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CULTIVO DA VIDEIRA 'BRS VITÓRIA' EM COMBINAÇÃO COM DIFERENTES PORTA-ENXERTOS EM REGIÃO SUBTROPICAL

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

Orientador: Marco Antonio Tecchio

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Título:

CULTIVO DA VIDEIRA 'BRS VITÓRIA' EM COMBINAÇÃO COM DIFERENTES PORTA-ENXERTOS EM REGIÃO SUBTROPICAL

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Botucatu, 19 de fevereiro de 2024.

Aos meus pais,

Selma e Marcos,

dedico

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“O conhecimento nos faz responsáveis”.

(Che Guevara)

RESUMO

Este estudo teve como objetivo avaliar os efeitos dos porta-enxertos ‘IAC 572 Jales’, ‘IAC 766 Campinas’ e ‘Paulsen 1103’ quanto às características agronômicas da uva para mesa ‘BRS Vitória’ em condições subtropicais. Durante três ciclos de produção, foram avaliados: duração dos estádios fenológicos, requerimento térmico e maturação das bagas; desempenho produtivo, vigor e características físicas de cachos e bagas; composição química e teores de compostos bioativos das bagas; teores e exportação de nutrientes e a eficiência em função da fertilização. Os porta-enxertos influenciaram diretamente na maioria das características avaliadas. Quanto à fenologia, demanda térmica e evolução da maturação das bagas, observou-se que as videiras enxertadas sobre o ‘1103P’ foram mais precoces quando comparadas às cultivadas sobre os porta-enxertos ‘IAC 572’ e ‘IAC 766’. A duração do ciclo da videira ‘BRS Vitória’ em condições subtropicais variou de 131 a 143 dias, com a demanda térmica variando de 1.545 a 1.725 GD. Foi verificado alta correlação positiva entre o vigor e produtividade das videiras e alta correlação negativa entre o vigor e qualidade química e bioquímica das uvas. Nesse caso, o ‘IAC 572’ induziu maior vigor e produtividade, enquanto que o ‘1103P’ promoveu maiores concentrações de sólidos solúveis, fenóis, flavonóides e antocianinas. O teor, extração e eficiência na utilização dos nutrientes também foram maiores nas videiras enxertadas sobre o ‘IAC 572’. Assim, os resultados sugerem que o porta-enxerto ‘IAC 572’ é mais indicado em combinação com a ‘BRS Vitória’ sob condições subtropicais. Além do mais, enfatiza-se que a ‘BRS Vitória’ apresentou boa produtividade e qualidade da uva. Desse modo, o aumento do seu cultivo em regiões subtropicais torna-se uma boa alternativa para suprir a crescente demanda de uvas sem semente.
Palavras-chaves: viticultura subtropical; enxertia; uva para mesa; uva sem semente.

ABSTRACT

The purpose of this study was to assess the impact of the rootstocks 'IAC 572 Jales', 'IAC 766 Campinas', and 'Paulsen 1103' on the agronomic features of the 'BRS Vitória' table grape under subtropical circumstances. The following factors were assessed during three production cycles: phenological stage duration, thermal requirements, and berry maturation; productive performance, vigor, and physical characteristics of bunches and berries; chemical composition and levels of bioactive compounds in the berries; nutrient levels and export and efficiency depending on fertilization. The rootstocks had a direct impact on the majority of the parameters studied. In terms of phenology, thermal demand, and the progression of berry maturation, vines grafted on '1103P' matured earlier than those grown on 'IAC 572' and 'IAC 766' rootstocks. In subtropical circumstances, the cycle length of the 'BRS Vitória' vine ranged from 131 to 143 days, with thermal demand ranging from 1,545 to 1,725 GD. There was a strong positive link between vine vigor and production, and a strong negative correlation between vine vigor and grape chemical and biochemical quality. In this example, 'IAC 572' increased vigor and productivity, but '1103P' increased soluble solids, phenols, flavonoids, and anthocyanin contents. Nutrient content, extraction, and efficiency were similarly increased in vines grafted with 'IAC 572'. As a consequence of the findings, the 'IAC 572' rootstock appears to be better suited in conjunction with 'BRS Vitória' in subtropical circumstances. It is also underlined that 'BRS Vitória' demonstrated high output and grape quality. As a result, boosting its production in subtropical locations becomes a viable option for meeting the increasing demand for seedless grapes.

Keywords: subtropical viticulture; grafting; table grape; seedless grape.

SUMÁRIO

INTRODUÇÃO GERAL

A videira está entre as plantas frutíferas mais produzidas do mundo (FAO, 2022), sendo que, no ano de 2021, a área destinada ao cultivo de videiras foi cerca de 7,3 milhões de hectares e a produção de 69,5 milhões de toneladas, dentre as quais, 48,8% foram uvas para vinho, 43,3% uvas para mesa e 7,9% uvas passas (OIV, 2022). Dentre os principais países produtores de uva para vinho estão a China, Itália, Estados Unidos da América, Espanha e a França. Por outro lado, com relação à produção de uvas para mesa destacam-se a China, Índia, Turquia, Egito e o Irã. O Brasil, por sua vez, é o décimo terceiro produtor mundial de uvas para processamento e oitavo na produção de uvas para mesa (OIV, 2022).

Do total de 1,6 milhões de toneladas de uvas produzidas no Brasil, em 2021, 48% foram destinadas para o processamento e 52% para mesa, com destaque para o Rio Grande do Sul, Pernambuco e São Paulo que, juntos, representaram 87% da produção nacional (Mello e Machado, 2022). Nesse caso, é importante mencionar que cada estado ou região tem características específicas em relação às condições climáticas, cultivares, finalidade de produção e manejos culturais adotados.

Na região Sul do país, onde ocorre o predomínio de clima temperado, a maior parte da produção refere-se a cultivares de uvas americanas e híbridas destinadas à elaboração de suco de uva e vinhos de mesa. Por outro lado, na região Nordeste, mais especificamente no Submédio do Vale do São Francisco, em condições tropicais semiáridas, a produção é majoritariamente voltada para o mercado interno e externo de uvas para mesa. Já no estado de São Paulo, onde há polos produtores situados em condições subtropicais e tropicais, a produção é majoritariamente voltada para o mercado interno de uvas para mesa (Maia *et al*., 2018; Mello e Machado, 2022).

Com relação à viticultura de mesa, as principais cultivares tradicionais de uvas com sementes produzidas no país são a ‘Niagara Rosada’ (rústica), ‘Itália’, ‘Rubi’, ‘Benitaka’ e ‘Brasil’ (finas). Quanto às uvas sem sementes, atualmente, a ‘Superior Seedless’, ‘Crimson Seedless’ e ‘Thompson Seedless’ vem sendo substituídas por novas cultivares híbridas mais adaptadas, produtivas e com características desejadas pelos consumidores, como a ‘Arra 15’, ‘BRS Ísis’, e, principalmente, a ‘BRS Vitória’ que, além de bastante comercializada no mercado interno, está entre as cultivares mais exportadas (Mello e Machado, 2022; Maia *et al*., 2018).

A ‘BRS Vitória’ é uma cultivar híbrida, resultante do cruzamento entre a CNPUV 681-29 e ‘BRS Linda’, que possui grande aceitação entre consumidores devido, principalmente, à ausência de sementes, ao sabor aframboezado, ao alto potencial glucométrico (até 23,0° Brix) e à manutenção das qualidades organolépticas da uva durante um longo período de armazenamento (Maia *et al*., 2012; Maia *et al*., 2016). Além disso, é rica em antocianinas e outros compostos bioativos (Colombo *et al*., 2020; Colombo *et al*., 2021), que são bastante desejáveis por promoverem muitos benefícios à saúde (Khoo *et al*., 2017).

Além da grande aceitação pelos consumidores, esta cultivar também vem agradando bastante aos produtores pois apresenta elevado vigor, boa produtividade, ampla adaptação climática, alta fertilidade de gemas e tolerância ao míldio e à rachadura de bagas, o que possibilita o seu cultivo mesmo em regiões com elevada precipitação pluvial (Maia *et al*., 2012; Maia *et al*., 2016). Nesse contexto, enfatiza-se que muitas dessas características contribuem para que o custo de produção seja relativamente baixo e, portanto, mais rentável aos viticultores. Contudo, sabe-se que alguns manejos culturais podem afetar diretamente as características das videiras e qualidade das uvas, por exemplo, porta-enxertos adequados.

A enxertia tem sido uma prática imprescindível na viticultura pois os porta-enxertos promovem diversos benefícios à cultura, como, principalmente, resistência ou tolerância às pragas e doenças do solo, dentre estas, Phylloxera (Granett *et al*., 2011), nematóides (Anwar *et al*., 2002) e fusariose (Garrido *et al*., 2004). Além do mais, propiciam o cultivo de videiras mesmo em condições adversas de solo, como alta salinidade (Suarez *et al*., 2019), deficiência hídrica (Tsegay *et al*., 2014), e com excesso de cobre e alumínio (Cançado *et al*., 2009; Marastoni *et al*., 2014).

Os porta-enxertos possuem diferentes capacidades de absorção, acúmulo e translocação de nutrientes para a parte aérea (Tecchio *et al*., 2011; Ibacache *et al*., 2020), além disso, podem ser mais ou menos eficientes na utilização dos minerais provenientes da fertilização, interferindo assim, no desenvolvimento das videiras e na qualidade dos frutos. Dalbó *et al*. (2011) mencionam que essa diferença na eficiência de absorção de nutrientes pelos porta-enxertos deve nortear a recomendação de adubação do vinhedo.

Outro aspecto relevante é que porta-enxertos podem influenciar em diversas características das videiras, dentre estas, o desempenho produtivo (Tecchio *et al*., 2020), vigor vegetativo (Jones *et al*., 2009), composição química (Silva *et al*., 2018), compostos bioativos (Silva *et al*., 2019) e duração do ciclo fenológico (Tecchio *et al*., 2019). Desse modo, é evidente que a escolha do porta-enxerto adequado é um aspecto crucial para o sucesso do vinhedo.

Entretanto, é importante enfatizar que, para a escolha do porta-enxerto ideal, alguns fatores devem ser considerados, como, vigor do porta-enxerto (Brighenti *et al*., 2011), afinidade e interação com a cultivar copa (Aloni *et al*., 2010; Tedesco *et al*., 2022) e a adaptação às condições edafoclimáticas do local de cultivo.

Entre os porta-enxertos que são comumente utilizados na viticultura brasileira estão o 'IAC 572 Jales', 'IAC 766 Campinas' e o 'Paulsen 1103'. O 'IAC 572' é bastante vigoroso, adaptado a solos argilosos e arenosos, com ótimo enraizamento, tolerância à salinidade e boa afinidade com cultivares *Vitis vinífera* e *Vitis labrusca*. O 'IAC 766' tem características similares ao 'IAC 572 Jales', contudo, é menos vigoroso. Apesar de possuírem ampla adaptação climática, são mais utilizados em condições subtropicais e tropicais (Tecchio *et al*., 2018; Viana *et al*., 2018).

Por sua vez, o 'Paulsen 1103' é o porta-enxerto mais utilizado da região Sul do país, pois apresenta tolerância à fusariose, que é uma doença comum na região. Este porta-enxerto possui boa afinidade com diversas cultivares, é vigoroso, enraíza com facilidade e tem bom índice de pegamento (Botelho *et al*., 2018; Tecchio *et al*., 2018).

