed by Embrapa Uva e Vinho (Tropical Viticulture Experimental Station), originated by crossing CNPUV 681-29 [Arkansas 1976 × CNPUV 147-3 (Niágara Branca × Vênus)] Linda (Ritschel et al. 2013). The rootstocks used were 'IAC 572 Jales' [(*Vitis caribaea* × (*Vitis riparia* × *Vitis rupestris* 101-14)], 'IAC 766 Campinas' (Riparia do Traviú × *V. caribaea*), and 'Paulsen 1103' (*Vitis berlandieri* × *V. rupestris*) (Table 1).

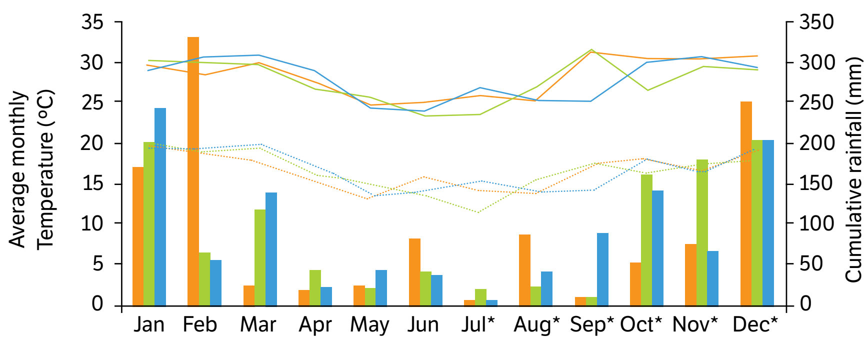
Table 1. Descriptions of rootstocks evaluated.

Rootstocks	Abbreviation	Pedigree	Country of origin
IAC 572 Jales	IAC 572	*V. caribaea* × (*V. riparia* × *V. rupestris* 101-14)	Brazil
IAC 766 Campinas	IAC 766	Riparia do Traviú × *V. caribaea*	Brazil
Paulsen 1103	1103P	*V. berlandieri* × *V. rupestris*	Italy

The experiment was conducted in an experimental vineyard located in the municipality of São Manuel, state of São Paulo, Brazil (22°46"S, 48°34"W, and 773 m altitude), over three consecutive harvest seasons (2020–2022).

The soil of the experimental area was classified as Red Latosol (Embrapa 2018), with a sandy texture. According to the Köppen-Geiger classification, the climate is of the Cfa type, mesothermal, warm temperate (Cunha and Martins 2009).

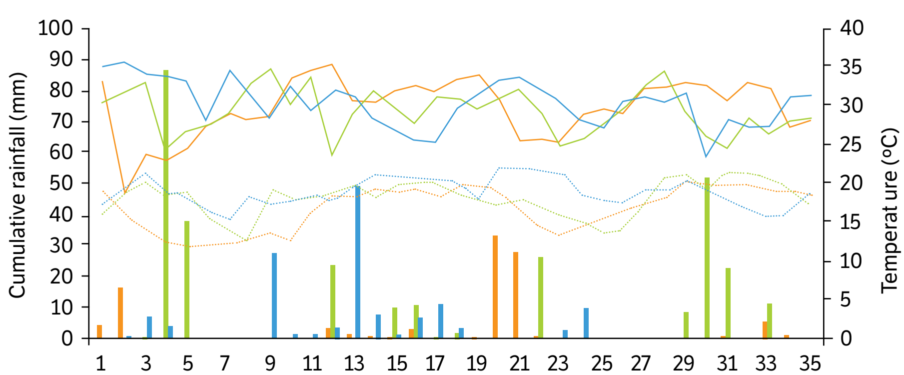
A climate station situated 100 m away from the orchard collected maximum, minimum, and average temperatures, as well as rainfall throughout the experiment. During the harvest seasons, from July to December, the average minimum temperature was 16.4 °C in 2020, 15.9 °C in 2021, and 16.1 °C in 2022. The average maximum temperature was 28.8 °C in 2020, 27.7 °C in 2021, and 27.7 °C in 2022. The accumulated precipitation during this period was 477 mm in 2020, 593 mm in 2021, and 543 mm in 2022, with the tendency for concentration in the summer months (Fig. 1).



*Productive period. The average maximum temperatures are represented by solid lines, and the average minimum temperatures are represented by dashed lines. The bars represent the total amount of rain, while the lines represent the minimum and maximum temperatures. The seasons 2020, 2021 and 2022 are represented by the colors orange, green and blue, respectively.

