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DESEMPENHO AGRONÔMICO DA VIDEIRA 'BRS ISIS' SOBRE DIFERENTES PORTA-ENXERTOS EM CLIMA SUBTROPICAL

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Tese apresentada à Faculdade de Ciências Agronômicas da Unesp Câmpus de Botucatu, para obtenção do título de Doutor em Horticultura

Orientador: Prof. Dr. Marco Antonio Tecchio

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Aos meus amados pais,

Camilo Enrique Contreras Sánchez e Margarida Claudia Pereira,

dedico

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“A sabedoria não vem automaticamente com a idade. Nada vem – exceto rugas. É verdade, alguns vinhos melhoram com o tempo, mas apenas se as uvas eram boas em primeiro lugar”.

BUREN, A.V. “A. O melhor da querida Abby. Kansas City:
Andrews e McMeel, 1981.

RESUMO

As tradicionais uvas sem sementes, perderam competitividade de mercado nos últimos anos em função da baixa produtividade e alta demanda de mão de obra para o manejo cultural. Com a introdução das uvas sem sementes e as novas variedades nacionais, o leque de opções de produção foi estendido. A cultivar BRS Isis, lançada em 2013 pela EMBRAPA, caracteriza-se como uma uva de mesa sem sementes, atualmente difundida no Vale do São Francisco. Com isso, existe uma carência de estudos relacionados a uvas sem sementes em regiões de condição de clima subtropical, como por exemplo, algumas regiões do Estado de São Paulo. A necessidade de pesquisa, principalmente relacionados a relação entre porta-enxertos e copa, são fundamentais para nortear e incentivar o cultivo das cultivares em regiões produtoras e na expansão agrícola da cultura. Com isso, o objetivo geral do estudo é avaliar e estabelecer a melhor relação entre porta-enxerto e copa, avaliando a cultivar de uva para mesa BRS Isis enxertada nos porta-enxertos IAC 766 Campinas, IAC 572 Jales e Paulsen 1103. O experimento avaliou os estádios fenológicos, demanda térmica, evolução da maturação, produção, produtividade, parâmetros físico-químicos, compostos bioativos da cultivar em condição de clima subtropical. No quesito das avaliações fenológicas, as condições climáticas influenciaram mais que os porta-enxertos, sendo o ‘Paulsen 1103’ atribuindo um ciclo mais tardio a BRS Isis, consequentemente a uma maior demanda térmica. Os porta-enxertos IAC 572 e IAC 766 resultaram em maiores produções e características físicas do cacho da BRS Isis, entretanto o ‘Paulsen 1103’ foi o porta-enxerto que acumulou maiores compostos fenólicos.

Palavras-chave: uva sem semente; uva híbrida, características químicas; enxertia; características físico-químicas.

ABSTRACT

In recent years, traditional seedless grapes have lost market competitiveness due to low productivity and high demand for labor in cultural management. The introduction of seedless grapes and new domestic varieties has expanded production options. The BRS Isis cultivar, released in 2013 by EMBRAPA, is a seedless table grape currently widespread in the São Francisco Valley. However, there is a lack of studies related to seedless grapes in subtropical climate regions, such as some areas in the State of São Paulo. Research needs, particularly concerning the relationship between rootstocks and scion, are essential to guide and encourage the cultivation of these cultivars in both traditional and non-traditional producing regions. Therefore, the general objective of this study is to evaluate and establish the best relationship between rootstock and scion, specifically assessing the BRS Isis table grape cultivar grafted onto the rootstocks IAC 766 Campinas, IAC 572 Jales, and Paulsen 1103. The experiment evaluated phenological stages, thermal demand, maturation progression, production, yield, physicochemical parameters, and bioactive compounds of the cultivar under subtropical climate conditions. Regarding phenological evaluations, climatic conditions had a greater influence than rootstocks, with 'Paulsen 1103' attributing a later cycle to BRS Isis, consequently requiring more thermal demand. Rootstocks IAC 572 and IAC 766 resulted in higher productions and physical characteristics of BRS Isis clusters, while 'Paulsen 1103' was the rootstock that accumulated higher phenolic compounds.

Keywords: seedless grape; hybrid grape; chemical characteristics; grafting; physicochemical characteristics.

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INTRODUÇÃO GERAL

A produção de uva no Brasil está concentrada na região Nordeste, Sudeste e Sul, onde foram cultivados 74028 ha de vinhedos, correspondendo a 99% da área colhida no país (AGRIANUAL, 2022), com volume de uva exportado de 43,29 mil toneladas em 2022 (BRASIL, 2023). Em 2021, a área cultivada com videiras no Brasil foi de 75.007 ha, sendo a região sul com a maior concentração de área na viticultura, com a participação de 73% de área plantada em 2021, com 54.755 ha em toda a região (Mello *et al.* 2022). A região Sudeste tem uma participação de 12,68% da área cultivada em 2021, em que o Estado de São Paulo apresentou uma área de 8.022 ha, enquanto no Nordeste do país, representado pelo Vale do São Francisco, apresentou uma área plantada de 14,04% em 2021 (Mello *et al.* 2022).

A produção nacional de uvas em 2021, foi de 1.697.680 t, 19,86% superior à verificada no ano de 2020. O sul do país obteve uma proporção de 62,92% em relação a produção nacional, seguido pela Região Nordeste, esta que apresentou uma contribuição de 26,81% da produção em 2021. A região Sudeste representou 10,02% da produção nacional em 2021, em que o Estado de São Paulo produziu 147.359 toneladas de uvas (Mello *et al.* 2022).

Dados da Companhia de Entre Postos e Armazéns Gerais do Estado de São Paulo (CEAGESP) mostram que na última década houve uma tendência no maior consumo de uvas sem sementes, em que no ano de 2007 se apresentava em 3.229 toneladas e em 2020 o consumo ascendeu para 13.919 toneladas, representando um aumento de 431%, sendo que no primeiro semestre de 2019, foram comercializadas 6,5 mil toneladas de uvas sem sementes brasileiras (CEAGESP, 2022).

As tradicionais uvas sem sementes, como ‘Thompson Seedless', 'Sugraone' e 'Crimson Seedless', perderam competitividade de mercado nos últimos anos em função da baixa produtividade, alta demanda de mão de obra para manejo cultural e a participação de novos países no mercado internacional, resultando na substituição por novas cultivares de uvas sem sementes provenientes de órgãos públicos e programas privados de melhoramento de plantas (Leão *et al.* 2020). Essas cultivares hoje são cultivadas principalmente no Vale do Rio São Franscisco, região no qual o índice de rachadura de bagas é menor pela baixa pluviosidade da região (Oliveira *et al*. 2017; Leão, 2021). Com a introdução das uvas sem sementes e as novas variedades nacionais, o leque de opções de produção foi estendido (Mello *et al.* 2022).

A cultivar BRS Isis, lançada em 2013 pela Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) (RNC 30769), caracteriza-se como uma uva de mesa com vestígios de sementes, bagas alongadas em formato elíptico, tamanho médio e textura firme e crocante. As plantas apresentam alto vigor e tolerância ao míldio (*Plasmopora vitícola*), alta fertilidade de gemas e produtividade superior a 30 ton/ha/ciclo no Vale do São Francisco (Ritschel *et al.* 2013; Leão *et al.* 2016; Mello, 2019). Esta cultivar está adaptada a um sistema de produção com duas colheitas por ano nas condições subtropicais do Brasil, recomendando manejo da carga de cultivo para uma densidade de 5 cachos/m^2, visando garantir produção estável nas duas safras (Ahmed *et al.* 2019). A BRS Isis pode ser cultivada com sucesso sobre os porta-enxertos IAC 572 Jales, no Noroeste de São Paulo, e IAC 313 Tropical e SO4 no vale do Submédio São Francisco (Ritschel *et al.* 2013). As uvas ao atingirem a plena maturação apresentam sabor neutro e alcançam o teor de sólidos solúveis entre 16 e 21°Brix (Nascimento, 2018). A acidez das bagas é baixa, variando entre 0,34 a 0,55 gramas de ácido tartárico por 100 mL^{-1} (Leão *et al.* 2017). As condições climáticas favoráveis em São Paulo proporcionam oportunidades para o cultivo em larga escala, contribuindo para o desenvolvimento econômico sustentável e abrindo portas para o mercado internacional (Hannah *et al.* 2013; Bindi e Nunes 2016; Maes *et al.* 2018).

Apesar desses avanços, as mudanças climáticas emergem como uma ameaça à resiliência das paisagens vitivinícolas, comprometendo a oferta de serviços ecossistêmicos. Os impactos das mudanças climáticas, exemplificados por temperaturas mais elevadas e regimes de precipitação modificados, já impõem desafios significativos à integridade e estado de muitas paisagens de vinhedos. A literatura carece de uma abordagem integradora para analisar essas condições no contexto das alterações climáticas, destacando a necessidade de uma abordagem mais holística e colaborativa na pesquisa (Candiago *et al.* 2023). Esse gap destaca a necessidade de um enfoque mais holístico e colaborativo na pesquisa, visando uma compreensão mais completa e efetiva das interações entre as condições climáticas, a viticultura e a sustentabilidade agrícola.

Na viticultura é essencial a utilização de enxertia nas plantas de videira, para prevenir problemas bióticos decorrentes de infecções de pragas e patógenos que afetam o sistema radicular da planta, bem como problemas abióticos, como adaptação a solos de baixa fertilidade, solos sujeitos a excesso ou deficiência de água, solos salinos, solos calcários e outros efeitos adversos (Peterson *et al.* 2017). Além disso, diversos estudos mostram que porta-enxertos influenciam no desempenho produtivo das videiras (Tecchio *et al.* 2020), composição química do mosto (Silva *et al.* 2018), bem como na duração dos estágios fenológicos (Tecchio *et al.* 2013), vida útil de prateleira (Lo'ay *et al.* 2017) e conteúdo de compostos antioxidantes (Borges *et al.* 2013).

A relação específica da compatibilidade e interação da cultivar copa e do porta-enxerto pode afetar o crescimento e o vigor da videira (Ollat *et al.* 2003; Cookson *et al.* 2012). Uma positiva correlação entre vigor e rendimento relacionado ao porta-enxerto tem sido relatada por alguns autores (Paranychianakis *et al.* 2004; Jones *et al.* 2009), mas em outros estudos essa correlação não foi observada (Keller *et al.* 2012; Kidman *et al.* 2013).

Dentre os principais portaenxertos utilizados na viticultura subtropical brasileira, destacam-se o 'IAC 766 Campinas' e o 'IAC 572 Jales', apresentando afinidade com as principais cultivares copa e condições edafoclimáticas das regiões produtoras. De acordo com Tecchio *et al*. (2018), o 'IAC 572' apresenta alto vigor e se adapta muito bem aos diversos tipos de solos, principalmente, aos solos ácidos. Por sua vez, o 'IAC 766 Campinas' tem elevado vigor e boa adaptação em solos com baixa fertilidade. Existem outras variedades de porta-enxertos bem utilizados na região Sul do País e no Vale do Rio São Francisco como o SO4 e o Paulsen 1103 por apresentarem afinidade com as cultivares copa, além das condições de solo e clima dessas regiões (Vrsic; Pulko *et al.* 2015; Tecchio *et al.* 2018; Monteiro *et al.* 2022).

Recentemente, esses portaenxertos têm sido avaliados em combinações com diversas cultivares de uvas (Silva *et al.* 2017; Tecchio *et al.* 2019; Tecchio *et al.* 2020; Simonetti *et al.* 2021; Callili *et al.* 2022a). Entretanto, há uma grande variação entre os resultados desses estudos, evidenciando a importância da afinidade e da interação entre portaenxertos e copa (Vrsic *et al.* 2015), e da adaptação às condições climáticas do local de cultivo (Kidman *et al.* 2013).