Destaca-se que esses porta-enxertos têm sido avaliados em combinações com diversas cultivares de uva para mesa que são produzidas no país, como a 'Niagara Rosada' (Callili *et al*., 2022), 'BRS Ísis' (Leão *et al*., 2020a), 'BRS Clara' (Leão *et al*., 2019), 'Superior Seedless' e 'Crimson Seedless' (Feldberg *et al*., 2007). Porém, ainda há poucos estudos que avaliem os efeitos de porta-enxertos na 'BRS Vitória' (Campos *et al*., 2022; Leão *et al*., 2020b), principalmente, em áreas subtropicais.

Assim, o principal objetivo deste estudo foi avaliar o desempenho agronômico da videira 'BRS Vitória' sobre diferentes porta-enxertos com vistas à identificação da melhor combinação para o cultivo em condições tropicais.

CAPÍTULO 1

PHENOLOGY, THERMAL DEMAND, AND MATURATION DEVELOPMENT OF THE ‘BRS VITÓRIA’ GRAPE CULTIVATED ON DIFFERENT ROOTSTOCKS IN SUBTROPICAL CONDITIONS

ABSTRACT

The purpose of this study was to assess how ‘IAC 572’, ‘IAC 766’, and ‘Paulsen 1103’ rootstocks affected the duration of phenological phases, thermal demand, and chemical evolution throughout production cycle of the 'BRS Vitória' table grape cultivated in subtropical conditions. The duration of the following phenological stages was measured in days after pruning throughout two production seasons: budburst, flowering, setting, maturation, and harvest date. The thermal requirement was determined using the degree-day concept. Titratable acidity, pH, soluble solids, and the maturation index were all measured throughout berry maturation. In general, the rootstocks ‘IAC 572’ and ‘IAC 766’ increased vine precocity in comparison to ‘Paulsen 1103’ during the early phenological phases. However, the vines grafted on ‘Paulsen 1103’ were earlier in the later phases, that is, at the veraison and at the harvest date, when compared to those grafted on the rootstocks ‘IAC 572’ and ‘IAC 766’. Under subtropical conditions, the total cycle period of the ‘BRS Vitória’ vine varied from 131 to 143 days, with thermal demands ranging from 1,545 to 1,725 DD. In comparison to the ‘IAC 572’ and the ‘IAC 766’, the ‘Paulsen 1103’ supplied the berries with a higher accumulation of soluble solids and a higher maturation index.

Index terms: seedless grape; table grapes; subtropical viticulture; grafting; chemical analysis.

1.1. INTRODUCTION

Grapes are among the most produced and sold fruits in Brazil (AGRIANUAL, 2020), and due to the country's diverse climatic conditions, Brazilian viticulture has a notable range of cultivars and production processes. According to Mello and Machado (2021), 46.7% of the 1,416,398 tons of grapes produced in Brazil in 2020 were processing grapes, while 53.3% were table grapes.

In the table grapes market, there has been a substantial increase in demand for seedless grapes over the previous decade, and from 2006 to 2017, the participation of

Capítulo redigido conforme as normas da **Revista Brasileira de Fruticultura** seedless grape cultivars increased from 7% to 30% of total table grapes sold at CEAGESP in São Paulo. Given the current situation, it is crucial to note that this new consumer behaviour has encouraged many producers to engage in the production of seedless grapes, particularly the new Embrapa cultivars ‘BRS Ísis’ and ‘BRS Vitória’ (Maia *et al*., 2018).

Based on its agronomic qualities, such as succulent consistency, high concentration of soluble solids, high fertility, strong yield, mildew tolerance, and cheap production cost, the black grape cultivar 'BRS Vitória' has gained popularity among consumers and grape grower (Maia *et al*., 2016; Maia *et al*., 2018).

The 'BRS Vitória' vine is mostly planted in the São Francisco Valley's sub-medium zone, under hot semi-arid (BSh) (Mello and Machado, 2021). However, due to its extensive edaphloclimatic adaptability (Maia *et al*., 2012) and expanding consumer demand, it is a promising choice for seedless grape production in temperate and subtropical climates.

According to Maia *et al*. (2012), the duration of the production cycle ranges from 90 to 135 days, depending on soil and climate conditions. However, in addition to the cultivation site conditions, other factors, like as the rootstock utilized, can have a direct impact on the duration of the production cycle (Tecchio *et al*., 2013) and the agronomic features of the vines (Silva *et al*., 2018; Leão *et al*., 2020a).

‘IAC 572 Jales’, ‘IAC 766 Campinas’, and ‘Paulsen 1103’ are among the most widely used rootstocks in Brazil. Because of its resistance to fusariosis, ‘Paulsen 1103’ is the most extensively used rootstock in Rio Grande do Sul; also, its cultivation has increased substantially in the São Francisco Valley's Submedium. ‘IAC 572’, on the other hand, presents high vigour, excellent roots, and adaptability to sandy or clayey soils. ‘IAC 766’, which is well suited to subtropical environments, has excellent roots and vigour (Leão and Silva, 2018; Tecchio *et al*., 2018). It is crucial to note, however, that while selecting the optimal rootstock, the affinity between rootstock and scion must be addressed (Tecchio *et al*., 2020).

In terms of phenology and thermal demand, these rootstocks were investigated in combinations with different grape cultivars, including ‘Niagara Rosada’ (Callili *et al*., 2022), ‘Cabernet Sauvignon’ (Miele, 2019), ‘Vênus’ (Tecchio *et al*., 2019a), ‘Merlot’ (Allebrandt *et al*., 2015), ‘Bordô’, ‘BRS Carmen’, ‘Concord’ (Barros *et al*., 2015), ‘Isabel’ and ‘Rubea’ (Sato *et al*., 2008). However, it should be noted that no research have been conducted to assess the impact of rootstocks on the phenology and thermal requirements of the ‘BRS Vitória’ vine, particularly in a subtropical climatic location.

Phenology and thermal demands studies are critical for viticulture since understanding the duration of each phenological stage allows grape grower to prepare for prospective harvest dates, periods of maximum labor demand, as well as cultural and phytosanitary management. Furthermore, they can provide an indicator of the region's climatic potential for grape production. Similarly, understanding the chemical changes that occur during berry maturity is a powerful tool since it allows you to determine the perfect time for harvest, that is, when the best balance of soluble solids and acidity occurs.

Thus, the purpose of this study was to assess the influence of rootstocks on the duration of phenological phases and thermal demand of the vines, as well as to confirm the chemical changes of the 'BRS Vitória' grape cultivated under subtropical conditions.

1.2. MATERIAL AND METHODS

The experimental design consisted of randomized blocks with seven blocks and three vines per plot for a total of 63 vines in the experimental area. The cultivar BRS Vitória (CNPUV 681-29 x ‘BRS Linda’) was grafted on the following rootstocks ‘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 V*itis rupestris*).

The research was conducted during the 2020 and 2021 crop seasons at an experimental vineyard in São Manuel, São Paulo, Brazil (22°46’35’’S and 48°34’08’’W; at an altitude of 773 m). Red Latosol soil was identified in the experimental region (EMBRAPA, 2018). The Köppen classification classifies the climate as Cfa, which means subtropical with hot summers.

Between July and December of the experiment, the minimum average temperature was 16.4°C in 2020 and 15.9°C in 2021, while the maximum average temperature was 28.8°C in 2020 and 27.7°C in 2021. The cumulative rainfall in this timeframe was 477 mm in 2020 and 593 mm in 2021, with a tendency for precipitation to be concentrated in the summer months (Figure 1). During the ripening of the grapes, the minimum average temperature was 17.1°C in 2020 and 17.9°C in 2021 and the maximum average temperature was 29.8°C in 2020 and 29.3°C in 2021. The cumulative rainfall in this period in 2020 was 106.6 mm and in 2021 it was 288.2 mm (Figure 2).

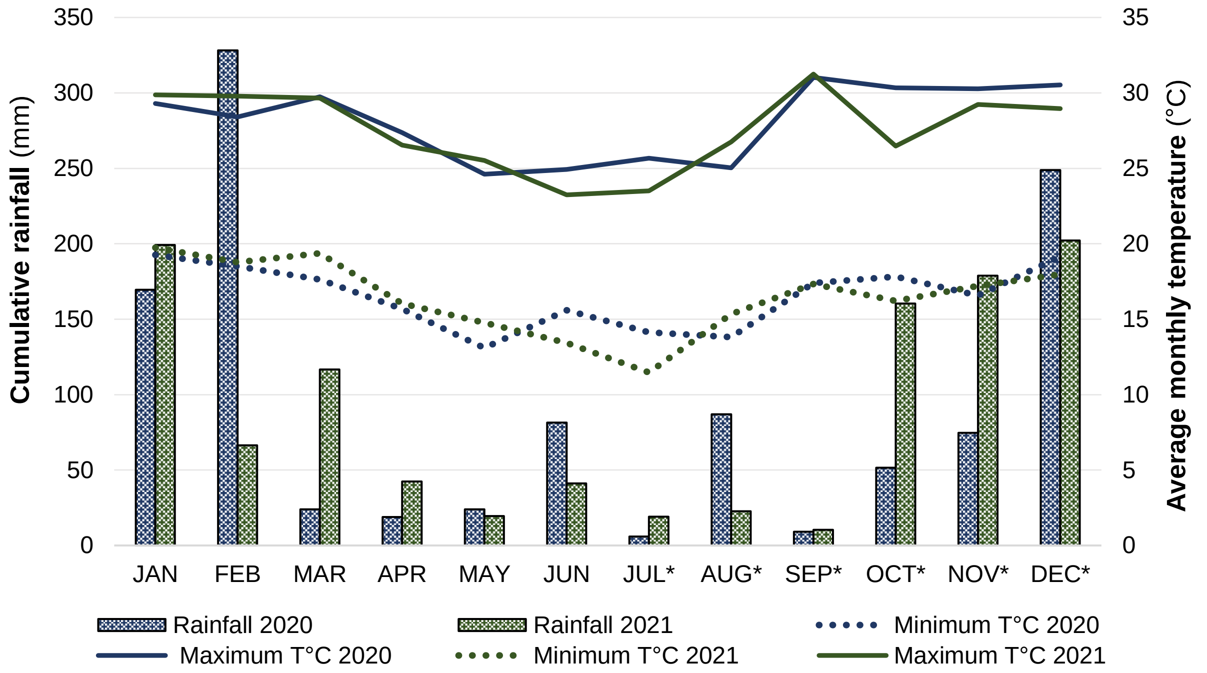

Figure 1. Meteorological data (temperature and cumulative rainfall) from the experimental site in 2020 and 2021. São Manuel, State of São Paulo, Brazil. *Productive period. The bars represent the total amount of rain, while the lines represent the minimum and maximum temperatures.