Figure 1. Climate data (temperature and cumulative rainfall) from the experimental site in 2020, 2021 and 2022. São Manuel, São Paulo, Brazil.

During berry ripening, the average minimum temperature was 16.6 °C in 2020, 18 °C in 2021, and 18.8 °C in 2022. The average maximum temperature was 29.6 °C in 2020, 29.1 °C in 2021, and 30.3 °C in 2022. The accumulated precipitation during this period in the 2020, 2021, and 2022 cycles was 95.5, 288.2, and 133.5 mm, respectively (Fig. 2).



*The average maximum temperatures are represented by solid lines, and the average minimum temperatures are represented by dashed lines. The bars represent the total amount of rain, while the lines represent the minimum and maximum temperatures. The seasons 2020, 2021 and 2022 are represented by the colors orange, green and blue, respectively.

Figure 2. Climate data (temperature and cumulative rainfall) from the experimental site during the ripening of 'BRS Isis' grapevine in 2020, 2021 and 2022. São Manuel, São Paulo, Brazil*.

Rootstock cuttings were planted in August 2018, and scion grafting was performed in July 2019. The spacing used was 3 m between rows and 2 m between wines. The support system was a "Y" shape (Open Gable) with a metal structure. To protect against bird attacks and hail, a polyethylene screen with 18% shading was over the support system.

Agricultural practices such as fertilization, application of plant growth regulators, shoot thinning, leaf removal, canopy thinning, and bunch thinning, as well as pest and disease control, were carried out according to the recommendations proposed by Ritschel et al. (2013).

Pruning for the 2020, 2021, and 2022 cycles was conducted on July 22, August 5, and July 14, respectively, during the summer harvest. Short pruning was performed, and two buds per spur were retained, followed by the application of 2.5% hydrogen cyanamide to induce bud sprouting.

The phenological stages were measured following the recommendations of Coombe (1995), with the duration of each phenological phase determined in days after pruning through visual observations conducted three times per week. The quantified periods included: from pruning to budbreak, full bloom, fruiting, onset of ripening, and harvest (Fig. 3). Grape harvest dates were determined when they reached 16°Brix. However, when the berries did not reach this minimum sugar content, harvest determination was based on the maturation curve, i.e., when there was stabilization in soluble solids content and titratable acidity.

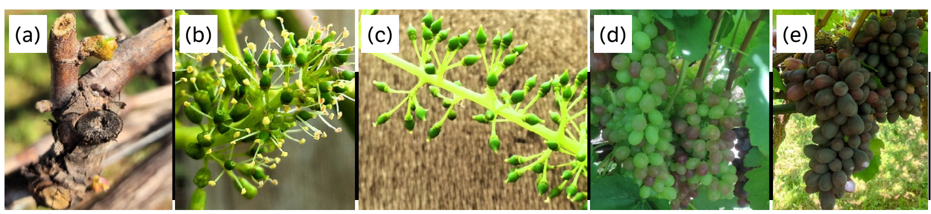


Figure 3. Characterization of phenological stages: (a) budburst, (b) full-bloom, (c) setting, (d) veraison, and (e) harvest of the 'BRS Isis' grapevine.

Thermal requirement was quantified using the concept of growing degree days (GDD), calculated as the sum from pruning to harvest, according to Eq. 1, proposed by Winkler (1965):

$$GDD = \Sigma \text{ (average temperature} - 10\ °C) \times \text{Days after pruning} \quad (1)$$

During grape ripening, the evolution of titratable acidity (TA), soluble solids content (SS), pH, and the maturation index (SS/TA) was determined. To achieve this, at the beginning of ripening, when the berries began to change color, 10 clusters per plot were randomly selected and assessed until full grape ripening. Berries were collected and evaluated every seven days, i.e., at 0, 7, 14, 21, 28, and 35 days after the onset of ripening.

TA was obtained by titration with 0.1 N NaOH to the equivalence point of pH = 8.2, with results expressed as a percentage of tartaric acid (%). SS content was quantified in °Brix using direct refractometry of grape must with a digital refractometer (Reichert, model r2i300, United States of America). pH was also determined by direct reading on a potentiometer Tecnal, model r2i300. The SS/TA was calculated as the ratio of SS to TA.

All data were subjected to two-way analysis of variance (ANOVA) to determine the effects of rootstocks and harvest seasons. For the duration of phenological stages and thermal requirement, mean comparisons were performed using the Tukey's test at a 5% significance level. To assess the effects of rootstocks on grape ripening, regression analysis was conducted using the statistical software Sisvar, version 5.6 (Ferreira, 2011).