A influência dos porta-enxertos sobre o conteúdo bioativo e a atividade antioxidante de várias espécies de uva é bem documentada em estudos recentes (Silva *et al.* 2019; Bascunán-Godoy *et al.* 2017; Cheng *et al.* 2017; Jogaiah *et al.* 2015). Contudo, é crucial destacar que essa influência está intrinsecamente ligada à afinidade específica da interação copa-porta-enxerto (Tecchio *et al.* 2022; Callili *et al.* 2022b). Esses compostos fenólicos desempenham um papel crucial como antioxidantes na eliminação de radicais livres, contribuindo assim para a saúde humana e a prevenção de doenças crônicas, como doenças cardiovasculares, câncer e diabetes (Granato *et al.* 2016; Gomez-Gomez *et al.* 2018; Lago-Vanzela *et al.* 2011; Toaldo *et al.* 2019). Dessa forma, a utilização de porta-enxertos pode potencialmente alterar de maneira significativa a composição de compostos bioativos nas uvas, o que, por sua vez, pode ter implicações importantes para a saúde humana.

Neste contexto, existe uma necessidade de estudos relacionados as uvas sem sementes em regiões de condição de clima subtropical, como por exemplo, o Centro-Oeste Paulista. Existe necessidade de pesquisas, principalmente relacionadas a relação entre porta-enxertos e copa, são fundamentais para nortear e incentivar o cultivo das cultivares em regiões produtoras e redimensionamento agrícola da cultura no Estado de São Paulo.

Com isso, o objetivo geral do estudo foi avaliar e estabelecer a melhor relação entre porta-enxerto e copa, avaliando a cultivar de uva para mesa BRS Isis enxertada nos porta-enxertos IAC 766 Campinas, IAC 572 Jales e Paulsen 1103. Os objetivos específicos foram avaliar os estádios fenológicos, demanda térmica, evolução da maturação, produção, produtividade, parâmetros físico-químicos e compostos bioativos da cultivar em condição de clima subtropical.

CAPÍTULO 1

PHENOLOGY, THERMAL REQUIREMENT AND RIPENING OF THE ‘BRS ISIS’ GRAPE GRAFTED ON DIFFERENT ROOTSTOCKS IN A SUBTROPICAL CLIMATE[1]

Camilo André Pereira Contreras Sánchez, Marco Antonio Tecchio, Daniel Callili, Reginaldo Teodoro de Souza, Ronny Clayton Smarsi, Sarita Leonel

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 mesothermal 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,' showing earlier maturation in o[2]ne of the studied years. Consequently, a variation in thermal requirement was higher in the third harvest season. This study underscored the effects of climate and rootstocks on the phenology and quality of grapes from the BRS Isis cultivar in environments characterized by a warm temperate climate (mesothermal).

Keywords: viticulture, grafting, physicochemical characteristics, red grapes, grape seedless.

1.1 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, grape growers have sought to increase and diversify seedless grape production to meet this demand. This is particularly relevant as the state is

[1] Capítulo redigido de acordo com as normas do periódico ‘Bragantia’

traditionally known for the production of '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 Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA). This cultivar is characterized as a red seedless table grape, recognized for its resistance to downy mildew (*Plasmopora vitícola*) 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 the state of São Paulo. The subtropical climate is a type of climate characterized by moderate to warm temperatures in the summer and cold winters. This climate type is generally found at middle latitudes, between temperate and tropical climate zones. One of the main features of the subtropical climate is the presence of four distinct seasons: spring, summer, autumn, and winter. Seasonal variations are more pronounced compared to tropical climates, where temperatures remain more constant throughout the year. Additionally, subtropical climates are often associated with well-distributed rainfall throughout the year, although regional variations may exist. These climatic characteristics favor the growth of a variety of plants and diverse ecosystems (Peel *et al.* 2007).

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, Albornoz & Zurita-Silva, 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 labor 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.

According to Candiago *et al.* (2023), the influences of temperature and precipitation patterns have been studied in only about 20% of articles related to phenology and temperature change, and merely 5% of articles correlating phenology with vineyard precipitation. Additionally, according to the World Meteorological Organization (2024), the year 2022 ranked as the 5th or 6th warmest year ever recorded. These data underscore the necessity of interpreting climate change effects on the phenological duration and ripening evolution of grape.

The study evaluated the duration of phenological stages, thermal requirements, and ripening curve of the 'BRS Isis' grape grafted onto 'IAC 572,' 'IAC 766,' and 'Paulsen 1103' rootstocks in a mesothermal climate in the central-west region of the state of São Paulo, Brazil.

1.2 MATERIAL AND METHODS

The experimental design employed in this study utilized a subdivided plot arrangement. The primary or main plots were dedicated to the different rootstocks, namely 'IAC 766', 'IAC 572', and 'Paulsen 1103'. Within each main plot, the subplots were defined by the production cycles, specifically for the years 2020, 2021, and 2022. The experimental setup consisted of seven blocks, each containing three plants per plot, resulting in a total of 63 vines in the experimental area.

The grape cultivar evaluated was 'BRS Ísis', developed by Embrapa Uva e Vinho (Estação Experimental de Viticultura Tropical), originated by crossing CNPUV 681-29 [Arkansas 1976 X CNPUV 147-3 (Niagara Branca X Vênus)] Linda (Ritschel *et al*. 2013). The rootstocks used were 'IAC 572 Jales' [(*Vitis caribaea* x (*Vitis riparia x Vitis rupestris* 101-14)], 'IAC 766 Campinas' (Riparia do Traviú x *Vitis caribaea*) and 'Paulsen 1103' (*Vitis berlandieri x Vitis 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) (Figure 1), over three consecutive harvest seasons (2020-2022).

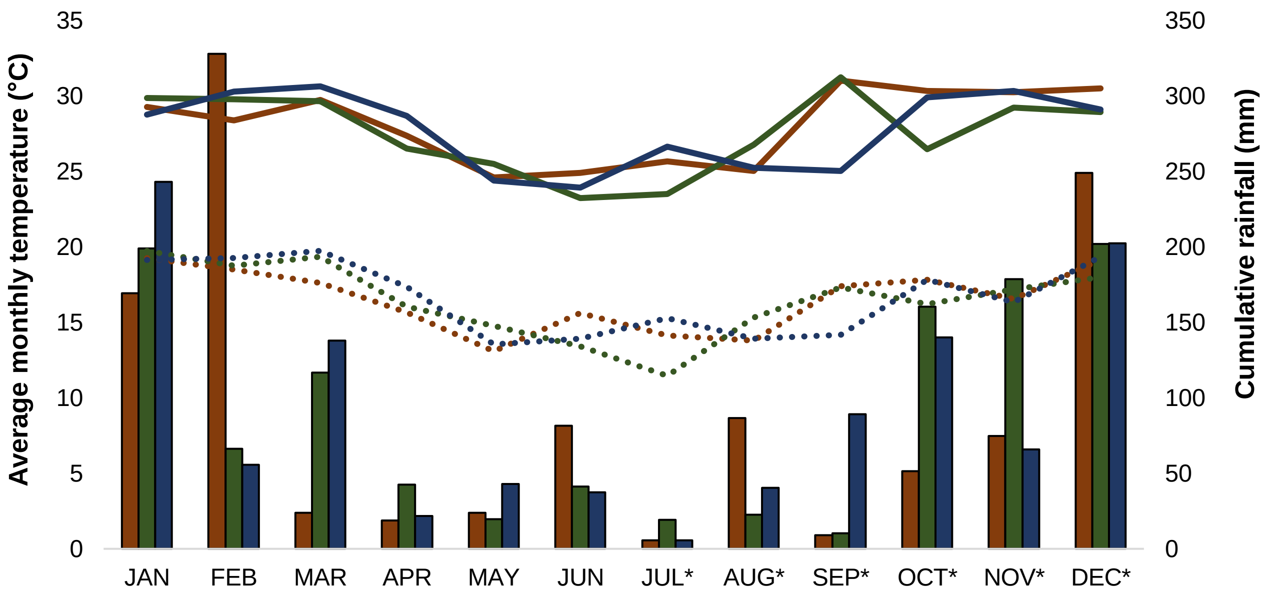
Figure 1. Aerial view of the experimental area.

Fonte: Autor

The soil within the experimental area was identified as Red Latosol according to Embrapa's classification (2018), displaying a sandy texture. Following the Köppen-Geiger classification, the climate falls under the *Cfa* category, characterized as mesothermal and warm-temperate. The average temperature in the warmest month exceeds 22 ºC. According to the Thornthwaite methodology, the climate was further delineated as **B2rB’3a’**, indicating a humid climate with slight water deficiency in the months of April, July, and August. This classification denotes a mesothermal climate with an annual evapotranspiration of 945.15 mm and a concentration of potential evapotranspiration in the summer reaching 33% (Cunha *et al*. 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 a tendency for concentration in the summer months (Figure 2).

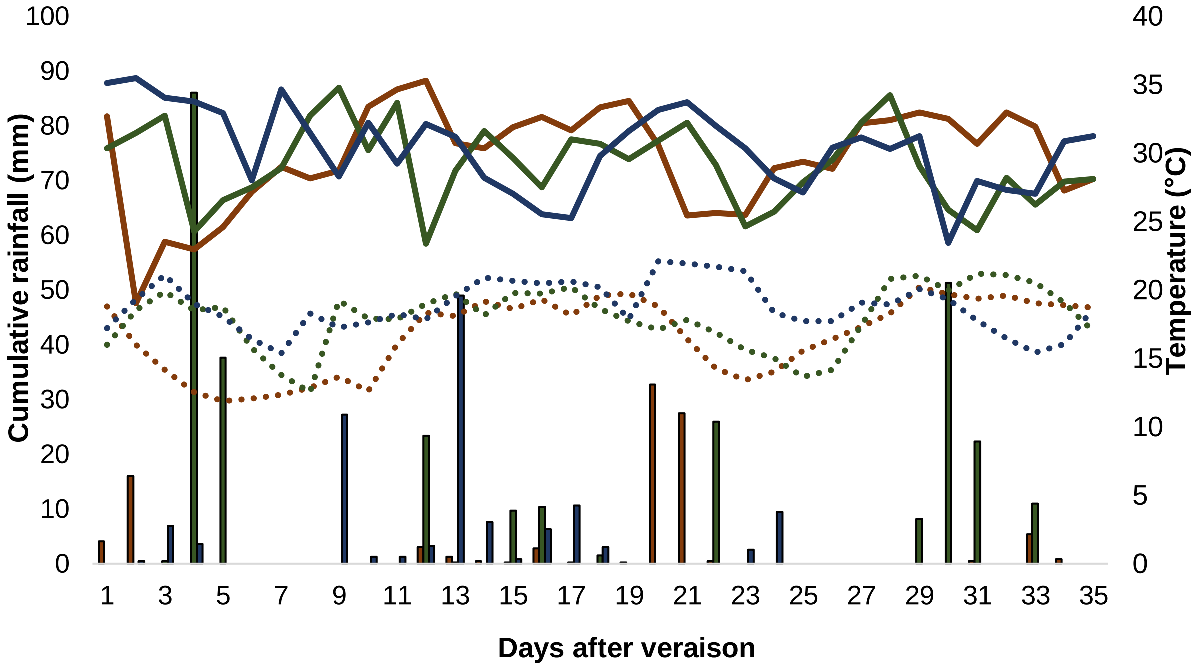
Figure 2. Climate data (temperature average and cumulative rainfall) from the experimental site in 2020, 2021 and 2022. São Manuel, State of São Paulo, Brazil.



*Productive period. The bars represent the total amount of rain while the lines represent the minimum and maximum temperatures. The years 2020, 2021 and 2022 are represented by the color's orange, green and blue, respectively.

During berry ripening, the average minimum temperature was 16.6°C in 2020, 18.0°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 (Figure 3).

Figure 3. Climate data (temperature and cumulative rainfall) from the experimental site during the ripening of 'BRS Ísis' grapevine in 2020, 2021 and 2022. São Manuel, State of São Paulo, Brazil.