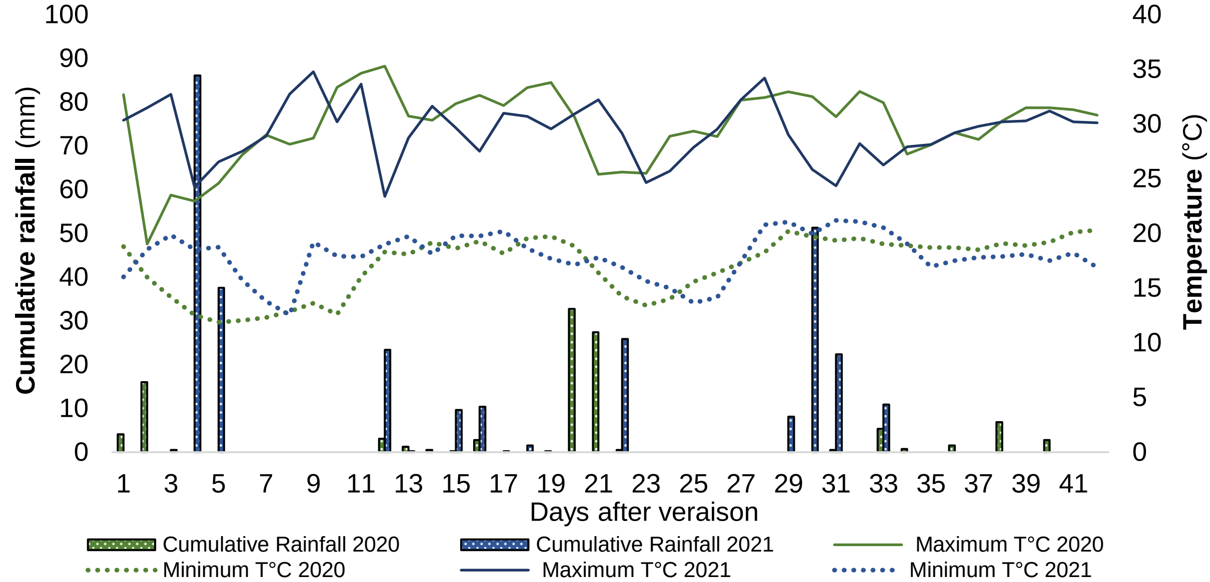

Figure 2. Meteorological data (temperature and cumulative rainfall) from the experimental site during the ripening of ‘BRS Vitória’ grape in 2020 and 2021. São Manuel, State of São Paulo, Brazil.

The rootstock cuttings were planted in August 2018, and the scion grafting was completed in July 2019. The row spacing was 3.0 m and the vine spacing was 2.0 m (density of 1,667 vines per hectare). Vines were trained in an Open Gable or Y training system, with a metallic framework. Micro sprinklers were implemented for the watering system. A polyethylene screen with 18% shading was installed for bird and hail protection.

Phytosanitary control, fertilization, plant regulators, pruning, defoliation, secondary shoot removal, shoot trimming, and bunch thinning were all carried out in line with the recommendations provided by Maia *et al*. (2016).

On July 22 and August 5, respectively, winter pruning for the 2020 and 2021 seasons was accomplished where one or two buds per spur were retained and 2.5% hydrogen cyanamide was applied after pruning to promote and standardize budburst. After budburst, the bud load was standardized with about 60 branches per vine.

The main phenological stages of the vines, that is, pruning to budburst, full-bloom, setting, veraison, and harvest date (full maturation) were all quantified (Figure 3) using the criteria suggested by Coombe (1995). Visual observations were done thrice a week to assess the length of each phenological stage in days after pruning (DAP).

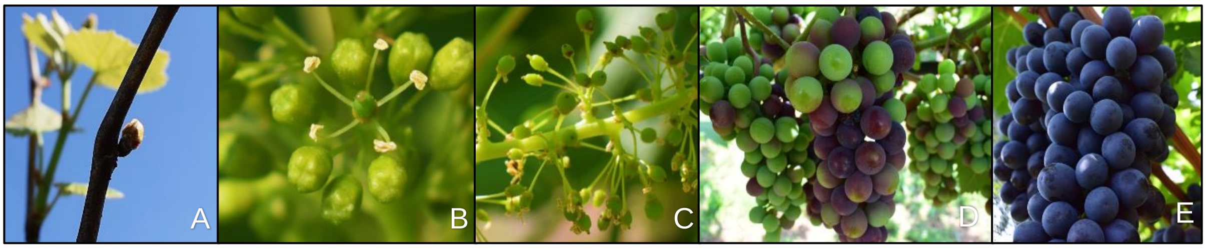

Figure 3. Characterization of phenological stages: budburst (A), full-bloom (B), setting (C), veraison (D) and harvest (E) of the 'BRS Vitória' grapevine.

The grape harvest dates were chosen when the berries reached roughly 19°Brix, as recommended by Maia *et al* (2012). However, when the berries did not achieve 19° Brix, the harvest date of the grapes was calculated according to the maturation curve, that is, when the content of soluble solids and titratable acidity stabilized in the interval between two samplings. Samplings were conducted up to 42 days following veraison since the berries began to exhibit signs of decay after this time.

To assess the heat demand in degree-days (DD), the total of the pruning to harvest dates was computed using the following Winkler (1965) equation: $DD = \Sigma$ (average temperature- 10° C) × days after pruning.

Grape maturity curves were developed based on the progression of the grapes' titratable acidity (TA), soluble solids (SS), pH, and maturation index (SS/TA). For this aim, 10 bunches per experimental plot were randomly selected and analyzed during veraison, that is, when the berries began to change color. Berries were harvested from selected bunches and assessed every 7 days following veraison, i.e. at 0, 7, 14, 21, 28, 35, and 42 days (coinciding, respectively, with 99, 106, 113, 120, 127, 135 and 142 DAP, and at 102, 109, 116, 123, 130, 137 and 144 DAP, of the 2020 and 2021 seasons).

TA was obtained by titrating with 0.1 N NaOH to the pH = 8.2 equivalence point (results expressed as percentage of tartaric acid). The SS was calculated using direct refractometry of grape must in a digital refractometer (Reichert®, model r2i300, USA), and the findings were represented in °Brix. The pH was evaluated using a Tecnal® potentiometer, model r2i300.

Statistical analyses were carried out over two production seasons (2020 and 2021). To identify the impacts of rootstocks, all data were treated to analysis of variance. The Tukey test (5% probability) was used to compare averages for phenology and thermal demands, and a regression analysis was used to examine the impact of rootstocks on the chemical development of the grapes during ripening, using the SISVAR® statistical software, version 5.6. (Lavras, MG, Brazil).

1.3. RESULTS AND DISCUSSION

The rootstocks had a significant influence ($p < 0,05$) on the duration of the assessed phenological phases in both production seasons (Table 1).

Table 1. Phenological stages (DAP) and thermal demands (DD) of ‘BRS Vitória' grapevine grafted on ‘IAC 572 Jales', ‘IAC 766 Campinas' and ‘Paulsen 1103’ rootstocks in two production seasons.

Phenological stages and thermal demands	Seasons	Rootstocks			
		IAC 572 Jales	IAC 766 Campinas	Paulsen 1103	p-value
Budburst	I	17.33 ± 1.80 b	18.69 ± 2.27 b	21.09 ± 1.25 a	< 0.01
	II	15.42 ± 1.02 b	16.00 ± 1.02 b	17.42 ± 0.52 a	< 0.01
Full-bloom	I	45.27 ± 1.22 c	47.07 ± 0.49 b	48.66 ± 0.73 a	< 0.01
	II	40.00 ± 1.00 b	41.14 ± 1.07 ab	42.57 ± 0.98 a	< 0.01

Setting	I	50.00 ± 0.82 c	52.85 ± 1.03 b	57.00 ± 1.30 a	< 0.01
	II	44.28 ± 0.76 b	45.14 ± 1.07 b	46.57 ± 0.76 a	< 0.01
Veraison	I	99.89 ± 1.41	97.85 ± 1.37	97.71 ± 0.76	0.16
	II	102.85 ± 1.34 a	99.42 ± 0.67 b	98.85 ± 1.01 b	< 0.01
Harvest	I	138.42 ± 3.40 a	134.00 ± 3.78 ab	131.14 ± 2.75 b	< 0.01
	II	143.42 ± 0.98 a	139.42 ± 6.60 a	132.00 + 3.42 b	< 0.01
Full cycle demands	I	1,651.4 ± 50.53 a	1,588.0 ± 54.45 ab	1,545.7 ± 28.51 b	< 0.01
	II	1,725.7 ± 12.2 a	1,662.7 ± 80.2 a	1,572.8 ± 41.7 b	< 0.01

Mean ± standard deviation (n = 7) is used to express the data. On the same line, values preceded by the same letter were similar by Tukey test.

In general, ‘Paulsen 1103’ had a late behaviour effect in the early phenological stages, that is, from pruning to budburst, full-bloom, and setting, when compared to the following rootstocks ‘IAC 572’ and ‘IAC 766’. The intervals from pruning to budburst were around 15 to 21 days in both production seasons. The vines were in full bloom between 40 and 48 DAP, while the setting was between 44 and 57 DAP (Table 1).

In terms of veraison, there was no significant difference between the assessed rootstocks in the first season, with an average of 98.4 DAP between treatments. In the second production cycle, however, vines grafted on ‘IAC 572’ (102.8 DAP) emerged at veraison substantially later than those grafted on ‘IAC 766’ (99.4 DAP) and ‘Paulsen 1103’ (98.8 DAP) (Table 1).

In terms of the production cycle, that is, the duration from pruning to harvest date of ‘BRS Vitória’, ‘Paulsen 1103’ induced an early precocity of 7 days in the first season when compared to ‘IAC 572’, with values of 131.1 and 138.4 DAP, respectively. In the second season, vines grafted on ‘Paulsen 1103’ (132.0 DAP) were 7 and 11 days sooner than vines growing on ‘IAC 766’ (139.4 DAP) and ‘IAC 572’ (143.4 DAP), respectively (Table 1).

Alvarenga *et al*. (2002) also reported that ‘Paulsen 1103’ afforded the grape ‘Niagara Rosada’ more precocity than ‘IAC 572’ and ‘IAC 766’. Rootstocks’ effect may be connected to their vigour, nutrient storage, and water uptake for vine photosynthesis, which helps in the absorption of stocks required for nutrition (Barros *et al*., 2015). However, it is vital to note that rootstock effect is directly tied to scion genotype and adaptability to soil and climatic conditions.

Few investigations have been conducted on the duration of the phenological phases of the vine 'BRS Vitória' under subtropical environments. According to Maia *et al*. (2016), the cycle duration varies from 130 to 135 days in the Northwest of São

Paulo, the North of Minas Gerais, and the North of Paraná. Borges *et al*. (2017) discovered that the 'BRS Vitória' cycle lasted 130 days in the summer crop in a *Cfa* climate, the same as in the current study. As a result, comparable values were discovered in the current investigation, with variations depending on rootstock and production cycle (Table 1).

In comparison to other studies that evaluated the duration of the phenological stages of other table grape cultivars in a subtropical climate, the duration of the pruning cycle at the harvest date of 'BRS Vitória' verified in this study was slightly earlier than 'BRS Ísis' (Ahmed *et al*., 2019) and 'Niagara Rosada' (Callili *et al*., 2022).

With regard to thermal demand, Maia *et al*. (2012) stated that the vines' thermal demand to complete the cycle is 1,511 DD. Borges *et al*. (2017) reported that the thermal demand in the summer crop and in subtropical circumstances was 1,679 DD. The thermal demand 1,545.7 to 1,651.4 DD in the first season and from 1,572.8 to 1,725.7 DD in the second season in the current study (Table 1). According to Silva *et al*. (2008), the duration of the phenological phases of the vines might vary depending on the scion genotype and climatic circumstances in each location, or even within the same region, owing to seasonal climatic fluctuations throughout the year.

All in all, it should be recognized that phenology information is critical in the planning of vineyard operations, as well as in the forecast of harvest dates and marketing. As a result, evaluating elements that might affect vine phenology, such as rootstocks, is critical for Brazilian viticulture.