RESULTS

There was no significant interaction ($p > 0.05$) between the factors (rootstocks and harvest seasons) for the stages from pruning to budbreak, full bloom, fruiting, and the onset of ripening. Therefore, the main effects were analyzed separately (Table 2).

Table 2. Phenological stages of 'BRS Isis' grapevine grafted on 'IAC 572 Jales,' 'IAC 766 Campinas,' and '1103 Paulsen' rootstocks in three seasons. São Manuel, São Paulo, Brazil, 2020–2023*.

Seasons - Rootstocks		Phenological stages (days after pruning)			
		Budburst	Full-bloom	Setting	Veraison
Rootstocks	IAC 572 Jales	21.38	49.71	55.23	116.04
	IAC 766 Campinas	21.09	49.14	55.61	115.00
	1103 Paulsen	21.38	49.61	55.33	115.00
	Average	21.28	49.48	55.39	115.34
	CV (%)	8.74	4.60	4.48	2.60
	p-value	0.88	0.69	0.87	0.51
Seasons	I	24.74 a	44.28 b	51.95 b	103.52 c
	II	19.33 b	44.90 b	48.66 c	110.71 b
	III	20.04 b	59.28 a	65.57 a	131.81 a
	Average	21.37	49.48	55.93	115.34
	CV (%)	10.21	4.61	5.25	2.87
	p-value	< 0.01	< 0.01	< 0.01	< 0.01

*Values are expressed as mean (three seasons). Values followed by different letters on the same column differ significantly (Tukey's test, $p < 0.05$); CV: coefficient of variation.

Concerning the effects of rootstocks, there was no significant difference ($p > 0.05$) in the duration of phenological stages up to the onset of ripening. Considering the average values for rootstocks, the duration from pruning to budbreak, full bloom, fruiting, and onset of ripening were, respectively, 21.2, 49.4, 55.3, and 115.3 days (Table 2).

There was a significant difference ($p < 0.05$) among harvest seasons for the duration of phenological stages up to the onset of ripening. It was observed that, from pruning to budbreak, the first harvest season (2020) was five days later compared to the second cycle (2021) and four days later compared to the third harvest season (2022).

However, from fruiting onward, it was noted that the third harvest season became later compared to the previous harvest seasons. The most substantial difference among harvest seasons occurred in the period from pruning to the onset of ripening, in which, in the first cycle, the duration was 103.5 days, in the second cycle, it was 110.7 days, and in the third cycle, it was 131.8 days (Table 2). Fruit ripening in the third productive cycle was longer compared to other seasons due to the lower average temperature during this phase, occurring in September (Fig. 1).

Regarding the duration from pruning to grape harvest, there was a significant interaction between factors, meaning that the effects of rootstocks varied according to the harvest seasons (Table 3).

Table 3. Harvest and total thermal requirement of 'BRS Isis' grapevine grafted on 'IAC 572 Jales,' 'IAC 766 Campinas,' and '1103 Paulsen' rootstocks in three seasons. São Manuel, São Paulo, Brazil, 2020–2023*.

Seasons – Rootstocks	Harvest (days after pruning)		
	IAC 572 Jales	IAC 766 Campinas	1103 Paulsen
I	139.00 aB	137.85 aC	138.71 aB
II	138.42 bB	146.00 aB	138.71 bB
III	168.71 aA	166.14 aA	164.57 aA
Average	148.71	149.99	147.33
CV (%)	2.23		
p-value (S × R)	< 0.01		
Seasons – Rootstocks	**Total thermal requirement (DD)**		
	IAC 572 Jales	**IAC 766 Campinas**	**1103 Paulsen**
I	1,661.57 aB	1,651.14 bB	1,657.42 aB
II	1,651.14 bB	1,742.71 aB	1,654.42 bB
III	1,651.14 bB	1,841.85 aA	1,834.00 aA
Average	1,654.6	1,745.23	1,715.28
CV (%)	2.54		
p-value (S × R)	< 0.01		

*Values followed by different letters, lowercase in column and uppercase in row, differ significantly (Tukey's test, $p < 0.05$); CV: coefficient of variation.

Comparing rootstocks within each harvest season, it was found that in the first and third harvest seasons there was no difference between rootstocks, with an average duration of 138.5 and 166.4 days, respectively. However, in the second season, it was observed that the rootstocks 'IAC 572' and '1103P' induced earliness of eight days compared to 'IAC 766' (138 *versus* 146 days) (Table 3).