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 color's orange, green and blue, respectively.

Rootstock cuttings were planted in August 2018, and scion grafting was performed in July 2019. The spacing used was 3.0 m between rows and 2.0 m between plants. The support system was a "Y" shape with a metal structure. To protect against bird attacks and hail, a polyethylene protective screen with 18% shading was installed.

Cultural practices such as fertilization, 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):

- To control the strong apical dominance characteristic of 'BRS Isis' during the plant formation phase, it becomes necessary to practice the topping of lateral branches when they reach approximately 8 to 10 leaves, leaving about eight buds. The objective of this practice is to redistribute vigor to other shoots along the main arm, allowing the attainment of plants with a more balanced initial structure.
- Green pruning involves removing green parts of the plant during the vegetative and productive phases. During the formation of canes, both in the plant and

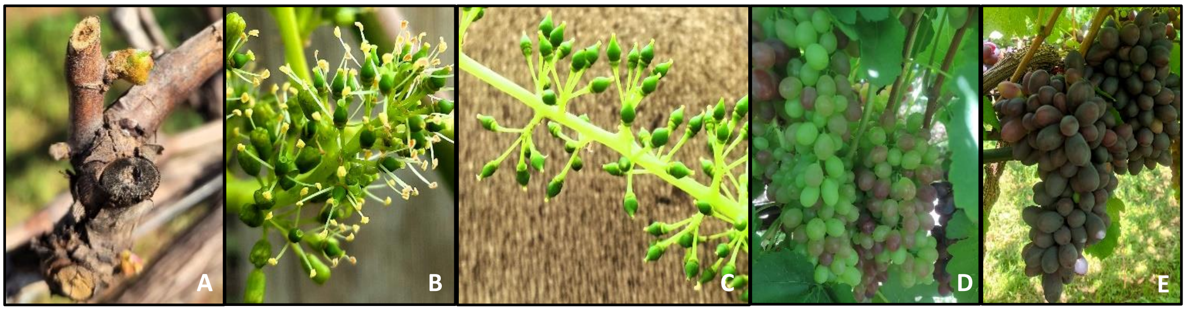
branch formation periods, there is a need to eliminate secondary lateral shoots (laterals or femelles) when they are 10 to 12 cm long. This practice generally aims to increase bud fertility and improve canopy aeration, resulting in positive effects on fungal disease control.

- In cane formation, for pruning in the next cycle, the shoots should have their tips topped when they reach 1.4 to 1.5 m in length, thereby restraining growth. Generally, a second topping is needed for shoots emitted at the ends.
- In shoots with clusters, topping should be done after fruit set, between the 'pea-sized' and 'marble-sized' stages (between 7 and 10 mm), leaving 13 to 15 leaves. It is not recommended to top before flowering, as this practice may result in better fruit set, leading to increased labor costs for berry thinning. Basal leaf removal is carried out only in shoots with clusters on the productive branches to allow better coverage of growth regulators during applications.

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, maintaining one to two buds per spur, 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 (DAP) through visual observations conducted three times per week. The quantified periods included: from pruning to budbreak, full bloom, fruiting, onset of ripening, and harvest (Figure 4). 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 4. Characterization of phenological stages: budburst (A), full-bloom (B), setting (C), veraison (D) and harvest (E) of the 'BRS Ísis' grapevine.



Thermal requirement was quantified using the concept of growing degree days (GDD), calculated as the sum from pruning to harvest, according to the equation proposed by Winkler (1965): GDD = Σ (average temperature - 10°C) × days after pruning.

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

Titratable acidity 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 (%). Soluble solids content was quantified in °Brix using direct refractometry of grape must with a digital refractometer (Reichert®, model r2i300, USA). pH was also determined by direct reading on a potentiometer Tecnal®, model r2i300. The maturation index was calculated as the ratio of SS to TA.

All data were subjected to analysis of variance (two-way ANOVA) to assess the effects of rootstocks and production cycles. Prior to conducting the analysis of variance, normality tests and assessments of homogeneity of variances were performed to ensure the assumptions of the statistical analysis were met. For the duration of phenological stages and thermal requirement, mean comparisons were carried out using the Tukey test at a 5% significance level. To evaluate the impact of rootstocks on grape ripening, regression analysis was conducted using the statistical software Sisvar®, version 5.6 (Lavras, MG, Brazil).

1.3 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 factors were analyzed separately (Table 2).

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

Seasons - Rootstocks		Phenological stages (DAP)			
		Budburst	**Full-bloom**	**Setting**	**Veraison**
Rootstocks	IAC 572 Jales	21.38 ± 3.12	49.71 ± 7.17	55.23 ± 7.65	116.04 ± 13.41
	IAC 766 Campinas	21.09 ± 2.79	49.14 ± 7.56	55.61 ± 8.18	115.00 ± 12.58
	1103 Paulsen	21.38 ± 2.96	49.61 ± 7.74	55.33 ± 8.17	115.00 ± 12.01
	Average	21.28 ± 2.95	49.48 ± 7.49	55.39 ± 8.00	115.34 ± 12.67
	CV (%)	8.74	4.60	4.48	2.60
	p-value	0.88	0.69	0.87	0.51
Seasons	I	24.74 ± 2.59 a	44.28 ± 3.73 b	51.95 ± 1.02 b	103.52 ± 2.04 c
	II	19.33 ± 1.06 b	44.90 ± 1.14 b	48.66 ± 2.80 c	110.71 ± 3.89 b
	III	20.04 ± 1.56 b	59.28 ± 1.10 a	65.57 ± 3.83 a	131.81 ± 3.14 a
	Average	21.37 ± 1.73	49.48 ± 1.99	55.93 ± 2.55	115.34 ± 3.02
	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) ± standard deviation ($n = 7$). Values followed by different letters on the same column differ significantly (Tukey test, $p < 0.05$).

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, 21.28, 49.48, 55.39, and 115.34 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 5 days later compared to the second cycle (2021) and 4 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, where, 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 years due to the lower average temperature during this phase, occurring in September (Figure 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 Ísis’ grapevine grafted on ‘IAC 572 Jales’, ‘IAC 766 Campinas’ and ‘1103 Paulsen’ rootstocks in three seasons. São Manuel, 2020-2023.

Seasons – Rootstocks	**Harvest** (DAP)		
	IAC 572 Jales	IAC 766 Campinas	1103 Paulsen
I	139.00 ± 1.41 aB	137.85 ± 2.04 aC	138.71 ± 2.63 aB
II	138.42 ± 3.95 bB	146.00 ± 4.40 aB	138.71 ± 3.90 bB
III	168.71 ± 3.40 aA	166.14 ± 3.90 aA	164.57 ± 2.37 aA
Average	148.71 ± 2.92	149.99 ± 3.44	147.33 ± 2.96
CV (%)	2.23		
p-value (S x R)	< 0.01		
Seasons – Rootstocks	**Total thermal requirement** (DD)		
	IAC 572 Jales	IAC 766 Campinas	1103 Paulsen
I	1661.57 ± 20.53 aB	1651.14 ± 47.26 bB	1657.42 ± 38.50 aB
II	1651.14 ± 47.26 bB	1742.71 ± 54.02 aB	1654.42 ± 46.66 bB
III	1651.14 ± 47.26 bB	1841.85 ± 43.02 aA	1834.00 ± 31.86 aA
Average	1654.61 ± 38.35	1745.23 ± 48.1	1715.28 ± 39.00
CV (%)	2.54		
p-value (S x R)	< 0.01		

Values are expressed as mean ± standard deviation (n = 7). Values followed by different letters. lowercase in column and uppercase in row. differ significantly (Tukey test, p < 0.05).

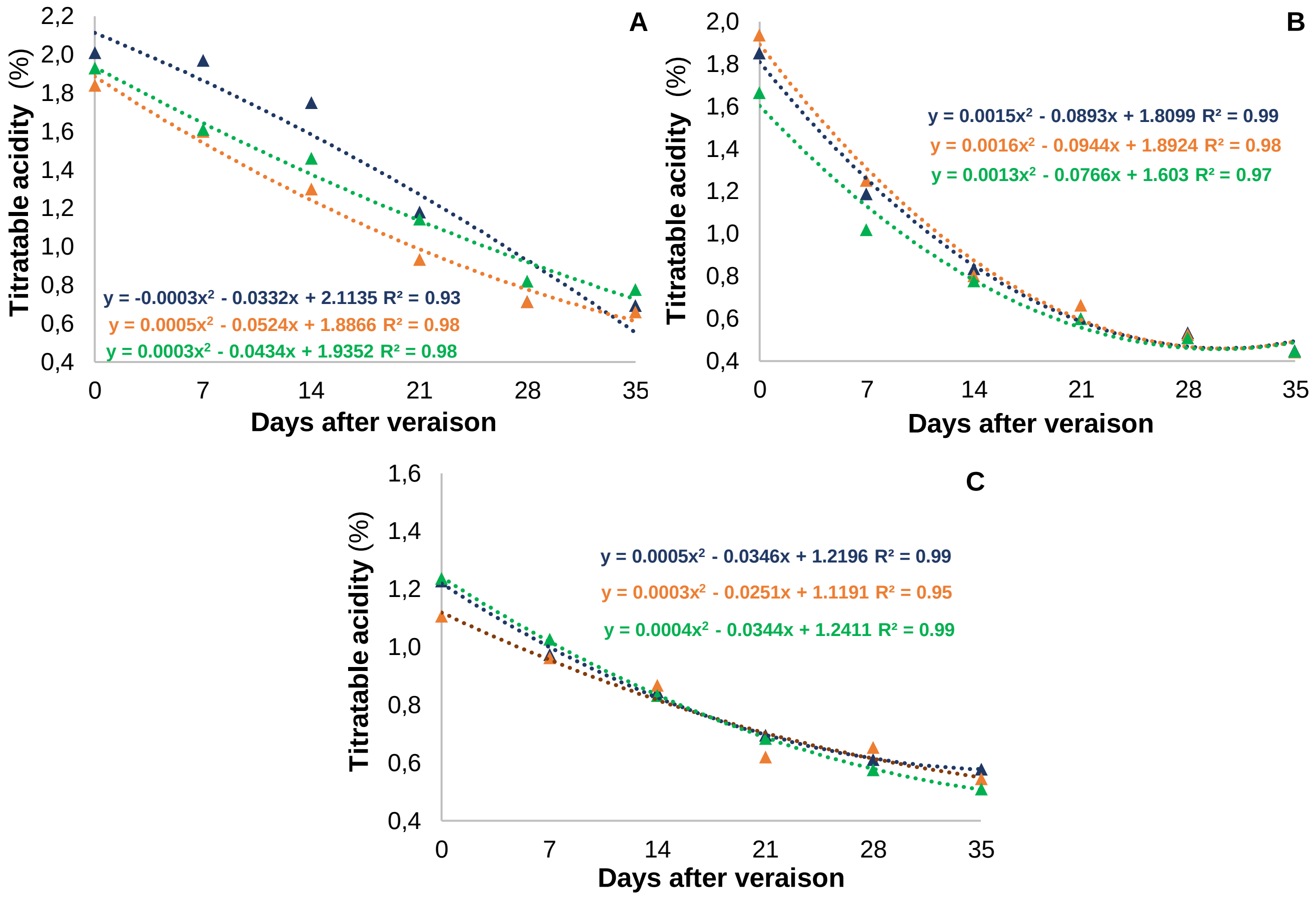
Comparing rootstocks within each harvest season, it was found that in the first and third harvest seasons, there was no difference between rootstocks, with an average duration of 138.5 and 166.4 days, respectively. However, in the second year, it was observed that the rootstocks 'IAC 572' and '1103P' promoted earliness of 8 days compared to 'IAC 766' (138 versus 146 days) (Table 3).