According to the Figure 4, the chemical changes that occurred during berry maturity followed the predicted pattern, with a rise in SS, pH, and maturation index and a decrease in TA, and quadratic regression models were fitted for all assessments and treatments.

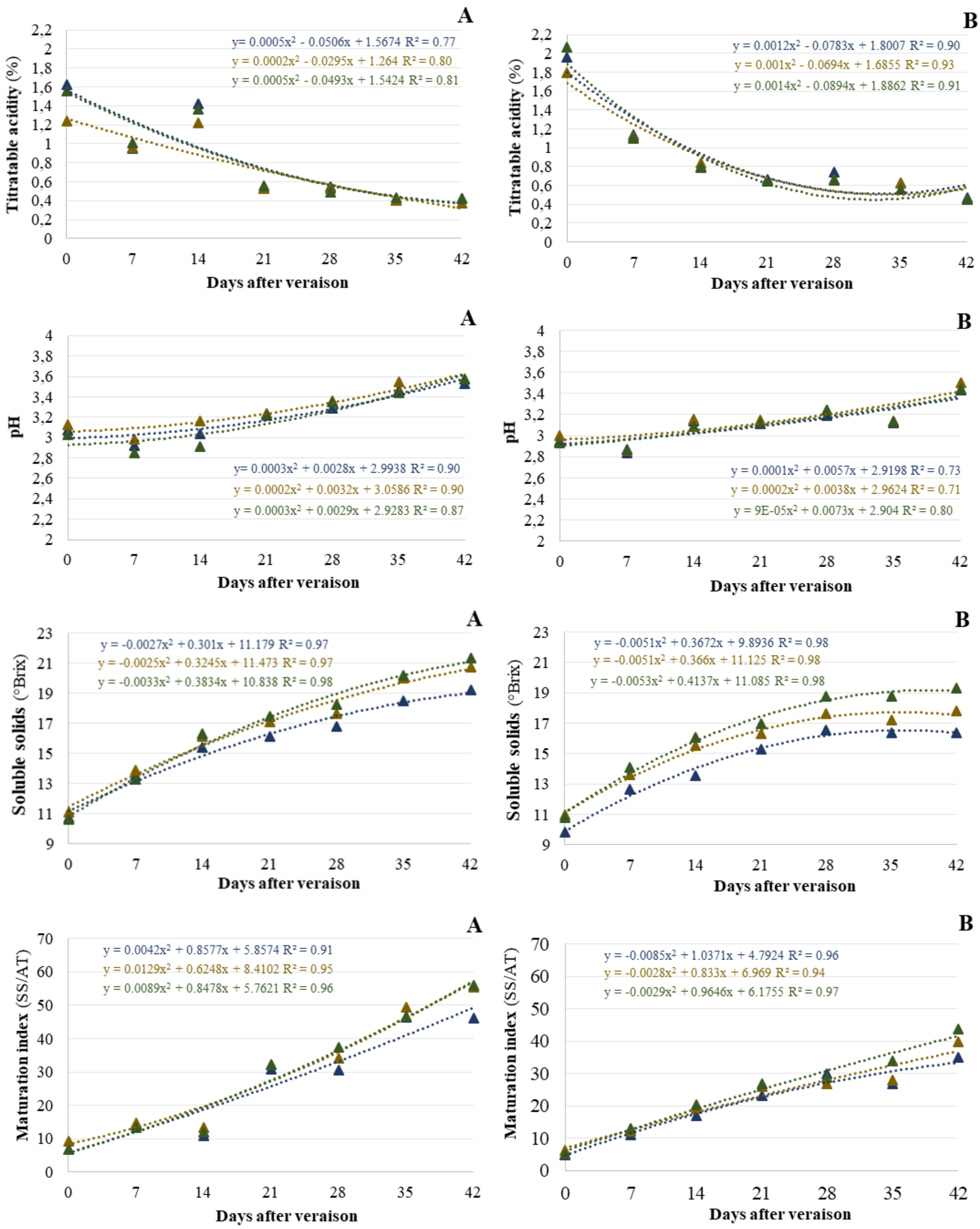

Figure 4. Development of titratable acidity, pH, soluble solids and maturation index during the ripening of ‘BRS Vitória’ grape grown in 2020 (A) and 2021 (B). The rootstocks 'IAC 572', 'IAC 766' and 'Paulsen 1103' are represented by the colors blue, gold and green, respectively.

According to Maia *et al*. (2012), the ‘BRS Vitória’ grape should be harvested when the berries reach at least 19° Brix, a point when there is an excellent balance of sugar and acidity, bestowing a very distinguishable raspberry taste without astringency in the bark. Figure 4b shows that the berries of the vines grafted on 'Paulsen 1103' and 'IAC 766' reached 19°Brix about 30 days after veraison in the first season, and the highest attained from these treatments was around 21°Brix. Berries on vines planted on rootstock 'IAC 572', on the other hand, attained 19° Brix just 42 days after veraison.

Only the berries of the vines planted on ‘Paulsen 1103’ achieved 19° Brix in the second season, whereas the maximum SS content reached by the rootstock ‘IAC 766’ was 17.8° Brix and by the ‘IAC 572’ was 16.3° Brix (Figure 4b). Lower quantities of SS were possibly found in the berries of vines grafted on ‘IAC 572’ in both seasons due to the higher robustness that this rootstock imparts to the vines (Alvarenga *et al*., 2002; Mota *et al*., 2009). Excessive vegetative vigour can create a microclimate with high humidity and low radiation, producing more shadowing to the bunches and preventing the buildup of soluble solids in the berries. Several studies have found that the vegetative and reproductive balance of rootstocks to vines has a significant impact on grape quality (Satisha *et al*., 2010; Brighenti *et al*., 2011; Jin *et al*., 2016). According to Bascunán-Godoy *et al*. (2017), rootstocks may have a direct influence on the scion's photosynthetic activity; additionally, they have different capacities for absorption and translocation of water and nutrients (Martínez-Ballesta *et al*., 2010), which can affect the chemical composition of the grapes.

In studies conducted using ‘Niagara Rosada’ in *Cwb* climate, Alvarenga *et al*. (2002) and Mota *et al*. (2009) showed that ‘IAC 572’ gave a lower concentration of SS than ‘Paulsen 1103’ and ‘IAC 766’. In contrast, Leão *et al*. (2020b) reported no significant difference in the accumulation of soluble solids in the ‘BRS Vitória’ grape among ‘IAC 572’, ‘IAC 766’, and ‘Paulsen 1103’ in semi-arid climatic conditions. As well as Leão *et al*. (2019), who found that these rootstocks had no effect on the chemical quality of the ‘BRS Clara’ grape, demonstrating that the affinity and interaction between rootstocks and scion is specific (Tecchio *et al*., 2022). and may differ based on the cultivation site's soil and climatic conditions (Vršič *et al*., 2015).

Another significant finding was that, independent of rootstock, the berries in the first season had greater levels of SS, higher pH, and lower acidity than in the second season (Figure 4), demonstrating the effect of climate fluctuations at each harvest. Leão *et al*. (2020a) argue that seasonal climate fluctuations have a greater impact on vine agronomic traits than rootstocks.

The grape matures during the sunniest time of year, when the temperature rises, causing a higher concentration of sugars and a decrease in acidity owing to the breakdown of organic acids (Santana *et al*., 2008). Furthermore, excessive precipitation during the ripening phase lowers the quantities of soluble carbohydrates in the fruit (Mandelli *et al*., 2008). Due to the larger precipitation during berry maturation, especially in the time leading up to harvest date, roughly 30 days following veraison, there was a lesser buildup of SS in 2021 compared to 2020 (Figure 2). However, it is underlined that the berries met the minimal requirement needed by international marketing regulations, which vary from 14 to 17.5ºBrix for table grapes depending on cultivar and growing circumstances.

In the current study, greater maturity index values were detected in the berries of vines grafted on ‘Paulsen 1103’ and ‘IAC 766’ in both seasons (Figure 4). The SS/TA ratio provides a more accurate assessment of the fruits than separate measurements of sugars or acidity and a high value is desirable for the domestic market, which should be equivalent to or more than 20 for table grapes (Bleinroth, 1993). According to Maia *et al*. (2012), the grape is best for eating when the SS/TA ratio is between 20 and 30 in cv. BRS Vitória. It was found that vines grafted on ‘Paulsen 1103’ and ‘IAC 766’ reached this range earlier than vines grafted on ‘IAC 572’ rootstock in both cycles. In this case, it is critical to emphasize that the precocity provided by these rootstocks promotes various benefits to the grape grower, including agility in product sale and a reduction in the risk of fruit loss in the field.

1.4. CONCLUSIONS

The rootstocks altered the duration of the phenological phases of 'BRS Vitória,' with the rootstock ‘Paulsen 1103’ providing the vines with more precocity.

The cycle from pruning to harvest date for cv. BRS Vitória was 131 to 143 days in subtropical conditions, with thermal demands ranging from 1,545 to 1,725 DD.

'Paulsen 1103' induced berries with greater soluble solids content and good balance between SS/TA earlier in both seasons. ‘IAC 572’, on the other hand, was the rootstock that promoted lower soluble solids content and a longer delay in berry maturation.

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CAPÍTULO 2

TABLE GRAPE 'BRS VITÓRIA' YIELD PERFORMANCE, VIGOUR, AND QUALITY AS INFLUENCED BY ROOTSTOCKS IN A SUBTROPICAL REGION

ABSTRACT

Considering the expansion of vine orchards to new sites and the need for diversification of scion and rootstock combinations in subtropical sites, the selection of proper rootstock can provide important improvements to the scions. Thus, the present study aimed to assess the influence of rootstocks 'IAC 572,' 'IAC 766,' and '1103P' on the productive performance, vigor, and quality of 'BRS Vitória' grapevine under subtropical conditions. Over three summer seasons, production and vigor components (number of clusters per vine, production per vine, productivity, and pruning mass), physical-chemical characteristics of clusters and berries (number of berries, fresh mass, length and width of clusters and berries, soluble solids, pH, titratable acidity, and maturation index), and levels of bioactive compounds in the berries (phenols, flavonoids, and anthocyanins) were evaluated. Significant influence of the rootstocks was observed for most of the variables assessed. Results indicated that the higher the vigor induced by the rootstock, the greater the vine productivity, but the lower the concentration of soluble solids and bioactive compounds in the grapes. The 'IAC 572' rootstock induced greater vigor and productivity, while grapes from vines grafted onto '1103P' had higher levels of soluble solids, phenols, flavonoids, and anthocyanins. Overall, 'BRS Vitória' cultivar exhibited good productivity and quality. Therefore, expanding cultivation in subtropical areas emerges as an excellent alternative to meet the growing demand for seedless grapes.
Keywords: grafting; subtropical viticulture; seedless grapes; hybrid grapes; bioactive compounds.

2.1. INTRODUCTION

Over the last decade, there has been a significant increase in demand for seedless grapes in Brazil. In this context, it is noteworthy that the cultivars Superior Seedless, Crimson Seedless, and Thompson Seedless are gradually being replaced by new hybrid and national cultivars, attributed to their adaptation, productivity, and commercial quality – characteristics highly desired by consumers. Notable among these cultivars are 'BRS Ísis' and, particularly, 'BRS Vitória,' the latter being not only well-received in the domestic market but also among the most exported grape varieties in the country (Mello and Machado, 2022).