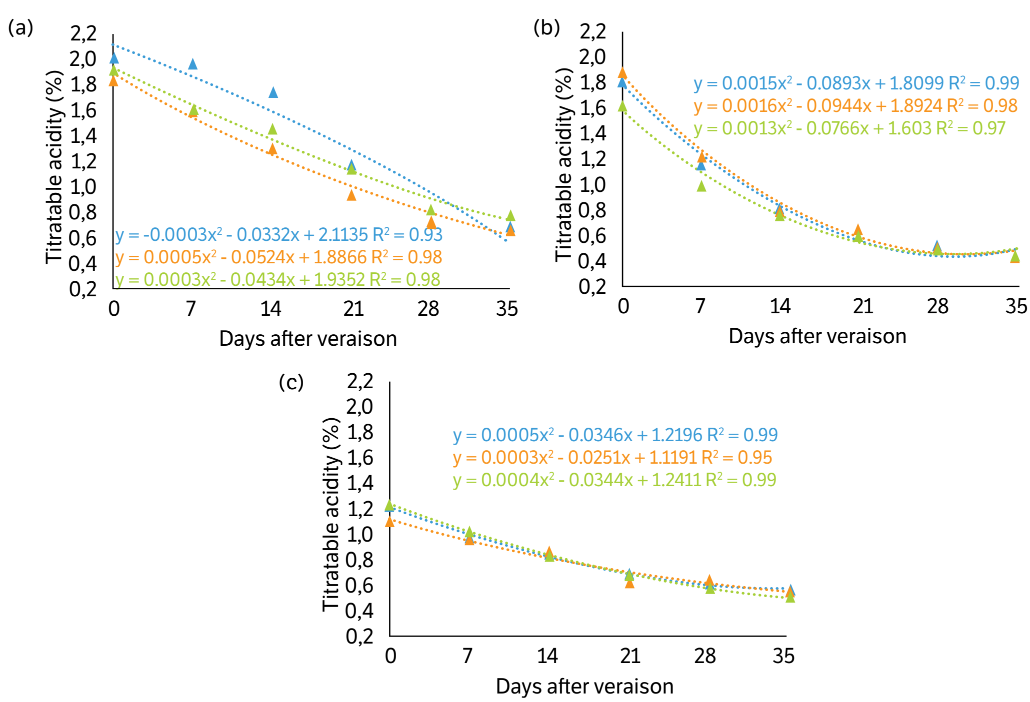
Analyzing the effects of harvest seasons in relation to rootstock, it was observed that, regardless of the rootstock, the third harvest season was later compared to the first two seasons. The duration of vine cycles grafted onto 'IAC 572' in the first, second, and third seasons was 139, 138.4, and 168.7 days, respectively (Table 3). The results in Table 3 also show that the duration of the phenological cycle of vines grafted onto 'IAC 766' was 137.8 days in the first year, 146 days in the second year, and 166.1 days in the third year. In turn, vines cultivated on '1103P' had a complete duration of 138.7, 138.7, and 164.5 days in the first, second, and third season, respectively.

As for the thermal requirement, the same pattern was observed, *i.e.*, the highest thermal demand for vines to complete the cycle occurred in the third season. Overall, the thermal requirement of vines ranged from 1,654.56 (average of the first season) to 1,851.61 growing degree (average of the third seasons) (Table 3).