Analyzing the effects of years in relation to rootstock, it was observed that, regardless of the rootstock, the third harvest season was later compared to the first two years. The duration of vine cycles grafted onto 'IAC 572' in the first, second, and third years was 139.0, 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, 146.0 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 years, respectively. These values lead to the late cycle classification of 'BRS Isis', as described by Ritschel *et al*. (2013).

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 year. Overall, the thermal requirement of vines ranged from 1654.56 GD (average of the first year) to 1851.61 GD (average of the third year) (Table 3).

There was no significant difference among rootstocks in the maturation progression, as evaluated separately for the variables and production cycles under consideration. 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 maturation index 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 (Figures 5,6,7 and 8).

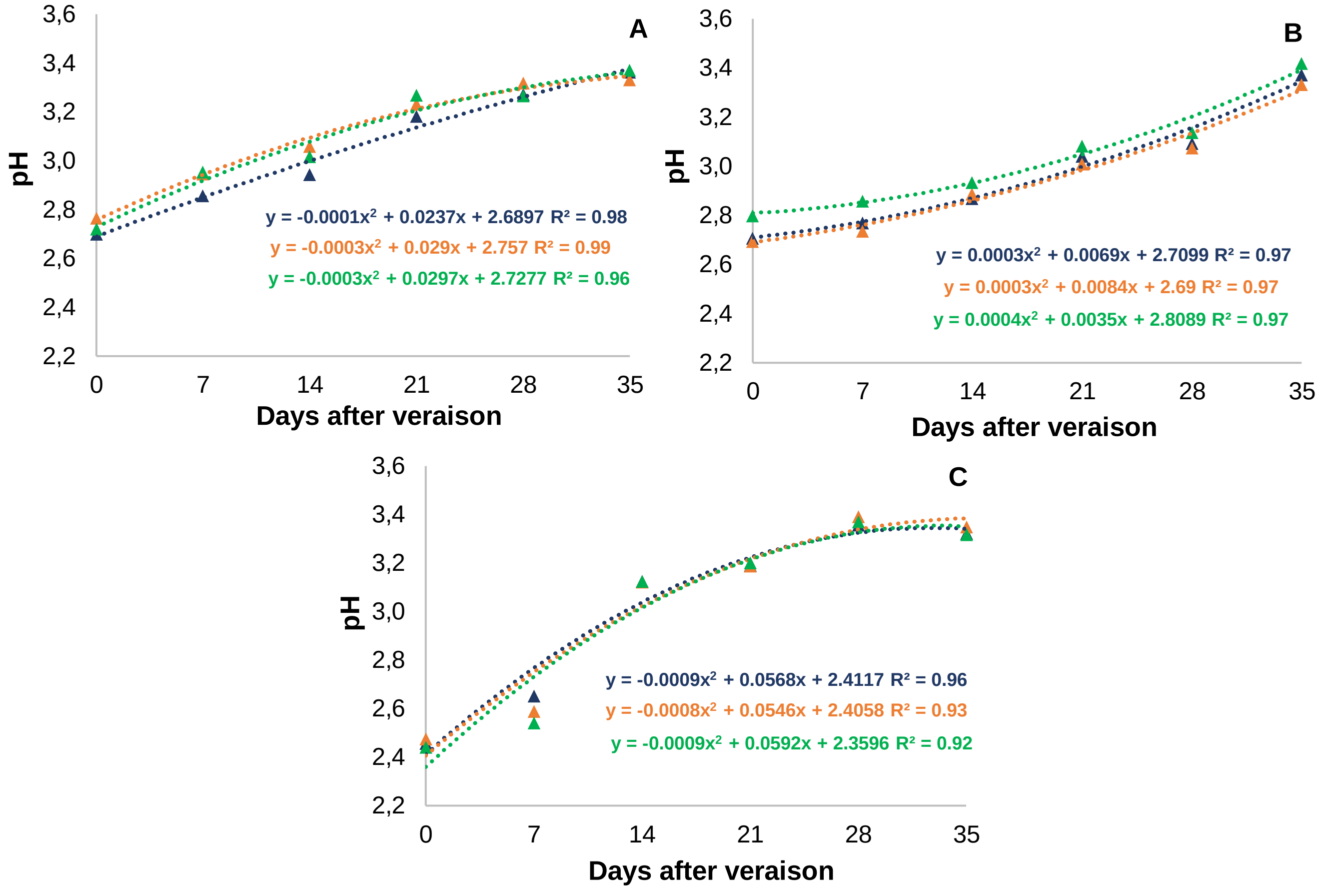
Figure 5. Modifications of titratable acidity (TA) during the ripening of 'BRS Ísis' grape grown in 2020 (A), 2021 (B) and 2022 (C).



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

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 cycle, 1.85 to 0.45% in the second cycle, and 1.23 to 0.58% in the third cycle. '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 cycles, 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 (Figure 5). 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 (Figure 6).

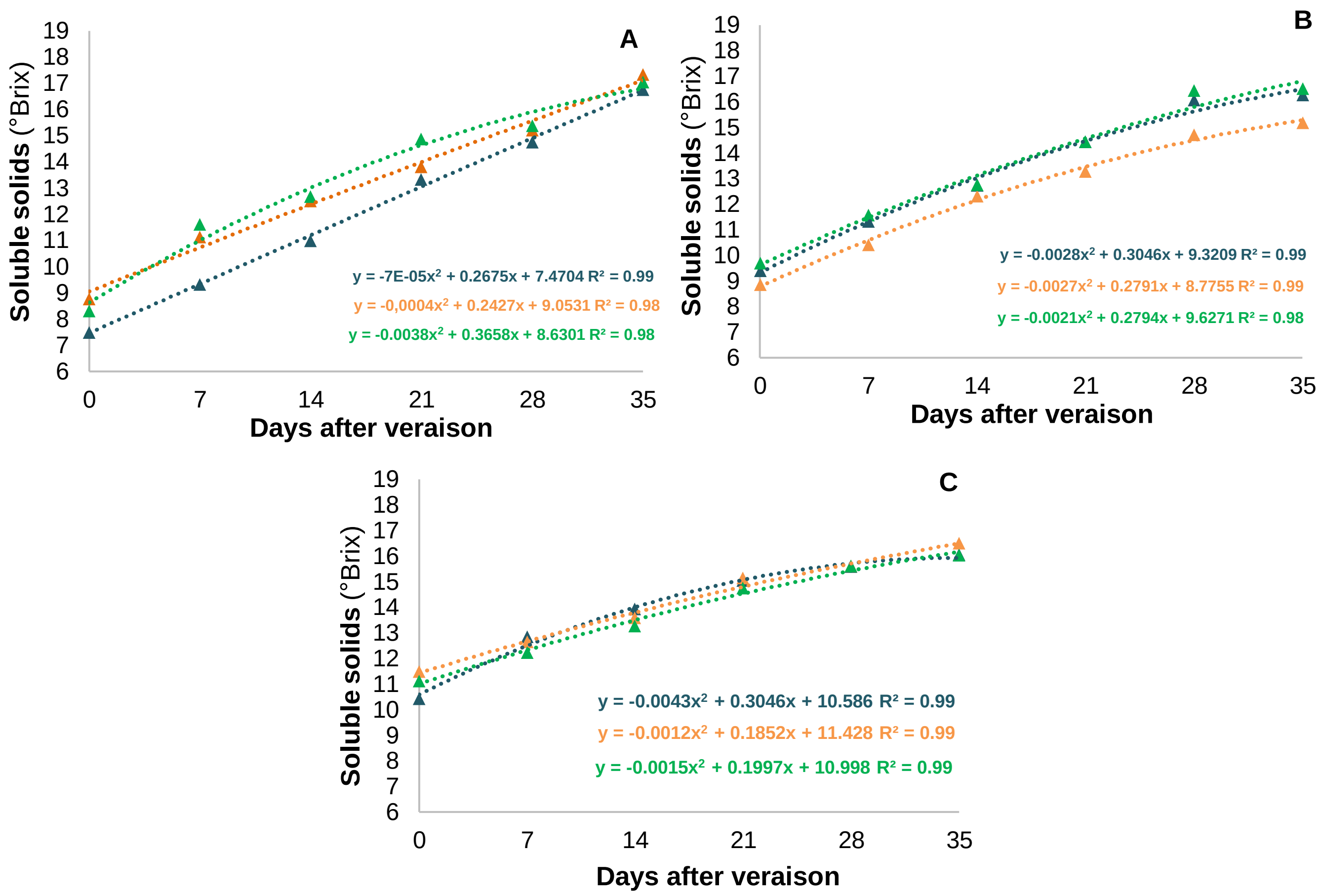
Figure 6. Modifications of pH during the ripening of ‘BRS Ísis’ grape grown in 2020 (A), 2021 (B) and 2022 (C).



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

In the first harvest, berries showed a higher soluble solids (SS) content compared to the others (Figure 7). The maximum value obtained was 17.36°Brix, from vines grafted onto 'IAC 766'. Overall, berries reached 16°Brix approximately 35 days after the onset of ripening in the first and third harvest periods. On the other hand, in the second harvest, 16°Brix was observed 28 days after the onset of ripening for rootstocks IAC 572 and Paulsen 1103, while 'IAC 766' reached 16°Brix at the end of the 35-day period after the onset of ripening.

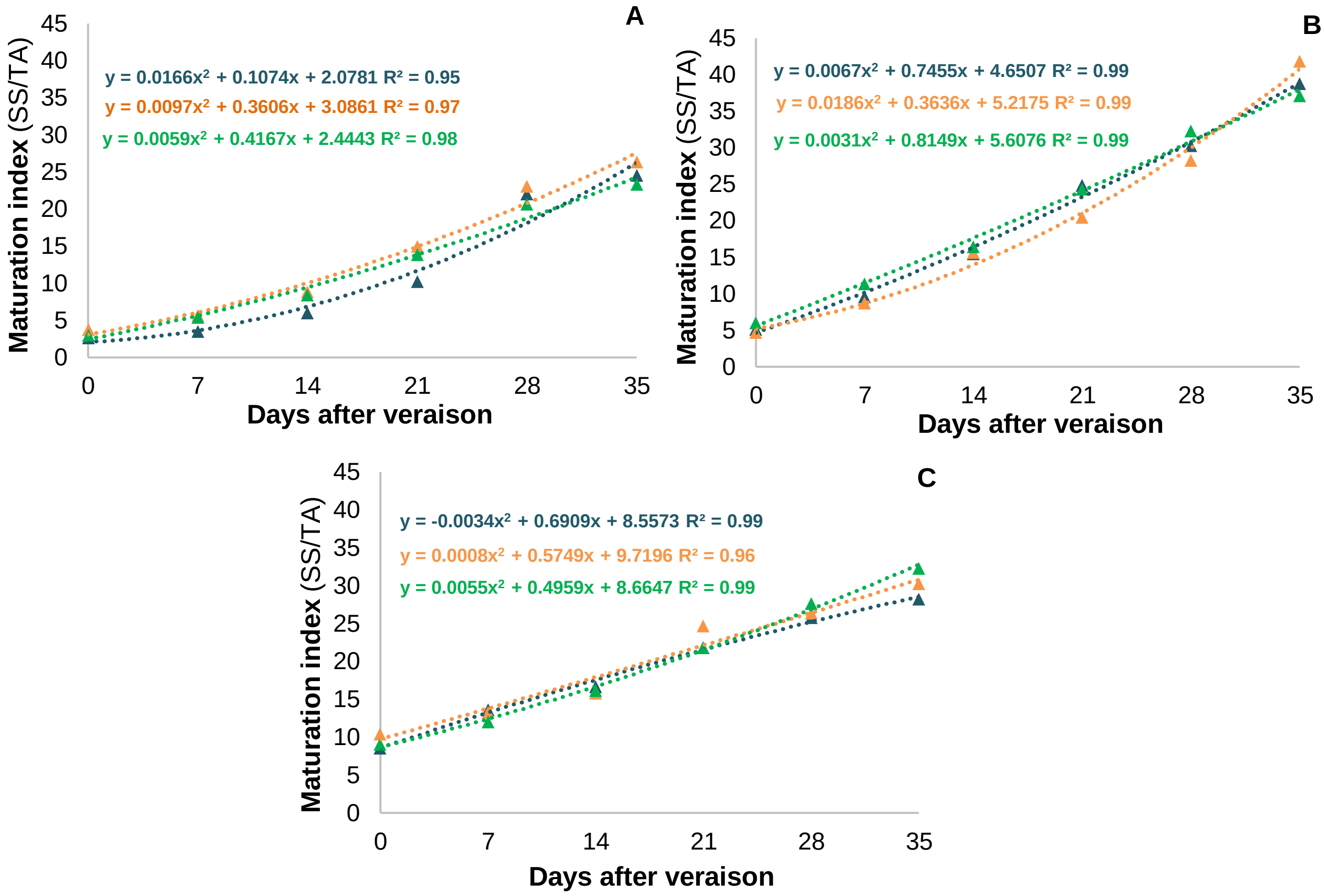
Figure 7. Modifications of soluble solids contents (SS) during the ripening of ‘BRS Ísis’ grape grown in 2020 (A), 2021 (B) and 2022 (C).