'BRS Vitória,' a seedless black grape, stands out in Brazilian viticulture due to its pleasant taste, high soluble solids content, and elevated productivity. Additionally, it exhibits high vigor, bud fertility, and tolerance to mildew and berry cracking (Maia *et al*., 2012). A relevant aspect is its lower production cost due to reduced pesticide and labor demands, ensuring higher economic returns for grape growers and sustainable production (Maia *et al*., 2018). While primarily cultivated in the semi-arid tropical climate of Brazil, 'BRS Vitória' demonstrates broad climatic adaptability (Maia *et al*., 2012), making it a promising option for subtropical and temperate regions.

Within the major viticultural regions of the State of São Paulo, there is a noteworthy increase in the cultivation of 'BRS Vitória' in the Northwest of São Paulo, emerging as a significant alternative for production diversification with increased profitability. However, as a cultivar introduced in 2013, further studies in these regions are required, particularly addressing important practices such as the use of suitable rootstocks.

Grafting is indispensable in viticulture, representing a consistently effective and successful technique in major viticultural countries for controlling various pathogens affecting vine root systems, notably phylloxera (Granett *et al*., 2001) and nematodes (Ferris *et al*., 2012). Furthermore, rootstocks play a crucial role in enabling vine cultivation even in adverse soil conditions, such as high salinity (Dunlevy *et al*., 2022), water deficit or drought (Serra *et al*., 2013), deficiency of essential nutrients (Livigni *et al*., 2019), and excess of toxic elements (Cançado *et al*., 2009). Beyond these benefits, studies indicate that rootstocks can influence various vine characteristics, including vegetative vigor (Li *et al*., 2019), productivity (Tecchio *et al*., 2020), physicochemical quality (Silva *et al*., 2018), levels of bioactive compounds (Cheng *et al*., 2017), and the duration of the phenological cycle (Callili *et al*., 2023). Thus, the selection of a rootstock with good compatibility with the scion cultivar is crucial for successful grape cultivation.

However, it is important to emphasize that the selection of a suitable rootstock involves considering factors such as compatibility and interaction between rootstock and scion cultivar (Vrsic *et al*., 2015) and the adaptation of both to climatic conditions (Leão *et al*., 2020a). Additionally, the vigor induced by the rootstock on the above-ground portion must be considered, as studies show that this parameter is intrinsically related to grape productivity and quality (Jones *et al*., 2009; Ibacache *et al*., 2016). Therefore, studies involving rootstocks in specific cultivation conditions are crucial and can serve as direct recommendations for grape growers.

Presently, Brazil has numerous rootstock cultivars available, each with its own characteristics and specific recommendations, including notable options such as 'IAC 572 Jales,' 'IAC 766 Campinas,' and '1103 Paulsen.' 'IAC 572' and 'IAC 766' are vigorous and widely used in subtropical and tropical areas, while '1103P' is the most utilized rootstock in temperate Brazilian conditions (Tecchio *et al*., 2018; Viana *et al*., 2018). While there are studies evaluating these rootstocks in combinations with widely produced table grape cultivars in Brazil (Feldberg *et al*., 2007; Leão *et al*., 2019; Leão *et al*., 2020a; Callili *et al*., 2022a), there is limited research on 'BRS Vitória' in subtropical and temperate conditions. Thus, the present study aimed to assess the influence of the rootstocks 'IAC 572,' 'IAC 766,' and '1103P' on the productive performance, vigor, and quality of the 'BRS Vitória' grapevine under subtropical conditions.

2.2. MATERIAL AND METHODS

2.2.1. Treatments and experimental design

The grape cultivar 'BRS Vitória' (CNPUV 681-29 x 'BRS Linda') was grafted onto the rootstocks 'IAC 572 Jales' ((*Vitis caribaea* x (*Vitis riparia* x *Vitis rupestris* 101-14)), 'IAC 766 Campinas' (Riparia do Traviú x *Vitis caribaea*), and '1103 Paulsen' (*Vitis berlandieri* x *Vitis rupestris*). The experimental design was a randomized block design, comprising 7 blocks with 3 plants per plot, totalling 63 grapevines.

2.2.2. Experimental location and cultivation conditions

The study was conducted in an experimental vineyard located in São Manuel, State of São Paulo, Brazil (22°46''S, 48°34''W, and 773 m altitude), over three consecutive summer seasons (2020 to 2022). According to the Köppen classification, the climate is of the *Cfa* type, i.e., subtropical with a hot summer. During the grapevine production cycles, 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. Meanwhile, the average maximum temperature in 2020, 2021, and 2022 was 28.8°C, 27.7°C, and 27.7°C, respectively. The accumulated rainfall in 2020, 2021, and 2022 was 477 mm, 593 mm, and 543 mm, respectively, with a tendency for concentration in the summer months

(Figure 1). According to Embrapa criteria (2018), the soil in the experimental area was classified as Red Latosol (equivalent to Oxisols in USDA soil taxonomy).

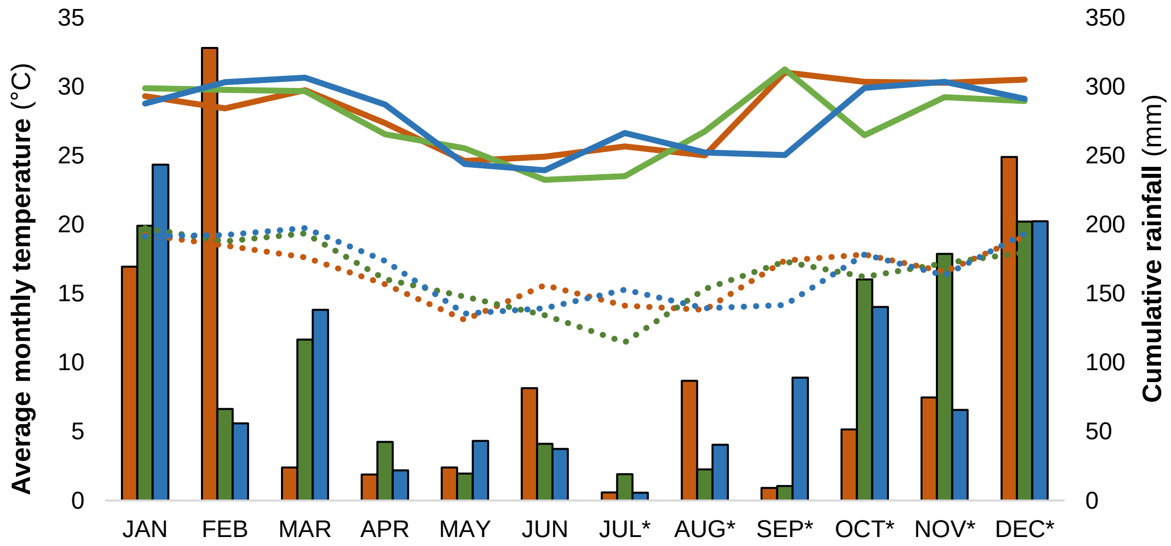

Figure 1. Climate data for the experimental site in 2020, 2021, and 2022 (including average temperature and total rainfall). Brazil's State of São Paulo, São Manuel.

*Productive time. The lines denote the minimum and maximum temperatures, while the bars depict the total amount of precipitation. The colours orange, green, and blue, respectively, stand in for the years 2020, 2021, and 2022, respectively.

Rootstock cuttings were planted in August 2018, with a spacing of 3.0 m between rows and 2.0 m between plants (density of 1,667 grapevines per hectare). Grafting of the scion cultivar was performed in July 2019. A "Y" system with a metal structure and eucalyptus treated stakes was used for vine support and training. Micro-sprinklers were employed for irrigation. The experimental vineyard was covered with 18% shading polyethylene mesh to protect against hail and bird attacks.

All cultural practices, including fertilization, plant growth regulators, shoot thinning, leaf removal, shoot positioning, and cluster thinning, as well as phytosanitary control, were carried out following the recommendations proposed by Maia *et al*. (2016).

Pruning for the 2020, 2021, and 2022 production cycles took place on July 22, August 5, and July 14, respectively (winter pruning). During pruning, one to two buds per spur were retained, and subsequently, to induce and standardize bud break, 2.5% hydrogen cyanamide was applied. Fruits were harvested when reaching full maturity, i.e., when they exhibited soluble solids and titratable acidity levels suitable for the 'BRS

Vitória' cultivar in subtropical regions (Maia *et al*., 2012). Additionally, berry colour and texture were considered in determining the ideal harvest time.

2.2.3. Productive components and vigour of vines

At harvest, the number of clusters per vine was recorded, and by their weight, vine production (kg $vine^{-1}$) was determined. Productivity (t ha^{-1}) was estimated based on vine production and planting spacing, considering a planting density of 1,667 plants per hectare.

To assess vine vigor, the accumulation of biomass from the shoots (kg $vine^{-1}$) was evaluated. At the pruning stage, the total fresh mass of shoots from each experimental plot was obtained. Subsequently, in samples comprising 3 shoots per plot, the percentage of dry mass of the shoots was determined. Thus, the accumulation of shoot biomass was estimated by multiplying the sample data of the dry mass percentage and the total fresh mass of the shoots.

2.2.4. Physical characteristics of grape bunches and berries

For physical characteristics of clusters and berries, 10 clusters were selected from each plot, and the fresh mass (g), width (cm), and length (cm) were determined. The number of berries per cluster was also quantified.

2.2.5. Chemical composition of grape must

For chemical characteristics of the berries, titratable acidity (TA), pH, soluble solids (SS) content, and maturation index (SS/TA) were assessed. TA was determined by titrating the berry must with 0.1 N NaOH, using a pH endpoint of 8.2, and the result was expressed as a percentage of tartaric acid (%). The pH was obtained by the direct reading of the must on a pH meter (Tecnal®, model Tec-5, Piracicaba, SP, Brazil). SS content was determined by direct refractometry of the must using a digital refractometer (Reichert®, model r2i300, Depew, NY, USA), and the maturation index was obtained by the SS/TA ratio.

2.2.6. Bioactive compounds

The analysis of total phenols content was performed using the Folin-Ciocalteau reagent (Singleton and Rossi, 1965), and the results were expressed in mg equivalent of gallic acid (mgEAG) per 100 g. The total flavonoids content was determined according to Popova *et al*. (2004), and the results were expressed in mg equivalent of quercetin (mgEQ) per 100 g. The total monomeric anthocyanins content was determined using the differential pH method (Giusti and Wrolstad, 2001), and the results were expressed in mg of malvidin-3-glucoside per 100 g.

2.2.7. Statistical analyses

Statistical analyses were conducted with the mean values obtained over the three production cycles. The data were subjected to analysis of variance (ANOVA) to determine the effect of rootstocks, and mean comparisons between treatments were performed using the Tukey test at a 5% probability level, using the statistical software SISVAR version 5.7. Data from 18 characteristics were evaluated by principal component analysis (PCA) using XLSTAT version 19.4, which was also used to calculate Pearson correlation, thus assessing the relationship between the evaluated variables.

2.3. RESULTS AND DISCUSSION

2.3.1. Productive components, vegetative vigour and physical attributes of bunches and berries

There was a significant difference ($p < 0.05$) among rootstocks concerning the productive performance of grapevines, with 'IAC 572' standing out by providing a yield 23% higher than 'IAC 766' and 51% higher than '1103P' (Table 1). Regarding vine vigor, 'IAC 572' also induced higher pruning mass compared to 'IAC 766' and '1103P', with values of 3.63, 2.31, and 1.58 kg vine^{-1}, respectively (Table 1). Pearson correlation analysis (data not shown) indicates a strong impact of pruning mass on vine productivity ($r = 0.99$). In a study comparing these same rootstocks, Mota *et al*. (2009) found that 'IAC 572' induced higher vigor and productivity in 'Niagara Rosada' and 'Bordô'. These results support other studies suggesting that higher vigor provided by the rootstock leads to increased vine productivity (Jones *et al*., 2009; Rizk-Alla *et al*., 2011; Ibacache *et al*., 2016).