Chemical characterization during berry ripening

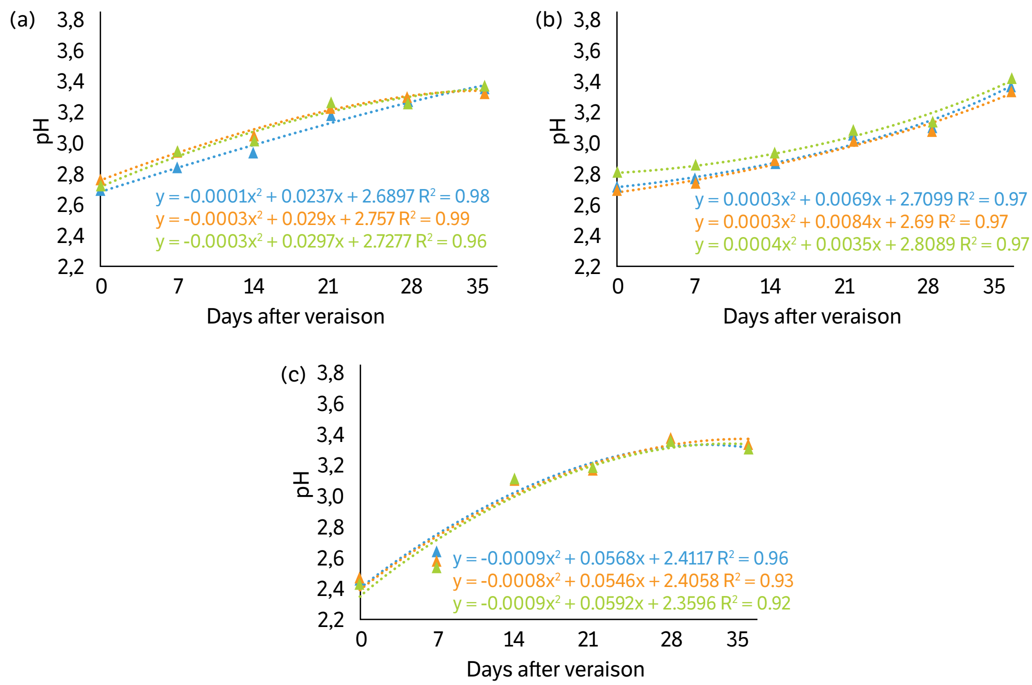
During the berry ripening period, changes in the chemical attributes of grapes followed the expected results, *i.e.*, a decrease in TA and an increase in pH, SS content, and the SS/TA in relation to days after the onset of ripening. Quadratic regression models were fitted for these variables in relation to days after the onset of ripening (Figs. 4, 5, 6, and 7).

Regarding TA, during the harvest period, *i.e.*, between 28 and 35 days after the onset of ripening, berries showed higher acidity in the first harvest season. Analyzing the effect of each rootstock separately, it was found that 'IAC 572' provided berries with a variation in TA from 2.01 to 0.69% in the first season, 1.85 to 0.45% in the second season, and 1.23 to 0.58% in the third season. 'IAC 766' induced variations in berries from 1.84 to 0.66%, 1.94 to 0.44%, and 1.11 to 0.55% in the first, second, and third season, respectively. In turn, the TA of berries from vines grafted onto '1103P' ranged from 1.93 to 0.78% in the first, 1.67 to 0.45% in the second, and 1.24 to 0.51% in the third harvest season (Fig. 4). The pH, also an indicator related to berry acidity, showed little difference between rootstocks; at 35 days after the onset of ripening, the pH values were around 3.3 for all harvest seasons (Fig. 5).



*The rootstocks 'IAC 572,' 'IAC 766' and '1103P' and their respective equations are represented by blue, orange and green colors, respectively.

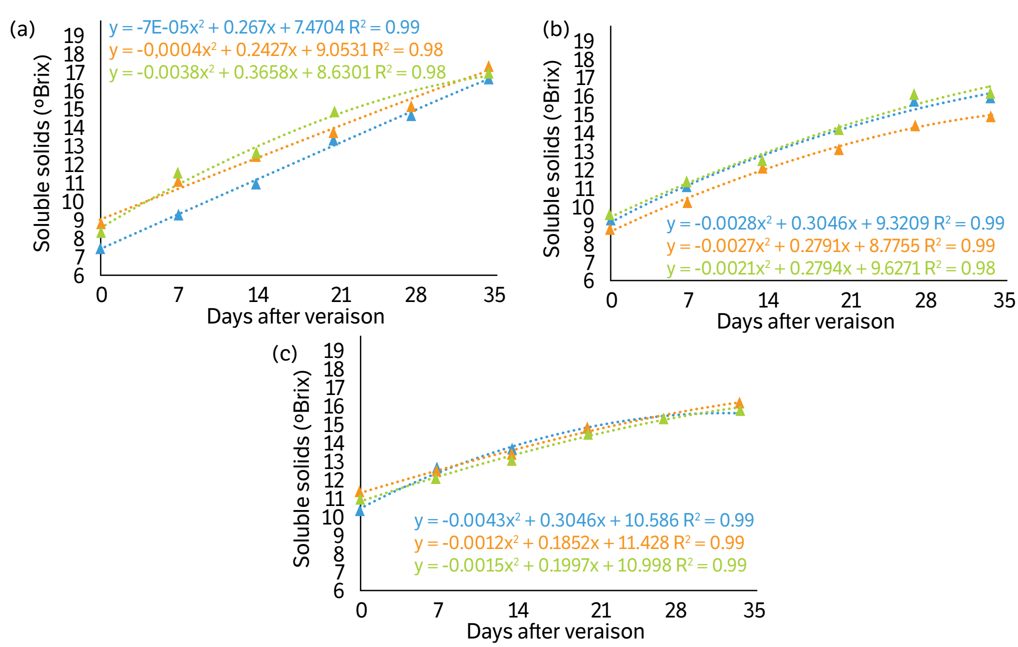
Figure 4. Modifications of titratable acidity during the ripening of 'BRS Isis' grape grown in (a) 2020, (b) 2021, and (c) 2022*.