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

The maturation index values at 28 days after the onset of ripening ranged from 20.6 to 23.0 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 (Figure 8).

Figure 8. Maturation index (SS/TA) during the ripening of 'BRS Ísis' grape grown in 2020 (A), 2021 (B) and 2022 (C).



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

1.4 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 approximately 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 (Figure 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 (Figure 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 (Figure 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 the 'IAC 766' rootstock in the summer harvest showed maturation initiation at 116 days after pruning, representing a difference of 13 and 6 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.* (2022b) 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 mesothermal 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 this study during the summer harvest, that the cycle of this cultivar extended to 144 days, when 100% of the grapes show intense color, with the total soluble solids content as high as possible. 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 (Figures 2 and 3), reducing the concentration of soluble solids 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, where 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 *et al.* 2013).

The effects attributable to rootstocks can be ascribed to various factors, such as plant vigor, nutrient storage capacity, and water absorption efficiency for photosynthesis in the grapevine. These factors play a crucial role in assimilating resources needed for plant nutrition (Barros *et al.* 2015). The data from this trial support the hypothesis that most phenological responses influenced by genes of canopy cultivars grafted onto rootstocks are controlled by the canopy genotype but primarily expressed in the growing environment. Complex plant factors, such as spring growth initiation, cold resistance, and fruit maturation, may manifest non-uniformly due to variations in climatic conditions during these phases.

Leão *et al.* (2013) reported an accumulation of 1800 growing degree-days (GD) 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; Santos *et al.* 2021; Callili *et al.* 2022b), resulting in the accumulation of growing degree-days for the cultivar.

The concept of thermal requirement (TR) is established by the difference between the average temperature and the base temperature (10°C), below which vegetative development does not occur (Miranda *et al.* 2013; Tecchio *et al.* 2013). There is a correlation between increasing air temperature and decreasing grapevine productive cycle duration (Hall *et al.* 2016). This concept aids in predicting plant development in various environments and serves as a valuable indicator for analyzing plant performance in a specific cultivation area. This assessment demonstrates the required amounts of growing degree-days to complete the grapevine cycle, varying from one region to another, and besides climatic conditions, it can be altered by rootstock and canopy cultivar combinations (Sato *et al.* 2008).

The values obtained in this study (Figure 5) are similar to those found by Ritschel *et al.* (2013) for titratable acidity 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 titratable acidity during ripening is caused by various physiological processes, including organic acid dilution, berry size increase (Leão *et al.* 2023), and suppression of organic acid synthesis and transformation into sugar (Keller, 2010).

The pH range found in 'BRS Isis' must in this study (Figure 6) 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 soluble solids 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.* 2022b). In the second harvest season, lower soluble solids content was obtained, possibly due to higher rainfall during the period preceding harvest (Figure 3). 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 (Figure 3), 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 soluble solids content in berries.

In this context, it became evident that the different climatic conditions occurring during each harvest, as shown in Figure 2, influenced the chemical properties of grapes (Figures 5, 7, and 8). 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 factor 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.

1.5 CONCLUSIONS

Seasonal climate variations between production cycles had a greater impact than rootstocks on the response of the 'BRS Isis' grapevine regarding the duration of phenological stages and thermal requirements. The productive cycle duration, from pruning to harvest, ranged from 137 to 168 days, with a degree-day accumulation of 1651 to 1841 DD. This duration categorizes BRS Isis as a late-cycle grape cultivar.

Rootstocks had minimal effects on the chemical characteristics marking the progression of berry maturation in the BRS Isis cultivar, 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.

1.6 ACKNOWLEDGEMENT

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CAPÍTULO 2

PRODUCTIVITY AND PHYSICOCHEMICAL PROPERTIES OF THE BRS ISIS GRAPE ON DIFFERENTS ROOTSTOCKS UNDER SUBTROPICAL CLIMATIC CONDITIONS[3]

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Abstract: Brazil has emerged as a significant producer of seedless grapes due to high consumer demand. This has led to increased production of seedless grapes in non-traditional cultivation regions, such as subtropical areas. To meet this demand, the search for new grape varieties suitable for these conditions, such as the 'BRS Isis' variety, has become an option for growers. The interaction between grape cultivars and rootstocks is specific, and their adaptability to climatic conditions can result in uneven performance. Therefore, the choice of rootstock should be considered before making any recommendations. The purpose of this study was to assess the productive performance, physical-chemical, and biochemical properties of the 'BRS Isis' vine grafted onto rootstocks ('IAC 572', 'IAC 766', and 'Paulsen 1103') in two production cycles. The experimental design consisted of randomized blocks, with seven blocks and three plants per plot, for a total of 63 vines. Thus, the vine's income components, physical qualities of bunches and berries, chemical profile, bioactive substances, and antioxidant activity were assessed. The Tukey test (5% probability) was used to compare means between rootstocks. The data on scion cultivar and rootstock pairings were further evaluated using principal component analysis (PCA). There were substantial variations in the rootstocks, with 'IAC 572' and 'IAC 766' producing more bunches, generating more fresh mass, and having a longer bunch length than 'Paulsen 1103'. However, phenolic compounds and flavonoids were greater in 'BRS Isis' grapes than in 'Paulsen 1103'. 'BRS Isis' shows good adaptation to subtropical environments when employing the IAC 572 and IAC 766 rootstocks due to their higher yield and bioactive component accumulation compared to grapes grafted onto 'Paulsen 1103'. However, regardless of the rootstock utilized, 'BRS Isis' grapes perform well commercially in subtropical environments.

Keywords: subtropical viticulture; grafting; hybrid grapes; table grape; seedless grape; bioactive compounds

2.1 Introduction

The production of seedless grapes is an important contributor to the economy, producing a considerable number of jobs in viticulture-related businesses. With the rising worldwide demand for seedless grapes (Ahmed *et al.* 2019), business has the potential to expand, particularly in places with subtropical temperature conditions,

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where grapes with seeds such as ‘Niagara Rosada’ are planted. The major seed-grape cultivar grown in the state of São Paulo is ‘Niagara Rosada’ (Mello *et al.* 2022). As a result, under these climatic conditions, the advent of seedless-grape growing plays a significant role in addressing an increasingly demanding consumer market.

Because of their good quality attributes (El Gengaihi *et al.* 2013), seedless grapes have gained in popularity as a result of customer acceptability. In this regard, Embrapa introduced the seedless grape ‘BRS Isis’ in 2013, the result of a hybrid between CNPUV 681-29 [Arkansas 1976 X CNPUV 147-3 (‘Niagara White’ × ‘Vênus’)] and ‘BRS Linda’. This cultivar is tolerant to downy mildew and adapts well to Brazil’s many temperatures. ‘BRS Isis’ has a high bud fertility, a hard and crisp texture, big red berries, and a sugar content ranging from 16 to 22 °Brix (Ritschel *et al.* 2013).

Grafting is commonly used in worldwide viticulture to prevent phytosanitary issues that impact the plant’s root system, as well as abiotic difficulties, and for adaptability to low-fertility soils, flooded soils, water shortage, saline soils, and other unfavourable condition effects (Peterson *et al.* 2017). The Agronomic Institute of Campinas (IAC) developed the main rootstocks used in Brazil, with the following being the most regularly used: IAC 313 ‘Tropical’, which is primarily used in the São Francisco Valley (Leão *et al.* 2018); IAC 766 ‘Campinas’ and IAC 572 ‘Jales’, which are currently among the most frequently employed in viticulture in the State of São Paulo (Tecchio *et al.* 2018). In addition, regions employing Paulsen 1103 and SO4 rootstocks (*V. riparia* × *V. berlandieri*) and, to a lesser degree, Freedom and Harmony [C1613 (Solonis Othello) X Dogridge] have increased in recent years.

Numerous studies have indicated that more robust rootstocks enhance production while decreasing levels of phenolic compounds and soluble solids in grape berries (Borges *et al.* 2013; Ibacache *et al.* 2016; Silva *et al.* 2018). However, the interaction between rootstock and scion variety is quite specific, as are adaptations to climatic conditions (Vrsic *et al.* 2015; Tecchio *et al.* 2020), which may result in non-uniform performance (Silva *et al*. 2018; Yağci *et al*. 2022), as well as in the absorption, accumulation, and translocation of nutrients (Fisarakis *et al.* 2005; Tecchio *et al*. 2011). Cookson *et al.* (2012) state that the unique compatibility and interaction between the scion cultivar and the rootstock can alter the vine’s growth and vigour based on climatic and nutritional parameters, as well as the cultivar’s bud fertility (Aliquó *et al.* 2010).

Based on the foregoing, the current study sought to assess the productive and physical-chemical features of the grape ‘BRS Isis’ grown on the rootstocks ‘IAC 572’, ‘IAC 766’, and ‘Paulsen 1103’ under subtropical climatic conditions.

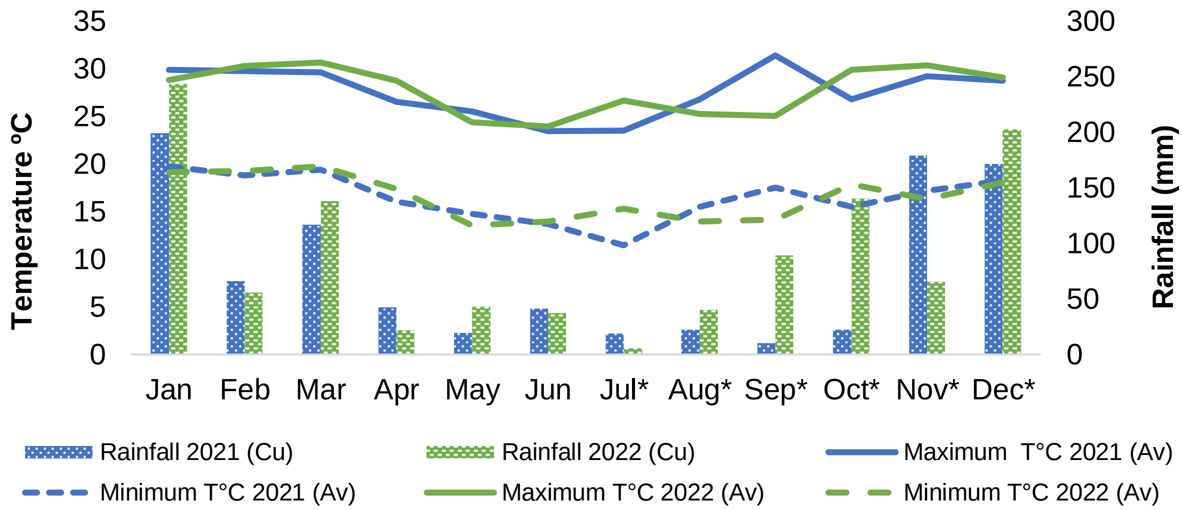
2.2 MATERIALS AND METHODS

The experiment was conducted in a research vineyard located in the Experimental Farm of the School of Agriculture (FCA) at UNESP (22°46′35″ S and 48°34′08″ O; elevation 773 m) in São Manuel, São Paulo, Brazil, during the summer production cycles of 2021 and 2022. The climate is classified as *Cfa* (subtropical with hot summers) by Köppen. According to the Brazilian soil classification system, the soil is classed as a dystroferric Red Oxisol with a sandy texture (Santos *et al.* 2018). The same soil is classed as Dystrophic Typic Hapludox using the USDA (United States Department of Agriculture) Soil Taxonomy (Soil Survey Staff, 1999).