Table 1. Yield and vigor components of 'BRS Vitória' vine grafted onto different rootstocks under subtropical conditions.

Yield and vigor components	Rootstocks			
	IAC 572 Jales	IAC 766 Campinas	1103 Paulsen	*p*-value
Yield per vine (kg vine^{-1})	23.87 ± 3.72 a	19.37 ± 1.34 b	15.80 ± 1.65 b	> 0.01
Productivity (t ha^{-1})	39.81 ± 6.20 a	32.27 ± 2.23b	26.27 ± 4.48 b	> 0.01
Number of clusters per vine	84.18 ± 8.45 a	81.78 ± 3.84 a	70.24 ± 9.53 b	> 0.01
Pruning mass (kg vine^{-1})	3.63 ± 0.98 a	2.31 ± 0.30 b	1.58 ± 0.20 b	> 0.01

Values are expressed as mean (three seasons) ± standard deviation (n = 7). On the same line, values that are followed by different letters differ significantly (Tukey test. $p < 0.05$).

According to Bascunán-Godoy *et al*. (2017), the vigor conferred by rootstocks to the canopy can be a decisive factor in altering vine productivity. These authors emphasize that higher yields in vines cultivated on rootstocks inducing greater vigor are related to increased light capture by the canopy. Additionally, rootstocks differ in water and nutrient uptake (Jin *et al*., 2016); that is, the greater the capacity for nutrient absorption and translocation, the higher the biomass accumulation in the aboveground part and, consequently, the greater the productivity of grapevines (Tecchio *et al*., 2019). Lower productivity was detected in vines grafted onto '1103P,' and this result is also related to the number of clusters per vine (r = 0.91). While 'BRS Vitória' grafted onto 'IAC 572' and 'IAC 766' produced 84 and 81 clusters per vine, respectively, those cultivated on '1103P' presented 70 clusters per vine (Table 1). However, the reverse was observed by Leão *et al*. (2020b); vines grafted onto '1103P' had a higher number of clusters than those grafted onto 'IAC 572' (104 *versus* 86). Still, this variable did not influence the production of 'BRS Vitória' under semi-arid tropical conditions.

The vigor conferred by rootstocks also strongly influenced the physical attributes of clusters. Pruning mass showed a high positive correlation with the number of berries per cluster (r = 0.98), cluster mass (r = 0.99), cluster length (r = 0.99), and cluster width (r = 0.93). 'BRS Vitória' grafted onto 'IAC 572' had a higher number of berries per cluster (70.75) and a higher cluster mass (332.74 g) compared to 'IAC 766' and '1103P'. Furthermore, concerning only '1103P,' 'BRS Vitória' cultivated on 'IAC 572' exhibited greater cluster length (16.32 *versus* 15.47 cm), cluster width (8.37 *versus* 7.31 cm), berry mass (4.51 *versus* 4.14 g), and berry width (1.87 *versus* 1.77 cm) (Table 2). Despite the significant effect of rootstocks in this study, Leão *et al*. (2020b) found no difference between these same rootstocks regarding the productivity of 'BRS Vitória' cultivated in semi-arid tropical conditions (*BSwh*). This indicates that the effect of the rootstock on vine characteristics is directly related to the soil and climatic conditions of the cultivation site. Additionally, when analyzing studies conducted with these rootstocks in combinations with other table grape cultivars, there is a significant variation in results. In general, 'Niagara Rosada' (Bruna and Back, 2015), 'BRS Clara' (Leão *et al*., 2019), 'Crimson Seedless,' and 'Superior Seedless' (Feldberg *et al*., 2007) grafted onto '1103P' showed higher productivity compared to 'IAC 572,' which is the opposite of what was observed in this study (Table 1). On the other hand, both rootstocks did not affect the productive performance of 'BRS Ísis' (Leão *et al*., 2020a). Therefore, it is also evident that the affinity and interaction between the rootstock and scion cultivar are extremely specific and vary according to the cultivation conditions.

Table 2. Physical attributes of 'BRS Vitória' vine clusters and berries grafted onto various rootstocks in subtropical environments.

Clusters and berries characteristics	Rootstocks			
	IAC 572 Jales	IAC 766 Campinas	1103 Paulsen	p-value
Number of berries per cluster	70.75 ± 3.67 a	67.10 ± 3.62 b	63.47 ± 4.31 c	> 0.01
Clusters mass (g)	332.47 ± 11.76 a	302.27 ± 12.01 b	273.90 ± 16.47 c	> 0.01
Clusters length (cm)	16.32 ± 0.51 a	15.87 ± 0.41 ab	15.47 ± 0.40 b	> 0.01
Clusters width (cm)	8.37 ± 0.27 a	8.20 ± 0.17 ab	7.81 ± 0.34 b	> 0.01
Berries mass (g)	4.51 ± 0.19 a	4.38 ± 0.14 a	4.14 ± 0.13 b	> 0.01
Berries length (cm)	2.40 ± 0.04	2.40 ± 0.03	2.34 ± 0.02	0.05
Berries width (cm)	1.87 ± 0.09 a	1.82 ± 0.10 ab	1.77 ± 0.01 b	> 0.05

Values are expressed as mean (three seasons) ± standard deviation (n = 7). On the same line, values that are followed by different letters differ significantly (Tukey test. $p < 0.05$).

The superior productive performance of vines grafted onto 'IAC 572' is related to the greater vigor induced by this rootstock and its better adaptation to the *Cfa* climate and Red Latosol, in addition to the better interaction with 'BRS Vitória' under these cultivation conditions. Moreover, it is essential to emphasize that, regardless of the rootstock used, 'BRS Vitória' showed good productive performance under subtropical conditions, with high productivity, i.e., above 25 ton ha^{-1}.

2.3.2. Chemical composition and bioactive compounds

Regarding the chemical composition of grapes, there was no difference among rootstocks for TA, pH, and maturation index, with average values of 0.51%, 3.48, and 37.7, respectively (Table 3). According to descriptions by Maia *et al*. (2012), the raspberry flavor of 'BRS Vitória' grapes is accentuated when the SS/TA ratio is between 20 and 30, values below those found in this study. This may be attributed mainly to the low acidity of the grapes. The fruit's flavor is largely due to the balance between sugars and acids (SS/TA), and high values of this index are desirable in the domestic market. Bleinroth (1993) mentions that the SS/TA ratio provides a good assessment of fruits, being more representative than the isolated measurement of sugars or acidity, and should be equal to or greater than 20 for table grapes. However, it is known that the quality parameter most used by grape growers, due to its practicality, is the isolated measurement of SS content.

Table 3. Chemical compositions and bioactive compounds of 'BRS Vitória' vine grafted onto various rootstocks in subtropical environments.

Chemical compositions and bioactive compounds	Rootstocks			
	IAC 572 Jales	IAC 766 Campinas	1103 Paulsen	*p*-value
Titratable acidity (%)	0.52 ± 0.03	0.50 ± 0.04	0.51 ± 0.04	0.63
pH	3.46 ± 0.04	3.49 ± 0.06	3.49 ± 0.05	0.37
Soluble solids (°Brix)	16.99 ± 0.47 b	18.08 ± 0.86 ab	19.08 ± 0.85 a	> 0.01
Maturation index (SS/TA)	34.38 ± 3.97	39.40 ± 6.11	39.32 ± 4.40	0.17
Total phenols (mg 100 g^{-1})	190.67 ± 22.78 b	213.46 ± 8.27 ab	226.70 ± 4.40 a	< 0.05
Total flavonoids (mg 100 g^{-1})	19.40 ± 1.78 b	19.62 ± 1.38 b	25.07 ± 0.85 a	< 0.01
Anthocyanins (mg 100 g^{-1})	81.98 ± 4.54 b	97.09 ± 7.41 b	181.29 ± 12.19 a	< 0.01

Values are expressed as mean (three seasons) ± standard deviation (n = 7). On the same line, values that are followed by different letters differ significantly (Tukey test. p < 0.05).

In 'BRS Vitória' grapes grafted onto '1103P,' the SS content was significantly higher compared to those cultivated on 'IAC 572' (19.08 *versus* 16.99 °Brix) (Table 3). This is primarily due to the higher vigor induced by 'IAC 572', as a high negative correlation was found between SS and pruning mass (r = -0.99), number of berries (r = -1.00), cluster mass (r = -1.00), berry mass (r = -0.99), and consequently, with productivity (r = -0.99). 'Niagara Rosada' and 'Bordô' also showed the same behavior when grafted onto 'IAC 572', exhibiting higher vigor and lower SS content compared to 'IAC 766' and '1103P' (Mota *et al*., 2009). In 'BRS Vitória' cultivated in the BSwh climate, there was no difference between these same rootstocks regarding SS content (19.4 °Brix) (Leão *et al*., 2020b), values higher than those obtained in this study (Table 3) due mainly to the conditions that occur in the semi-arid tropical climate, i.e., low precipitation and high temperature during the harvest period, factors that favor SS accumulation.

From the climatic data shown in Figure 1, it is observed that in the period preceding the harvest (December), there was a high rainfall index, thus unfavoring SS accumulation. However, it is emphasized that, regardless of the rootstock, the values found are within the international standards for commercialization, with the minimum SS content of table grapes being 14 to 17.5 ºBrix, depending on the cultivar and cultivation conditions (Maia *et al*., 2012). Furthermore, when compared with 'Niagara Rosada,' which is the most produced table grape cultivar in subtropical Brazilian regions, 'BRS Vitória' has a higher SS content, a feature pleasing to consumers. In similar climatic conditions, Callili *et al*. (2022b) detected 15.6 °Brix in 'Niagara Rosada' grapes. It is also worth noting that 'BRS Vitória' has good tolerance to berry cracking (Maia *et al*., 2012), making its cultivation viable even in regions with high precipitation.

'BRS Vitória' grafted onto '1103P' has higher levels of total phenols, total flavonoids, and monomeric anthocyanins (Table 3). As observed for SS, a high negative correlation was also observed between phenolic compounds and vine vigor components. Other studies have also verified the influence of rootstocks on the content of phenolic compounds in grapes and mention that vegetative vigor is considered an important factor for the concentration of some bioactive compounds (Silva *et al*., 2017; Silva *et al*., 2019; Callili *et al*., 2022b). The variation in phenolic compound levels may be due to changes in secondary metabolism in response to biotic or abiotic factors, such as light, temperature, altitude, soil type, water, microbial interactions, nutritional status, pathogenesis, wounds, defoliation, and phytohormones. However, the most probable factor influencing the content of phenolic compounds is excessive vigor (Downey *et al*., 2006).

The greatest difference among rootstocks was observed regarding anthocyanin content. 'BRS Vitória' grapes on '1103P' have higher levels of anthocyanins compared to 'IAC 766' and 'IAC 572,' i.e., 181.29, 97.09, and 81.98 mg per 100 g, respectively (Table 3). Suriano *et al*. (2016) also observed that rootstocks directly affect the anthocyanin content of grapes. Anthocyanins are compounds related to the pigmentation of fruits; thus, higher levels tend to promote a more intense color to the berries, making them more attractive to consumers. Furthermore, due to their antioxidant properties, these compounds are highly desirable as they provide various health benefits to humans (Haminiuk *et al*., 2012).