*The rootstocks 'IAC 572,' 'IAC 766,' and '1103P' and their respective equations are represented by blue, orange and green colors, respectively.

Figure 5. Modifications of pH during the ripening of 'BRS Isis' grape grown in (a) 2020, (b) 2021, and (c) 2022*.

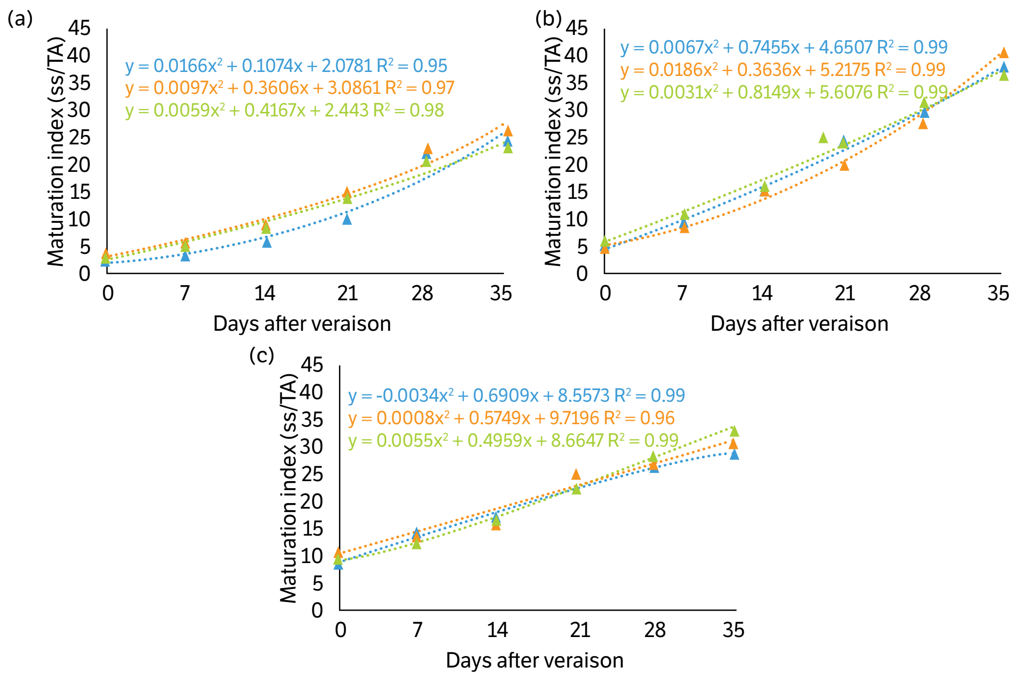
In the first harvest season, berries had a higher SS content compared to the other ones (Fig. 6). The maximum value obtained was 17.36°Brix, from vines grafted onto 'IAC 766.' Overall, berries reached 16°Brix around 35 days after the onset of ripening in the first and third harvest seasons. On the other hand, in the second harvest season, 16°Brix were observed at 28 days after the onset of ripening, except for vines cultivated on 'IAC 766.'



*The rootstocks 'IAC 572,' 'IAC 766,' and '1103P' and their respective equations are represented by blue, orange and green colors, respectively.

Figure 6. Modifications of soluble solids contents during the ripening of 'BRS Isis' grape grown in (a) 2020, (b) 2021, and (c) 2022*.

The SS/TA values at 28 days after the onset of ripening ranged from 20.6 to 23 in the first harvest season, from 28.2 to 32.3 in the second, and from 25.7 to 27.6 in the third harvest season. At 35 days after the onset of ripening, the values were from 23.2 to 26.3 for the first, from 37.0 to 41.8 for the second, and from 28.2 to 32.2 for the third harvest season (Fig. 7).



*The rootstocks 'IAC 572,' 'IAC 766,' and '1103P' and their respective equations are represented by blue, orange and green colors, respectively.

Figure 7. Maturation index during the ripening of 'BRS Isis' grape grown in (a) 2020, (b) 2021, and (c) 2022*.