The experimental design consisted of randomized blocks of the cultivar ‘BRS Isis’ (‘CNPUV 681-29′ X ‘BRS Linda’) grafted onto three different rootstocks, with seven blocks and three plants per plot, for a total of 63 vines. ‘IAC 572 Jales’ [*Vitis caribaea* × (*Vitis riparia* × *Vitis rupestris* 101-14)], ‘IAC 766 Campinas’ (Riparia do Traviú × *Vitis caribaea*), and ‘Paulsen 1103’ (*Vitis berlandieri* × *Vitis rupestris*) were utilized as rootstocks.

A meteorological station near the experimental region recorded daily rainfall (mm) and maximum, minimum, and average temperatures (°C) during the experimental period. Between July and December of each year, the average lowest and maximum temperatures were roughly 15.9 °C and 27.7 °C, respectively. In the years 2021 and 2022, the cumulative rainfall was 424 mm and 543 mm, respectively (Figure 1).

Figure 1. Maximum and minimum temperatures and precipitation between the 2021/22 and 2022/23 cycles. Source: Data provided by the Department of Soils and Environmental Resources, 2023.



* Production period. The bars represent the total amount of rain, while the solid lines represent maximum temperatures and the dotted lines represent the minimum temperatures.

Rootstock cuttings were planted in August 2018, and scions were grafted in July 2019. The row spacing was 3.0 m and the plant spacing was 2.0 m (density of 1667 plants per hectare). A "Y"-shaped support system was adopted, with a metal framework reinforced with treated eucalyptus posts. The watering system made use of micro-sprinklers. A polyethylene screen with 18% shading was employed to defend against birds from the beginning of bunch maturity until harvest.

Phytosanitary control, fertilizing, debudding, defoliation, denetting, and branch and bunch thinning were all carried out in line with Ritschel *et al.* (2013) recommendations.

Production pruning for the cycles 2021 and 2022 was completed in August and July, respectively. Hydrogen cyanamide (2.5%) was sprayed after pruning to encourage and normalize bud sprouting. The grape harvest was calculated using the maturity curve, when the soluble solids content stabilized in the interim between two samplings at 16 °Brix.

At harvest, the number of bunches per vine was counted and the yield per plant (kg $vine^{-1}$) was calculated using their mass. Yield (t ha^{-1}) was calculated using a density of 1666 plants per hectare as a function of production per vine and planting spacing.

The mass (g), length (cm), and breadth (cm) of bunches, stalks, and berries were used to determine their physical attributes. The berry diameter is computed as the berry length divided by the berry width, using a graduated ruler, expressed in cm. Each bunch's berry count was also recorded. For these evaluations, ten bunches were selected from each plot, and ten berries were removed from each bunch, for a total of 100 berries per plot. The number of berries per bunch was estimated using the relation [(bunch mass − rachis mass)/berry mass].

The soluble solids content (SS, reported in °Brix), titratable acidity (TA, stated in percentage of tartaric acid), pH, and ripeness index (SS/TA) of the grape must were determined. Direct refractometry of the grape must was used to estimate SS via the use of a digital refractometer (Reichert®, model r2i300, Depew, NY, USA), and the findings were represented in Brix. The pH of the grape must was established by directly reading it (Tecnal® model Tec-10 potentiometer, Piracicaba, Brazil). Titration with 0.1 N NaOH to the equivalency point of pH = 8.2 yielded TA, which was stated as a percentage of tartaric acid. The maturity index was computed as the ratio of SS to TA.

The total phenolic component content of the peel and pulp was calculated using the Folin–Ciocalteu reagent (Singleton *et al.* 1965) and represented in milligrams of gallic acid equivalent (GAE) per kilogram of peel and pulp (mg GAE 100 mg^{-1}). Popova *et al.* (2004) developed a technique for determining total flavonoid content. The pH differential technique (Giusti *et al.* 2001) was used to quantify the monomeric anthocyanin content, which was expressed as malvidin 3,5-diglucoside equivalents per 100 mg^{-1}.

Statistical analyses were performed on the outcomes of the two manufacturing cycles. To investigate the influence of the rootstocks on the scion cultivar, the results were subjected to analysis of variance (ANOVA). The Tukey test (5% probability) was used to compare means amongst rootstocks using the statistical program SISVAR® version 5.7 (Lavras, MG, Brazil).

The data from scion cultivar and rootstock pairings were further evaluated using principal component analysis (PCA) using the XLSTAT program (Addinsoft, NY, USA).

2.3. RESULTS AND DISCUSSION

2.3.1. PRODUCTIVITY FEATURES

‘BRS Isis’ grown on ‘IAC 572’ and ‘IAC 766’ produced more bunches as well as more kg per plant than when grown on ‘Paulsen 1103’, with 37.4, 36.1, and 21.2 bunches per plant and 18.42, 18.05, and 11.99 kg per plant, respectively. As a result, production was higher when ‘IAC 572’ and ‘IAC 766’ were used, with 30.7 and 30.0 t per hectare, respectively (Table 1). Other table-grape cultivars that were grafted onto ‘Paulsen 1103’ (Ibacache *et al.* 2016), ‘IAC 572’, and ‘IAC 766’ (Leão *et al.* 2020), as well as grape cultivars for processing juices (Silva *et al.* 2018) and wines (Tecchio *et al.* 2022), showed a positive correlation between production and number of bunches.

Table 1. Productive performance and vigour of ‘BRS Isis’ vine grown on different rootstocks under subtropical conditions in two consecutive production cycles.

Yield Components	Rootstocks			
	IAC 572 Jales	**IAC 766 Campinas**	**Paulsen 1103**	***p*-Value**
Yield per vine (kg vine^{-1})	18.42 ± 3.13 a	18.05 ± 1.72 a	11.99 ± 1.93 b	>0.01
Productivity (t ha^{-1})	30.70 ± 5.22 a	30.09 ± 2.86 a	19.99 ± 3.22 b	>0.01
Number of bunches per vine	37.40 ± 8.78 a	36.11 ± 10.64 a	21.19 ± 4.28 b	>0.01

Values are expressed as mean (two cycles) ± standard deviation (n = 7). Values followed by different letters on the same line differ significantly (Tukey test, $p < 0.05$).

Ahmed *et al.* (2019) reported a higher yield (36.5 t/ha/cycle) under subtropical circumstances utilizing the ‘IAC 766’ rootstock, with greater spacing and a low-altitude location. The yield observed in the current study, on the other hand, is like that reported by Ritschel *et al*. (2013) of 26 t/ha/cycle and higher than that reported for this cultivar (Leão *et al.* 2016; Leão *et al.* 2018), representing a 7% increase over the average yield of 25 t/ha/cycle under semi-arid conditions. Because of their increased tolerance to subtropical environments, both ‘IAC 766’ and ‘IAC 572’ rootstocks offered higher yield in this research. Higher yields have been observed in vines for fresh consumption grafted onto ‘IAC 572’, such as ‘Niagara Rosada’ and ‘Vênus’, in subtropical high-altitude climates (Mota *et al.* 2009) and tropical climates (Tecchio *et al.* 2019). The table grape ‘BRS Maria Bonita’ yielded more in a semi-arid tropical region when grown with the ‘IAC 766’ rootstock (Leão *et al.* 2023). As a result, production is affected by rootstock as well as climate and cultivation circumstances. However, in terms of yield, ‘IAC 766’ appears to be a promising rootstock for usage in both subtropical and tropical climates.

These yield discrepancies might be attributed to the interspecific connection between the scion cultivar and the rootstock. Maia *et al.* (2012) classifies the rootstocks ‘IAC 572’ and ‘IAC 766’ as high-vigour, suggesting that both rootstocks are more suited to subtropical and tropical climatic conditions than ‘Paulsen 1103’. The poor yield of ‘Paulsen 1103’ is attributable to the interaction with the scion cultivar, rootstock genotype, and its origin, since it is from a Mediterranean region with dry summers and wet winters (Bettiga *et al.* 2003). Furthermore, ‘BRS Isis’ is a strong cultivar with exuberant growth that is better compatible with ‘IAC’ rootstocks (Ritschel *et al.* 2013).

2.3.2. PHYSICAL FEATURES OF THE BUNCH

Both the fresh bunch mass ($p > 0.05$) and bunch length ($p > 0.01$) of the ‘BRS Isis’ table grape differed significantly between rootstocks. Bunches from ‘IAC 766’ had the largest mass (502.58 g), followed by ‘IAC 572’ and ‘Paulsen 1103’, with 458.26 and 387.22 g, respectively (Table 2). These findings outperform those reported by Ritschel *et al.* (2013) for ‘BRS Isis,’ who reported 348.12 g under tropical circumstances on the ‘IAC 572’ rootstock and 292.53 g in semi-arid settings on the ‘IAC 313’ and ‘SO4’ rootstocks. Under tropical circumstances, ‘IAC 572’ had a substantial impact on the bunch length of ‘BRS Isis’ compared to ‘Paulsen 1103’, with, respectively, 18.4 and 16.99 cm (Table 2). When evaluating the influence of rootstocks under semi-arid circumstances, (Leão *et al.* 2020) found that ‘BRS Isis’ on ‘IAC 572’ had a larger curl length than on ‘Paulsen 1103’, a behaviour like that seen in the current study. More robust rootstocks often have a greater ability for water and nutrient absorption and translocation, which benefits scion performance (Silva *et al.* 2022).

Table 2. Physical characteristics of bunches, berries, and rachis of ‘BRS Isis’ grown on different rootstocks under subtropical conditions in two consecutive production cycles.

Physical Characteristics of Bunches, Berries, and Rachis	Rootstocks			
	IAC 572 Jales	**IAC 766 Campinas**	**Paulsen 1103**	***p*-Value**
Number of berries per bunch	72.28 ± 13.38	78.28 ± 15.70	64.14 ± 8.69	0.07
Bunch mass (g)	458.3 ± 110 ab	502.58 ± 84.08 a	387.72 ± 49.06 b	>0.05
Bunch length (cm)	18.4 ± 1.64 a	18.34 ± 0.88 ab	16.99 ± 0.57 b	>0.01
Bunch width (cm)	8.67 ± 1.16	9.42 ± 0.66	9.48 ± 0.58	0.10
Berry Mass (g)	6.23 ± 0.61	6.34 ± 0.46	5.91 ± 0.40	0.23
Berry Length (cm)	3.03 ± 0.17	3.04 ± 0.13	2.95 ± 0.11	0.42
Berry Width (cm)	1.60 ± 0.08	1.62 ± 0.15	1.63 ± 0.13	0.84
Berry diameter (cm)	1.81 ± 0.13	1.77 ± 0.11	1.80 ± 0.17	0.61
Rachis mass (g)	12.59 ± 3.06	13.34 ± 2.08	11.31 ± 1.50	0.14

Values are expressed as mean (two cycles) ± standard deviation (n = 7). Values followed by different letters on the same line differ significantly (Tukey test, $p < 0.05$).