2.3.3. Principal component analysis (PCA)

Principal Component Analysis (PCA) was applied to all variables studied in the cultivar BRS Vitória grafted onto the rootstocks 'IAC 572,' 'IAC 766,' and '1103P.' The experiment's variability was explained by two principal components (PC) (Table 4 and Figure 2).

Table 4. Factor loadings, eigenvalues and proportion of variation associated with two main components (PC) of yield components, physicochemical and biochemical attributes of the combination between 'BRS Vitória' grape and 'IAC 572', 'IAC 766' and '1103P' rootstocks.

Traits	PC1	PC2
YldV	0.998	0.066
Pdt	0.998	0.062
NCV	0.934	-0.358
CM	1.000	0.015
CL	1.000	0.019
CW	0.978	-0.209
NBC	1.000	0.001
BM	0.993	-0.116
BL	0.950	-0.312
BW	0.995	-0.098
PrngM	0.987	0.158
TA	0.562	0.827
pH	-0.875	-0.484
SS	-1.000	-0.021
SS/TA	-0.860	-0.510
Phnl	-0.989	-0.148
Flvn	-0.881	0.472
Anth	-0.927	0.376
Eigenvalue	16.108	1.892
Variability (%)	89.491	10.509
Cumulative %	89.491	100.000

Trait abbreviation: number of clusters per vine [NCV], number of berries per cluster [NBC], yield per vine [YldV], productivity [Pdt], pruning mass [PrngM], cluster mass [CM], cluster length [CL], cluster width [CW], berry mass [BM], berry length [BL], berry width [BW], pH [pH], soluble solids [SS], titratable acidity [TA], maturation index [SS/TA ratio], phenols [Phnl], flavonoids [Flvn], anthocyanins [Anth].

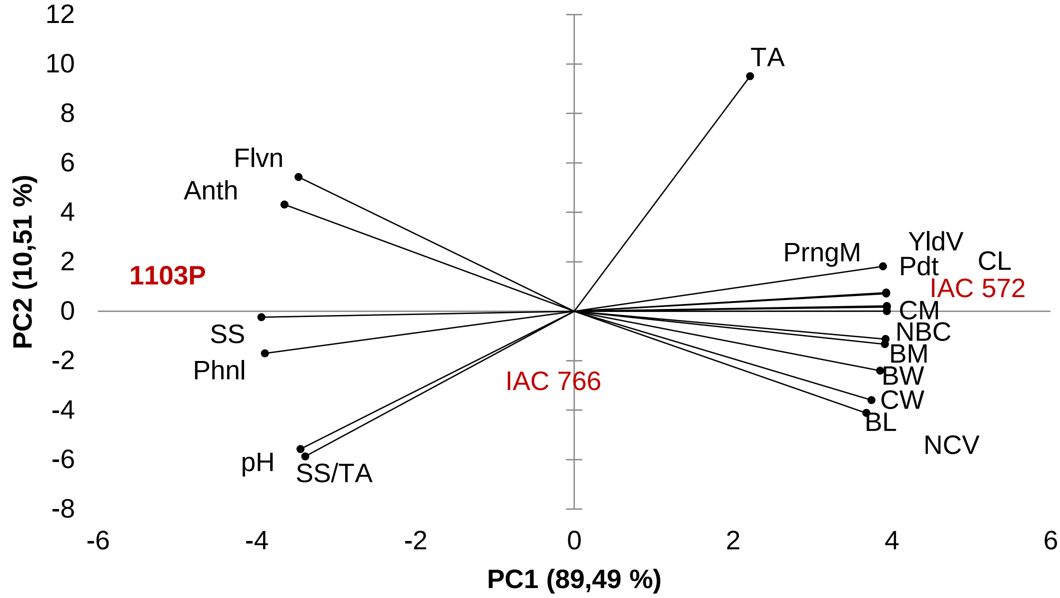

Figure 2. Plot of the principal component analysis of 18 yield and quality traits of the combination between 'BRS Vitória' grape and 'IAC 572', 'IAC 766' and '1103P' rootstocks. See Table 4 for trait labels.

PC1 explained 89.49% of the total variability and effectively separated the studied rootstocks, especially 'IAC 572' from '1103P.' Except for titratable acidity, all other variables contributed strongly to the separation of these rootstocks. Variables such as yield, productivity, physical characteristics of clusters and berries, and pruning mass showed high positive loadings. On the other hand, variables such as pH, soluble solids, phenolic compounds, anthocyanins, and flavonoids expressed high negative loadings. PC1 scores and loadings suggest that 'BRS Vitória' grafted onto 'IAC 572' has higher yield, positively correlated with higher values of physical characteristics of clusters and berries. In turn, when 'BRS Vitória' was grafted onto '1103P,' the berries contained higher levels of soluble solids and a higher content of bioactive compounds. Regarding the use of the rootstock 'IAC 766,' the berries showed lower titratable acidity.

2.4. CONCLUSIONS

Throughout the three studied harvests, all three rootstocks directly influenced the productivity, vigor, and quality of 'BRS Vitória' grapes. There is a clear separation between 'IAC 572' and '1103' when compared to 'IAC 766.' 'BRS Vitória' grafted onto 'IAC 572' exhibits the best characteristics for commercialization, i.e., higher vigor and productivity, taking into account the number of clusters per vine, number of berries per cluster, yield per vine, productivity, pruning mass, cluster mass, cluster length, cluster width, berry mass, berry length, and berry width. On the other hand, when seeking fruit richer in bioactives compounds, grafting onto '1103P' is recommended, with berries having higher levels of soluble solids, phenolic compounds, flavonoids, and anthocyanins under similar cultivation conditions.

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CAPÍTULO 3

ROOTSTOCK EFFECTS ON YIELD, NUTRIENT ABSORPTION, AND EXTRACTION IN 'BRS VITÓRIA' GRAPEVINE

ABSTRACT

The current study sought to assess the impact of the rootstocks 'IAC 572', 'IAC 766', and '1103P' on the productive performance, nutrient content, and extraction of the 'BRS Vitória' vine in a subtropical environment. Productivity, dry mass of branches and bunches, nutrient content in branches and bunches, nutrient extraction by branches and bunches, and nutrient absorption by bunches were all examined in proportion to the total content extracted in two production cycles. 'IAC 572' supplied the vines with a higher dry mass of branches and bunches and, as a result, higher yields than 'IAC 766' and '1103P'. Nutrient content and extraction were likewise increased in vines grafted with 'IAC 572'. However, nutrient export to the bunch was lower in comparison to 'IAC 766' and '1103P'. As a result, the results indicate that the 'IAC 572' rootstock is more suitable in combination with 'BRS Vitória' under subtropical conditions due to higher productivity, better nutrient accumulation capacity, and nutrient efficiency.

Keywords: subtropical viticulture, hybrid grapes, seedless grapes, table grapes, grafting.

3.1. INTRODUCTION

Rootstocks are primarily used in winemaking to provide tolerance or resistance to infections that impact plant root systems (Granett *et al*., 2001; Smith *et al*., 2016) and to allow grape cultivation in poor soil conditions (Fisakaris *et al*., 2004; Prinsi *et al*., 2021). However, in addition to being an effective tool for overcoming biotic and abiotic stress constraints, rootstocks can directly affect several characteristics of the vines and fruit composition, such as productivity, vegetative vigor, phenological cycle duration, soluble solids content, and bioactive compounds (Jin *et al*., 2016; Cheng *et al*., 2017; Silva *et al*., 2018; Callili *et al*., 2023).

As a result of these considerations, it is evident that the adoption of appropriate rootstocks is a critical aspect in the vineyard's success. Given that rootstock interference varies depending on edaphoclimatic conditions as well as affinity and interaction with the scion cultivar (Vrsic *et al*., 2015; Clingeleffer *et al*., 2019; Tecchio *et al*., 2020), research is critical because it informs winegrowers about which combinations to use in specific growing conditions.

The influence of rootstocks on nutrient accumulation and extraction has been studied on several wine grape cultivars (Schreiner and Scagel, 2006; Csikász-Krizcics and Diófási, 2008; Sato *et al*., 2016; Gautier *et al*., 2020; Nikolaou *et al*., 2022), as well as table grape cultivars such as 'Itália' (Albuquerque and Dechen, 2000), 'Flame Seedless', 'Thompson Seedless', 'Superior Seedless', 'Red Globe' (Ibacache and Sierra, 2009), 'Vênus' (tecchio *et al*., 2019) and 'Niagara Rosada' (Tecchio *et al*., 2011; Tecchio *et al*., 2014).

Rootstocks can improve fertilizer usage efficiency; Keller *et al*. (2001) state that nutrient application can be reduced by employing rootstocks with high absorption capacity. With the rising expense of fertilizers and the environmental effect of their manufacture and usage, the proper selection of rootstocks becomes even more critical for the long-term viability of grape production.

There have been no investigations on the impact of rootstocks on nutrient extraction and accumulation in 'BRS Vitória'. 'BRS Vitória' is well-known in Brazilian viticulture as one of the most widely grown, eaten, and exported seedless table grape varieties (Maia *et al*., 2018). Its cultivation is expanding mostly because to its mildew tolerance, high productivity, low production cost, high soluble solids content, and raspberry taste (Maia *et al*., 2012).

As a result, the goal of this study was to assess the effect of various rootstocks on nutrient accumulation and extraction, productivity, and vegetative vigor of the 'BRS Vitória' vine under subtropical circumstances.

3.2. MATERIAL AND METHODS

3.2.1. Treatments and experimental design

The grape cultivar 'BRS Vitória', a hybrid created by crossing 'CNPUV 681-29' with 'BRS Linda' (Maia *et al*., 2012), was tested on three rootstocks: 'IAC 572 Jales' ((*V. caribaea* x (*V. riparia* x *V. rupestris* 101-14)), 'IAC 766 Campinas' (Riparia do Traviú x *V. caribaea*) and 'Paulsen 1103' (*V. berlandieri* x *V. rupestris*) Three plants composed the experimental units in a totally randomized block design with seven replications.

3.2.2. Experimental site and growing conditions

During two summer harvests (2021 and 2022), the experiment was conducted out at São Manuel, State of São Paulo, Brazil (22°46''S, 48°34''W, and 773 m height). The soil in the region is classed as Red Oxisol with a sandy texture, according to Embrapa standards (2018). Prior to each production cycle, the soil was chemically analyzed at depths of 0-20 cm and 20-40 cm using the approach outlined by Raij *et al*. (2001) (Table 1).

Table 1. Results of chemical soil analysis performed at the start of production cycles (2021 and 2022).