DISCUSSION

The duration of phenological stages observed in this study, including bud break, flowering, fruiting, and maturation of 'BRS Isis' (Table 2), was influenced by the climatic variations during the harvest seasons. The study took place in the spring and summer, characterized by intense metabolic activity and higher temperatures, conditions favoring better responses to bud break inductions, resulting in a shorter time needed to reach harvest, as described by Hall et al. (2016).

However, one factor contributing to the prolonged growing cycle was the significant precipitation. The average rainfall between August and December 2022 was 26.4 mm higher compared to 2021 (81.2 *vs.* 107.6 mm), representing a 32.5% increase. During the productive period, the rainfall in 2022 was 118.6 mm higher than in 2021 (Fig. 2). The high rainfall, coupled with cloudy days, lower solar radiation, and average temperature, may have impacted the plant's photosynthetic assimilate production. Additionally, increased field capacity and water absorption by the plant, along with reduced air temperature, extended the grapevine cycle, particularly in November and December (Fig. 2), coinciding with the maturation phase.

In the same region, different harvest seasons are directly influenced by microclimatic changes, promoting grape maturation at varied stages. Decreased temperatures and increased precipitation can hinder vine vegetative development and cluster maturation (Keller 2010). According to Ferlito et al. (2020), the 'Paulsen 1103' rootstock exhibits reduced development in waterlogged soils. In the third harvest season, there was an increase in precipitation compared to the previous year (Fig. 2), potentially overwhelming the vine's water absorption capacity and prolonging phenological stages, consequently extending the cycle.

Regarding rootstocks, Ahmed et al. (2019) reported that the 'BRS Isis' grafted onto 'IAC 766' rootstock in the summer harvest showed maturation initiation at 116 days after pruning, representing a difference of 13 and six days more than the first and second cycles, respectively. However, concerning the third cycle in this study, it was 15 days later than reported by Ahmed et al. (2019). Previous studies by Callili et al. (2022) noted different effects of 'IAC 572' and 'IAC 766' rootstocks on the phenological cycle duration of various cultivars. Still, among the evaluated rootstocks, seasonal climatic conditions had a more substantial impact on the phenological characteristics of 'BRS Isis' in a subtropical climate, with increased durations of flowering, fruiting, and cluster maturation in the third cycle, around 15, 15, and 25 days, respectively (Table 2). Colder temperatures can delay development, while warmer temperatures can accelerate it, shortening the productive cycle (Sánchez et al. 2023).

According to Ritschel et al. (2013), the average duration of the phenological cycle of the 'BRS Isis' vine ranges from 135 to 145 days in the northwestern region of São Paulo. Ahmed et al. (2019) observed, in a climate similar to the one of this study during the summer harvest, that the cycle of this cultivar extended to 144 days. Thus, the results obtained in this study (Table 3) were earlier in the first and second harvest seasons, lasting on average 138 and 140 days, respectively. The increased duration of the harvesting phase in the third harvest season was due to the higher precipitation and lower average temperature during the maturation phase (Figs. 1 and 2), reducing the concentration of SS in the fruits (Ribeiro et al. 2012).

In addition to the challenge of establishing experiments that effectively distinguish the performance of the canopy and rootstocks, few studies have been conducted on evaluating the duration of phenological stages of the 'BRS Isis' vine in subtropical regions. The limited understanding of rootstock effects is evident in viticulture, in which more than 90% of all wine grapevines worldwide are grafted onto fewer than 10 rootstocks, primarily chosen for their pest tolerance and resilience to adverse soil conditions, particularly related to water availability or pH (Keller 2010). This concern is further amplified when considering potential sources of variability among vines within a vineyard and indeed among characteristics within the canopy of an individual vine (Sabbatini and Howell 2013).

The impacts associated with rootstocks can be ascribed to multiple factors, including plant vigor, nutrient storage capacity, and water absorption efficiency for vine photosynthesis. These elements are pivotal in the assimilation of resources essential for plant nutrition (Barros et al. 2015). Furthermore, intricate plant factors such as the initiation of spring growth, tolerance to cold temperatures, and ripening of fruits may exhibit non-uniform patterns owing to fluctuations in climatic conditions during these stages.

Ritschel et al. (2013) reported an accumulation of 1,800 GDD from pruning to the end of maturation in the 'BRS Isis' cultivar under tropical climate conditions (Aw), which is lower than the findings in this subtropical study (Table 3). According to Pedro Júnior et al. (1993), climatic conditions alter the duration of phenological stages, as well as the seasons (Ahmed et al. 2019, Callili et al. 2022), resulting in the accumulation of GDD for the cultivar.