The rootstocks utilized with ‘BRS Isis’ had no significant effect on the physical properties of the berry and rachis (Table 2), yielding average values of 6.23 g of berry mass, 3.03 cm of length, 1.6 g of berry breadth, 1.81 cm of diameter, and 12.59 g of rachis mass. In comparison to the current study, Ahmed *et al.* (2019) discovered similar values for the physical properties of berries and bunches, with 6.5 g of fruit mass, 2.7 cm in length, 1.9 cm in diameter, and bunches weighing 521 g on average. It is vital to note that a minimum diameter of 1.2 cm is necessary for the commercialization of table grapes on the national and international markets (Brasil, 2002), with implied averages between 1.4 and 1.7 cm to maximize the value and quality of bunches for export (Santos *et al.* 2013, Santos *et al.* 2015). ‘BRS Isis’ achieved these values in this case, independent of the rootstock utilized, with berry diameter values of 1.79 cm.

Several authors, however, documented considerable impacts of the rootstock on the morphological properties of the fruit and rachis across multiple table- and processing-grape varieties (Satisha *et al.* 2010, Tecchio *et al.* 2014, Aly *et al*. 2015, Ibacache *et al.* 2016, Silva *et al.* 2018). According to Bascunán-Godoy *et al.* (2017), the amount of vigour transmitted to the scion by different rootstocks is a critical component in modifying the physical features of grapes. The rootstock’s descendant genotype influences gene expression in the crown of grafted vines, indicating that rootstock interaction, even when subtle, is complex, manifesting itself with certain factors such as time and adaptability to soil conditions and climate (Callili *et al.* 2023, Harris *et al.* 2023). The improved performance of 'BRS Isis' grafted onto 'IAC 572' and 'IAC 766' rootstocks is attributable to greater adaptation to the research site's edaphoclimatic conditions (*Cfa* climate and distroferric Red Latosol).

2.3.3. CHEMICAL PROPERTIES OF THE GRAPE MUST

The chemical properties of 'BRS Isis' grape berries grown on different rootstocks showed no significant variations ($p > 0.05$) (Table 3). Regardless of the rootstock employed, the titratable acidity in the grape must of 'BRS Isis' grapes ranged from 0.39 to 0.42% (Table 3). The average values are lower than those found by Ahmed *et al.* (2019), i.e., 0.40 versus 0.70. They do, however, coincide with the range reported by Ritschel *et al.* (2013) (0.34 to 0.55). Leão *et al.* (2020) reported that rootstocks had no effect on the titratable acidity of 'BRS Isis' must under semi-arid circumstances, with values lower than those found in this study (0.40 versus 0.38). Multiple factors, including genetic characteristics (Liu *et al.* 2005), physiological processes (Lee *et al.* 2013), temperature variation, light intensity, and rainfall (Neumann *et al.* 2014), promote TA reduction during ripening, resulting in variation in vine metabolism, which can promote or hinder grape genetic potential (Ribeiro *et al.* 2012).

Table 3. Chemical composition of 'BRS Isis' grapes grown on different rootstocks under subtropical conditions in two consecutive production cycles.

Chemical Parameters of Grape Must	Rootstocks			
	IAC 572 Jales	IAC 766 Campinas	Paulsen 1103	*p*-Value
Titratable acidity (%)	0.42 ± 0.05	0.39 ± 0.02	0.41 ± 0.06	0.46
pH	3.45 ± 0.03	3.45 ± 0.05	3.44 ± 0.06	0.69
Soluble Solids (°Brix)	16.43 ± 0.33	16.38 ± 0.39	16.71 ± 0.33	0.28
Maturation index (SS/AT)	39.11 ± 5.45	42.00 ± 1.53	40.75 ± 6.42	0.43

Values are expressed as mean (two cycles) ± standard deviation ($n = 7$). Values followed by different letters on the same line differ significantly (Tukey test, $p < 0.05$).

The pH of the ‘BRS Isis’ rootstock requirement was 3.45 (Table 3). The authors of (Ahmed *et al*. 2019, Ritschel *et al.* 2013) reported higher values ranging from 3.78 to 4.4. The concentrations of tartaric and malic acid, the primary acids present in vines, as well as the concentration of potassium (K) in the soil and must, are closely connected to the overall acidity of the grape (Mota *et al.* 2010). The lower pH discovered in this study might be attributed to the lower concentration of minerals in the soil solution, particularly K, the type of soil, the quantities of nitrogen fertilizer applied, rainfall, and the vine’s vegetative vigour (Rizzon *et al.* 1998).

The varied rootstocks had no effect on the soluble solids in the grape must in the two cycles studied. The average soluble solids of the rootstocks were 16.5 °Brix (Table 3). The current study’s results outperformed those obtained by Ahmed *et al.* (2019) and Leão *et al.* (2020), which ranged from 14.2 to 16.4 °Brix. Ritschel *et al.* (2013) found that ‘BRS Isis’ had a range of soluble solids concentration at complete maturity between 16 and 21 °Brix, which was comparable to what was discovered in the current study. The reactions in soluble solids content based on rootstock relate to aspects such as cultivar genetics, seasonal fluctuations, cultural management, and different vineyard management methods, with inconsistent results in the literature (Leão *et al.* 2020).

In terms of the ripening index, which is determined from the ratio of sugar to acidity contents (SS/TA), the low acidity obtained for ‘BRS Isis’ resulted in higher ripening index (40.6) values among the rootstocks. This result falls within the ‘BRS Isis’ range established by Ritschel *et al.* (2013), which is between 38 and 48. The maturity index can suggest a grape cultivar’s perfect balance of sugar and acidity for a specific location; however, it should normally be more than 18 (Ahmed *et al.* 2019).

2.3.4. BIOACTIVE COMPOUNDS OF THE GRAPE MUST

Significant variations in total phenol and total flavonoid levels in the grape must were promoted by the rootstocks. The greatest total phenol content was obtained when ‘BRS Isis’ was grafted onto ‘Paulsen 1103’ (123.89 mg 100 g^{-1}), as opposed to those grafted onto ‘IAC 572’ and ‘IAC 766’, which had similar values of 109.93 and 110.08 mg 100 g^{-1}. ‘BRS Isis’ had the greatest total flavonoid content when grafted onto ‘Paulsen 1103’ and ‘IAC 572 Jales’ (12.45 and 12.44 mg/100 g, respectively) compared to ‘IAC 766’ (6.70 mg 100 g^{-1}) (Table 4).

Table 4. Biochemical composition of ‘BRS Isis’ grapes grown on different rootstocks under subtropical conditions in two consecutive production cycles.

Total Bioactive Compounds	Rootstocks			
	IAC 572 Jales	**IAC 766 Campinas**	**Paulsen 1103**	***p*-Value**
Total Phenolics (mg 100 g^{-1})	109.93 ± 2.47 b	110.08 ± 4.76 b	123.89 ± 1.47 a	<0.01
Total Flavonoids (mg 100 g^{-1})	12.44 ± 0.39 a	6.70 ± 0.20 b	12.45 ± 0.28 a	<0.01
Total Monomeric Anthocyanins (mg 100 g^{-1})	26.84 ± 7.24	32.84 ± 3.37	43.04 ± 6.35	0.1

Values are expressed as mean (two cycles) ± standard deviation (n = 7). Values followed by different letters on the same line differ significantly (Tukey test, $p < 0.05$).

The total phenol concentration of the three rootstocks employed was greater than that reported by Ahmed *et al*. (2019) for ‘BRS Isis’ grapes grafted onto ‘IAC 766’ in a tropical environment (26.1 mg 100 g^{-1}). Lower levels of total phenols were also reported in ‘Redglobe’ (Özcan *et al.* 2017) and ‘BRS Clara’ (Brito *et al.* 2019) grapes grafted onto ‘Paulsen 1103’, namely 97.413 mg 100 g^{-1} and 81.39 mg 100 g, respectively. According to Ritschel *et al*. (2013), 'BRS Isis' accumulated 2.5 times more anthocyanins and a 30% higher polyphenol content compared to Crimson Seedless produced in the São Francisco Valley.

These findings highlight the great diversity in the rootstock’s effect on the biosynthesis and composition of these chemicals (Corso *et al.* 2016), as well as the direct influence of climatic factors such as temperature, light, and precipitation (Ahmed *et al.* 2019). The optimal canopy, training method, and rootstock combination optimizes variety performance, resulting in climatic adaptability, high yield, and superior fruit quality (Neto *et al.* 2023).

The heightened accumulation of phenols, flavonoids, and anthocyanins in grapevines is intricately associated with the inadequate acclimatization of the rootstock to subtropical conditions, consequently leading to enhanced physiological stress in the vine and ultimately culminating in an augmented synthesis of these chemical constituents (Neto *et al.* 2023, Pereira *et al.* 2018); In other words, the rootstock Paulsen 1103 exhibits lower adaptability to subtropical conditions in comparison to the rootstocks IAC 572 and IAC 766. Studies have demonstrated that phenolic compounds can function as antioxidants that scavenge free radicals. Furthermore, the consumption of polyphenol-rich foods may be associated with a reduced risk of chronic diseases, such as cardiovascular diseases, cancer, and diabetes (Silva *et al.* 2022).

Rootstocks had little effect on anthocyanin levels, which averaged 34.24 mg 100 g ^{1}. Ahmed *et al.* (2019) reported 30 mg 100 g^{-1} in 'BRS Isis,' which is like the amount reported in the current study when the 'IAC 766' rootstock was utilized (32.84 mg 100 g^{-1}). These results, however, are lower than the combination of 'BRS Isis' and the 'Paulsen 1103' rootstock (43.04 mg 100 g^{-1}) (Table 4). The difference in anthocyanin concentration of 'BRS Isis' grapes between this study and Ahmed *et al.* (2019) is attributable to the use of different rootstocks, as well as the effects of meteorological conditions and soil type. Furthermore, bunch thinning (load modification) has been shown to increase the formation of certain phenolic compounds (Fanzone *et al.* 2011). Ahmed *et al*. (2019) noticed a higher yield and lower concentration of bioactive compounds in 'BRS Isis' compared to those reported in this work, which could be explained by the negative correlation of production variables, productivity, and number of bunches per plant in relation to total anthocyanins, which was $r = -0.9$, ($p > 0.01$) (Table 5).

Rootstocks that favour the accumulation of these compounds can enhance the market value of grapes, especially if they are intended for the production of antioxidant-rich red wines (Silva *et al.* 2022). Furthermore, the health benefits associated with consuming grapes rich in phenolics and flavonoids can be a significant marketing factor for producers. Therefore, careful rootstock selection is crucial for optimizing the quality and value of 'BRS Isis' grapes in the market. In addition to phenolic acids, grape pulp also contains primary metabolites such as organic acids and sugars (Li *et al.* 2013). Glucose, fructose, and tartaric and malic acids are the compounds that most contribute to the sweetness and acidity of grapes (Rizzon *et al.* 1998). These characteristics significantly influence their organoleptic quality (Ahmed *et al.* 2019, Silva *et al*. 2019).

Table 5. Pearson dynamic analysis between all variables.

Traits	YldV	Pdt	NBchV	BchM	BchL	BchW	BM	BL	BW	RM	BD	NBBch	SS	pH	TA	MI	TPC	TF	TMA
YldV	**1**	1,000	1,000	0,908	1,000	1,000	0,955	0,983	0,712	0,891	-0,068	0,890	-0,507	0,919	-0,045	-0,123	-0,999	-0,457	-0,948
Pdt	1,000	**1**	1,000	0,908	1,000	1,000	0,955	0,983	0,712	0,891	-0,068	0,890	-0,507	0,919	-0,045	-0,123	-0,999	-0,457	-0,948
NBchV	1,000	1,000	**1**	0,899	0,999	1,000	0,949	0,979	0,698	0,882	-0,048	0,881	-0,490	0,911	-0,025	-0,143	-0,998	-0,439	-0,954
BchM	0,908	0,908	0,899	**1**	0,914	0,900	0,991	0,970	0,941	0,999	-0,480	0,999	-0,822	1,000	-0,460	0,305	-0,924	-0,787	-0,727
BchL	1,000	1,000	0,999	0,914	**1**	0,999	0,959	0,985	0,722	0,898	-0,082	0,897	-0,520	0,925	-0,059	-0,109	-1,000	-0,469	-0,943
BchW	1,000	1,000	1,000	0,900	0,999	**1**	0,949	0,980	0,700	0,883	-0,050	0,882	-0,492	0,912	-0,027	-0,140	-0,998	-0,441	-0,953
BM	0,955	0,955	0,949	0,991	0,959	0,949	**1**	0,993	0,889	0,986	-0,362	0,985	-0,741	0,995	-0,340	0,178	-0,966	-0,701	-0,810
BL	0,983	0,983	0,979	0,970	0,985	0,980	0,993	**1**	0,829	0,959	-0,251	0,959	-0,657	0,976	-0,228	0,062	-0,990	-0,613	-0,873
BW	0,712	0,712	0,698	0,941	0,722	0,700	0,889	0,829	**1**	0,953	-0,749	0,954	-0,966	0,931	-0,733	0,609	-0,740	-0,950	-0,451
RM	0,891	0,891	0,882	0,999	0,898	0,883	0,986	0,959	0,953	**1**	-0,513	1,000	-0,843	0,998	-0,493	0,341	-0,909	-0,810	-0,700
BD	-0,068	-0,068	-0,048	-0,480	-0,082	-0,050	-0,362	-0,251	-0,749	-0,513	**1**	-0,515	0,894	-0,455	1,000	-0,982	0,109	0,919	-0,253
NBBch	0,890	0,890	0,881	0,999	0,897	0,882	0,985	0,959	0,954	1,000	-0,515	**1**	-0,844	0,998	-0,495	0,343	-0,908	-0,812	-0,699
SS	-0,507	-0,507	-0,490	-0,822	-0,520	-0,492	-0,741	-0,657	-0,966	-0,843	0,894	-0,844	**1**	-0,805	0,884	-0,793	0,542	0,998	0,206
pH	0,919	0,919	0,911	1,000	0,925	0,912	0,995	0,976	0,931	0,998	-0,455	0,998	-0,805	**1**	-0,434	0,277	-0,935	-0,770	-0,746
TA	-0,045	-0,045	-0,025	-0,460	-0,059	-0,027	-0,340	-0,228	-0,733	-0,493	1,000	-0,495	0,884	-0,434	**1**	-0,986	0,086	0,909	-0,276
MI	-0,123	-0,123	-0,143	0,305	-0,109	-0,140	0,178	0,062	0,609	0,341	-0,982	0,343	-0,793	0,277	-0,986	**1**	0,082	-0,827	0,433
TPC	-0,999	-0,999	-0,998	-0,924	-1,000	-0,998	-0,966	-0,990	-0,740	-0,909	0,109	-0,908	0,542	-0,935	0,086	0,082	**1**	0,493	0,934
TF	-0,457	-0,457	-0,439	-0,787	-0,469	-0,441	-0,701	-0,613	-0,950	-0,810	0,919	-0,812	0,998	-0,770	0,909	-0,827	0,493	**1**	0,149
TMA	-0,948	-0,948	-0,954	-0,727	-0,943	-0,953	-0,810	-0,873	-0,451	-0,700	-0,253	-0,699	0,206	-0,746	-0,276	0,433	0,934	0,149	**1**

Values in bold are different from 0 with a significance level of alpha = 0.05. Trait abbreviations: number of bunches per vine [NBchV], yield per vine [YldV], productivity [Pdt], bud fertility [BdF], bunch mass [BchM], bunch length [BchL], bunch width [BchW], berry mass [BM], berry length [BL], berry width [BW], rachis mass [RM], berry diameter [Bd], number of berries per bunch [NBBch], soluble solids [SS], titratable acidity [TA], maturation index [MI], total phenolic compounds [TPC], total flavonoids [TF], total monomeric anthocyanins [TMA].

2.3.5. PRINCIPAL COMPONENT ANALYSIS (PCA)

Principal component analysis (PCA) revealed that the first two principal components (PCs) explained 100% of the variation and these were utilized to visualize the data in a two-dimensional format (Figure 2). PC1 accounted for 74.59% of the overall data variability, encompassing factors such as bioactive substances, productive properties, and morphological features of the bunch, berries, and stalk. The PC1 study showed that it was successful in separating the rootstocks, primarily ‘IAC 572’.

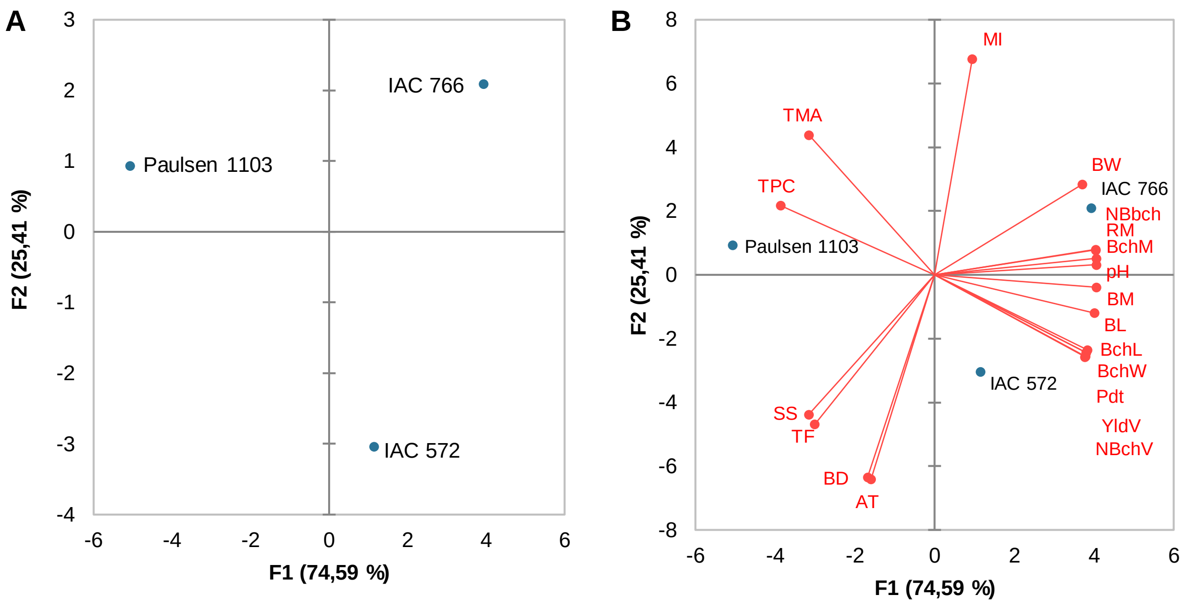


Figure 2. Principal component analysis of 19 yield components and physicochemical traits in 3 scion–rootstock grapevine combinations. Scores plot (**A**) and loadings plot (**B**). Scion–rootstock combinations: ‘BRS Isis’; ‘IAC 766’, ‘IAC 572’, and ‘Paulsen 1103’ rootstocks. See Table 5 for trait labels.

Clustering was found to be caused by berry width [BW], number of berries per bunch [NBBch], fresh rachis mass [RM], bunch mass [BchM], pH, fresh berry mass [BM], berry length [BL], bunch length [BchL], bunch width [BchW], productivity [Pdt], yield per vine [YldV], on PC1 loads (Figure 2B). These characteristics all have strong positive loadings (>0.70) (Table 6).

Table 6. Factor loadings, eigenvalues, and proportion of variation associated with two principal components (PC) of the principal components analysis of 19 yield components and physicochemical traits in 2 scion-rootstock grapevine combinations.

Traits	PC1	PC2
YldV	0,937	-0,350
Pdt	0,937	-0,350
NBchV	0,929	-0,369
BchM	0,997	0,074
BchL	0,941	-0,337
BchW	0,930	-0,367
BM	0,998	-0,056
BL	0,985	-0,172
BW	0,913	0,408
RM	0,994	0,113
BD	-0,413	-0,911
NBBch	0,993	0,115
SS	-0,777	-0,629
pH	0,999	0,046
TA	-0,392	-0,920
MI	0,233	0,973
TPC	-0,950	0,312
TF	-0,739	-0,673
TMA	-0,776	0,631
Eigenvalue	14.172	4.828
Variability (%)	74.589	25.411
Cumulative (%)	74.589	100.000

PC1 scores and loadings indicated that ‘BRS Isis’ had higher yields than ‘IAC 572’ and had greater bunch and rachis masses, number of berries per bunch, berry breadth, and fruit maturation index when employing ‘IAC 766’. In contrast, the application of ‘Paulsen 1103’ resulted in poorer yield, smaller clusters, and smaller fruit size, corroborating the negative factors among the analyses (Table 5 and 6).

PC2 accounted for 25.41% of the overall variance and was mostly associated with the chemical properties of the berries. The most important factors contributing to PC2 were maturation index [MI] according to the PC2 loading graph (Figure 2B and Table 6). When the notes and loadings of this component were analysed, the ‘BRS Isis’ grapes on the ‘Paulsen 1103’ rootstock had the greatest levels of total phenolic compounds [TPC] and total anthocyanins [TMA], as well as the greatest diameter of berries [BD] on ‘IAC 572’. There was a negative correlation between phenolic chemicals and bunch physical features ($r = -1.0$) (Table 5), which also confirmed the concentration of these compounds when ‘Paulsen 1103’ was employed (Table 4).

2.4. CONCLUSIONS

The rootstocks IAC 572 ‘Jales’ and IAC 766 ‘Campinas’ increased ‘BRS Isis’ production and productivity, as well as the size and weight of the bunches. Meanwhile, the Paulsen 1103 rootstock increased the phenolic compounds and total flavonoids in the grapes.

Under subtropical temperature circumstances, regardless of the rootstock employed, the ‘BRS Isis’ grape demonstrated high output and productivity, commercial physical qualities, and chemical quality, with soluble solids levels over 16 °Brix.

The findings presented in this study offer practical implications for grape producers in real-world scenarios. Producers can make informed decisions regarding rootstock selection based on specific objectives. For instance, for those seeking increased yield and larger bunches, employing rootstocks such as IAC 572 ‘Jales’ and IAC 766 ‘Campinas’ is recommended.

Thus, these results provide valuable guidance to grape producers for the selection of the most suitable rootstock in alignment with their specific objectives.

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CONSIDERAÇÕES FINAIS

O estudo destacou que as flutuações climáticas sazonais exerceram um impacto mais significativo nas respostas da videira 'BRS Isis' do que os efeitos dos diferentes porta-enxertos, influenciando tanto a duração das fases fenológicas quanto os requisitos térmicos.

A duração do ciclo da variedade BRS Isis, independentemente do porta-enxerto utilizado, mostrou-se prolongada, o que, associado à sua característica de alto vigor, resultou em custos de manejo da cultura mais elevados.

A 'BRS Isis' demonstrou ser altamente produtiva em condições subtropicais, independentemente do porta-enxerto utilizado. Entretanto, essa alta produtividade está relacionada ao vigor da variedade BRS Isis, o que demanda práticas culturais desde o estabelecimento da planta até a condução dos ramos, acarretando em custos adicionais de mão de obra. Além disso, destaca-se que o estabelecimento inicial das plantas é dificultado devido ao seu alto vigor, requerendo cuidados específicos durante essa fase inicial do ciclo de cultivo.

Com base nos resultados do estudo, recomenda-se a utilização dos porta-enxertos IAC 572 'Jales' e IAC 766 'Campinas', pois demonstraram aumentar a produção e o tamanho dos cachos da uva BRS Isis nas condições subtropicais avaliadas.

Dessa forma, o estudo oferece orientações práticas para os produtores, possibilitando a seleção criteriosa de porta-enxertos de acordo com os objetivos desejados.

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