The values obtained in this study (Fig. 4) are similar to those found by Ritschel et al. (2013) for TA in tropical regions and by Ahmed et al. (2019) in subtropical conditions for 'BRS Isis.' The results are also close to those obtained with other seedless table grape cultivars produced in subtropical regions of Brazil, such as BRS Vitória (Maia et al. 2016) and BRS Melodia (Koayama et al. 2020). The reduction in TA during ripening is caused by various physiological processes, including organic acid dilution, berry size increase (Leão and Oliveira 2023), and suppression of organic acid synthesis and transformation into sugar (Keller 2010).

The pH range found in 'BRS Isis' must in this study (Fig. 5) aligns with Yamamoto et al. (2015). They observed that suitable pH values in grapes, especially red grapes, should be between 3.2 and 3.4, as this attribute is directly related to anthocyanin stability.

According to Ritschel et al. (2013), the SS content of 'BRS Isis' grapes can range from 16°Brix to 21°Brix, depending on climatic conditions during the ripening phase. One of the main characteristics of maturation development is the accumulation of sugars, namely glucose and fructose in grapes (Callili et al. 2022). In the second harvest season, lower SS content was obtained, possibly due to higher rainfall during the period preceding harvest (Fig. 2). High rainfall, as reported by Ribeiro et al. (2012), reduces sugar deposition in berries, as observed in this study. This occurs when sugars are diluted in berries due to increased water absorption resulting from rain. It is noteworthy that some berries showed signs of wilting and deterioration after 28 days from the onset of maturation (Fig. 6), due to cluster rot. Therefore, under these conditions, it may be recommended to harvest grapes within 28 days after the berries change color. However, this may vary depending on the climatic conditions of the production area and the weather during the harvest season. Rootstocks have different water translocation capacities (Ozden et al. 2010) and nutrient (Tecchio et al. 2011) translocation to the canopy, thus influencing the SS content in berries.

In this context, it became evident that the different climatic conditions occurring during each harvest, as shown in Fig. 1, influenced the chemical properties of grapes (Figs. 4, 6, and 7). Additionally, temperature, sunlight, and rainfall have a significant influence on plant metabolism, potentially favoring or hindering the genetic potential of grapes (Ribeiro et al. 2012). Delay in the occurrence and duration of different phenological stages can affect the maturation curve of grapevines, resulting in the presence of both ripe and unripe fruits (Parr et al. 2007). Overall, sugar and acid content determine the organoleptic quality of grapes (Jin et al. 2016). Therefore, the choice of the appropriate rootstock, one that provides better must quality, is crucial. However, the results observed in this study highlight that factors such as the affinity and interaction between rootstock and canopy, vineyard cultural practices, and, primarily, the adaptation of both to climatic conditions should be considered when choosing the ideal rootstock.

The obtained results can also be valuable in planning the establishment of new vineyards in subtropical conditions in the state of São Paulo, Brazil.

CONCLUSION

Seasonal climate variations between harvest seasons had a greater impact than rootstocks on the response of the 'BRS Isis' grapevine regarding the duration of phenological stages and thermal requirements. The harvest seasons duration from pruning to harvest ranged from 137 to 168 days, with an accumulation of degree days from 1,651 to 1,841.

Rootstocks had minimal effects on the chemical characteristics marking the progression of berry maturation in the 'BRS Isis' seedless grape, occurring in an isolated manner between the studied cycles, making it challenging to distinguish a specific rootstock with superior performance for these characteristics.

The table grape cultivar 'BRS Isis' shows good compatibility with the rootstocks Paulsen 1103, IAC 766 Campinas, and IAC 572 Jales in the evaluated characteristics.

CONFLICT OF INTEREST

Nothing to declare.

AUTHORS' CONTRIBUTION

Conceptualization: Tecchio, M. A.; **Methodology:** Tecchio, M. A., Souza, R. T.; **Investigation:** Sánchez, C. A. P. C. and Callili, D.; **Writing – Original Draft:** Sánchez, C. A. P. C. and Callili, D.; **Writing – Review and Editing:** Tecchio, M. A., Leonel, S., Sánchez, C. A. P. C. and Callili, D.; **Funding Acquisition:** Tecchio, M. A., Souza, R. T. and Smarsi, R. C.; **Resources:** Tecchio, M. A., Souza, R. T. and Smarsi, R. C.; **Supervision:** Tecchio, M. A.; **Final approval:** Sánchez, C. A. P. C.

DATA AVAILABILITY STATEMENT

All dataset were generated and analyzed in the current study.

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