Chemical soil analysis	**Seasons and soil layer sampled**			
	2021, 0 to 20 cm	2021, 20 to 40 cm	2022, 0 to 20 cm	2022, 20 to 40 cm
pH ($CaCl_2$)	5.86 ± 0.28	5.68 ± 0.56	6.05 ± 0.17	5.54 ± 0.19
Organic matter (g/dm^3)	6.89 ± 1.33	4.76 ± 1.05	6.18 ± 1.16	4.49 ± 0.48
P (mg/dm^3)*	81.72 ± 28.61	48.60 ± 29.65	84.73 ± 2.78	85.18 ± 2.97
H+Al (mmolc/dm^3)	10.76 ± 2.12	12.19 ± 3.14	9.81 ± 0.71	12.14 ± 2.15
K (mmolc/dm^3)*	3.17 ± 1.83	2.92 ± 1.88	1.62 ± 0.39	2.35 ± 0.52
Ca (mmolc/dm^3)*	21.18 ± 2.70	11.84 ± 2.79	22.51 ± 4.04	13.40 ± 1.73
Mg (mmolc/dm^3)*	6.74 ± 2.28	4.99 ± 2.76	5.71 ± 1.02	4.34 ± 0.63
SB (mmolc/dm^3)	31.09 ± 3.26	19.75 ± 3.75	29.84 ± 5.04	20.10 ± 2.27
CTC (mmolc/dm^3)	41.84 ± 1.71	31.94 ± 1.16	39.65 ± 4.90	32.23 ± 2.78
V (%)	74.17 ± 5.73	61.67 ± 10.50	74.90 ± 3.70	62.39 ± 5.32
S (mg/dm^3)**	4.10 ± 0.65	3.90 ± 0.86	3.65 ± 0.31	3.46 ± 0.44
B (mg/dm^3)***	0.16 ± 0.05	0.16 ± 0.07	0.21 ± 0.02	0.29 ± 0.05
Cu (mg/dm^3)***	0.94 ± 0.09	0.81 ± 0.06	0.98 ± 0.09	0.89 ± 0.11
Fe (mg/dm^3)***	15.82 ± 6.68	17.05 ± 8.56	12.89 ± 1.24	17.70 ± 3.65
Mn (mg/dm^3)***	12.60 ± 1.20	15.29 ± 2.92	6.23 ± 0.86	9.85 ± 2.05
Zn (mg/dm^3)***	2.65 ± 0.70	1.17 ± 0.11	2.95 ± 0.42	1.38 ± 0.27

Values are expressed as mean (eight composite samples) ± standard deviation (n = 8). *extracted with ion-exchange resin;** extracted with Ca(H2PO4)2 0,01 mol L-1; *** extracted with DTPA.

The climate is classified as *Cfa* (subtropical with hot summers) by the Köppen climatic classification. During the vine production cycles, from July to December, the average lowest temperature was 15.9°C in 2021 and 16.1°C in 2022, with the average maximum temperature being 27.7°C and 27.7°C, respectively. The total rainfall in 2021 was 593 mm, while in 2022 it was 543 mm, with a tendency to be concentrated in the summer months.

Planting of rootstock cuttings took place in August 2018, and grafting of the scion cultivar took place in July 2019. The plants were spaced at 3.0 m × 2.0 m (1,667 plants per hectare). A "Y" system with a metal framework and treated eucalyptus poles was employed to support and guide the vines. The watering system made use of micro sprinklers. To guard against hail and bird assaults, the vineyard in the experimental area was covered with a polyethylene screen (18% shade).

Production pruning for the 2021 and 2022 cycles took place on August 5th and July 14th, respectively. During pruning, one to two buds were kept per spur, and 2.5% hydrogen cyanamide was sprayed thereafter. According to the guidelines of Maia *et al*. (2012), the harvest was determined based on the soluble solids concentration and titratable acidity.

Cultural management, such as the use of plant regulators, thinning, defoliation, netting, branch trimming, cluster trimming and phytosanitary control were carried out in accordance with the recommendations proposed by Maia *et al*. (2016) for the cultivation of ‘BRS Vitória’ in subtropical regions.

The IAC's Technical Bulletin 100 (Tecchio *et al*., 2022) advice for fertilizing the experimental area was followed in both cropping cycles. Both cultivation cycles used the same fertilizer. 3 liters per plant of organic compost (Biovitta™, N: 1.2%, total organic C: 19.4%), 300g per plant of 4-14-8, and 300g of heat-treated rock phosphate (Yoorin Master™, P_2O_5: 17%) were sprayed in early May. During the production pruning, 100g of KCl and 10g of borax were administered to each plant. At the start of sprouting, when the shoots were 10cm long, 150g of 20-5-20 was administered per plant. This treatment was repeated during the berry's pea phase. The yearly N, K_2O, and P_2O_5 dosages were 150, 180, and 333 kg ha^{-1}, respectively, with all fertilizers applied as topdressing 40 cm from the planting row.

3.2.3. Variables analysed

Productivity, dry matter mass of branches and bunches, nutrient content in branches and bunches, nutrient extraction by branches and bunches, and nutrient absorption by bunches in proportion to the total amount of extracted nutrients in both production cycles.

After harvest, all bunches of the experimental plot were weighed, and productivity (ton ha^{-1}) was evaluated as a function of planting density (1667 plants ha^{-1}).

To determine the dry matter mass of the branches following production pruning, the total fresh mass of the excised branches was weighed in each experimental plot. At harvest, 10 bunches from each experimental plot were sampled. The samples of branches and bunches were then transported to the laboratory and washed and dried in a forced ventilation oven (65°C for 7 days) to determine the percentage of dry mass of the branches and bunches, according to the methods utilized by Tecchio *et al*., 2011, Tecchio *et al*., 2014, and Tecchio *et al*., 2019. Thus, biomass buildup was calculated by multiplying the sample's percentage of dry mass by its total fresh mass.

To assess nutritional content, branches and bunches were pulverized and chemically analyzed for macro and micronutrients using the approach outlined by Malavolta *et al*. (1997). Nutrient extraction was calculated by multiplying the nutrient content by the total dry matter mass of the branches and bunches gathered in each experimental plot. The sum of nutrient extraction by branches and clusters was used to calculate total nutrient extraction. The percentage of nutrients removed by the bunches was then calculated using the quotient between the nutrients extracted by the bunches and the total nutrients extracted by the vines, yielding nutrient absorption by the bunches as a function of total nutrient extracted.

Fixen *et al*., (2015) and Jones (2021) presented two indices for evaluating the usage efficiency of N, P, and K fertilizers. The first includes calculating the ratio of fruit mass produced per unit of nutrient used for each treatment (Partial factor productivity - PFP), which is calculated as follows:

$$PFP=Y/F,$$

where: Y=fruit production under fertilization (kg ha^{-1} year^{-1}) and F=dose of N, P or K applied in the treatment (kg ha^{-1} year^{-1} of N, P_2O_5 or K_2O).

The other index is a ratio of nutrients withdrawn during harvest to nutrients provided with fertilizers for each rootstock (partial nutrient balance - PNB), which is calculated as follows:

$$PNB=U_h/F,$$

Where: U_h=nutrient removal (pruned branches + harvested fruit) and F=dose of N or K applied in the treatment (kg ha^{-1} year^{-1} of N, P_2O_5 or K_2O).

3.2.4. Statistical analyses

The data were subjected to analysis of variance (Two-Way ANOVA) to determine the effects of rootstocks and each production cycle, and their interaction. The comparison of the means of both factors was performed using the Tukey test (5% probability), using the statistical software Sisvar® version 5.4 (Lavras, MG, Brazil).

3.3. RESULTS AND DISCUSSION

For the great majority of variables tested, there was no significant interaction ($p > 0.05$) between components (rootstocks and production cycles); hence, the factors were studied individually.

3.3.1. Productivity and dry matter mass of branches and bunches

The rootstocks had a substantial ($p < 0.05$) effect on the production and dry matter mass of branches and bunches (Table 2). Vines grafted on 'IAC 572' produced much more than vines growing on 'IAC 766' and '1103P,' with average values of 49.7, 38.6, and 31.4 ton ha^{-1}, respectively. Furthermore, 'IAC 572' produced more dry matter mass in the vines than 'IAC 766' and '1103P'. In terms of bunch dry mass, only 'IAC 572' differed significantly from '1103P' (7837 against 5996 kg ha^{-1}) (Table 2).

Table 2. Fruit yield and dry matter mass (DM) of branches and bunches of 'BRS Vitória' grapevine grafted onto different rootstocks measured over two seasons.

Treatments	**Fruit yield**	**DM Branches**	**DM Bunches**
Rootstocks	ton ha^{-1}	———— kg ha^{-1} ————	
IAC 572	49.7 a	3146 a	7837 a
IAC 766	38.6 b	2060 b	6780 ab
1103P	31.4 b	1401 b	5996 b
p-value	< 0.01	< 0.01	0.02
CV rootstocks	22.4	29.95	22.55
Seasons			
2021	30.9 b	1867 b	4938 b
2022	48.9 a	2538 a	8803 a
p-value	< 0.01	< 0.01	< 0.01
CV seasons	12.0	15.7	13.1
Mean	39.9	2202.6	6871

Different letters within a column for each factor (rootstocks and seasons) indicate a significant difference according to Tukey's test ($p < 0.05$). CV (%): coefficient of variation.

These findings support previous research indicating that the more the vegetative growth that rootstocks transfer to the scion, the larger the vine productivity (Sato *et al*., 2016; Tecchio *et al*., 2019). As a result, the vigor of the rootstock is a key component that must be considered. According to the current study, 'IAC 572' and 'IAC 766' rootstocks are more robust and adaptable to subtropical and tropical climates than '1103P' rootstock (Tecchio *et al*., 2018; Viana *et al*., 2018). However, the rootstock-induced vigor in the scion might degrade grape quality (Mota *et al*., 2009; Sánchez *et al*., 2023). As a result, care is required to achieve a healthy vegetative-productive balance, particularly in robust cultivars.

The impact of these rootstocks on the productive performance of table grape cultivars under various climatic conditions has also been assessed by other studies. Examples of these studies include the rustic cultivar 'Niagara Rosada' (Bruna and Back, 2015, Callili *et al*., 2022) and the seedless cultivars, including 'Crimson Seedless', 'Superior Seedless' (Feldberg *et al*., 2007), 'BRS Ísis' (Leão *et al*., 2020a; Sanchez *et al*., 2023) and 'BRS Vitória' (Leão *et al*., 2020b). The findings of these experiments exhibit significant diversity, indicating that the impacts of the rootstocks are related to their compatibility with the scion cultivar and differ depending on soil type, climate, and cultural care. Different from our subtropical study results (Table 2), Leão *et al*. (2020) found that the rootstocks evaluated ('IAC 572', 'IAC 766', and '1103P') did not affect the productivity of the 'BRS Vitória' vine. This study was conducted in a semi-arid tropical climate.

As anticipated, the second production cycle saw a large increase in vine productivity compared to the first cycle (48.9 against 30.9 ton ha^{-1}) as a result of the vines' increased vegetative growth, or their increased dry mass of branches and bunches (Table 2). These findings are consistent with the descriptions provided by Maia *et al*. (2014), who claim that 'BRS Vitória' can produce more than 30 ton ha^{-1}. Leão *et al*. (2020) found that in tropical environments with two harvests annually, the average productivity was 24 ton ha^{-1}, or 48 tons ha^{-1}. These findings align with the findings confirmed in this study, indicating that the 'BRS Vitória' is a well-suited cultivator for subtropical environments. Additionally, it's crucial to note that 'BRS Vitória' exhibits significantly higher productivity in a subtropical climate than 'Niagara Rosada' (Tecchio *et al*., 2014; Callili *et al*., 2022), the cultivar of the most produced table grape in the State of São Paulo (Mello and Machado, 2022). Consequently, growing 'BRS Vitória' under subtropical circumstances is a great substitute for Brazilian subtropical viticulture, particularly when planted on the 'IAC 572' rootstock.

3.3.2. Nutrient contents in branches and bunches

The levels of N, P, Ca, S, Fe, and Mn in branches and K, Ca, B, Cu, Fe, and Mn in bunches were significantly influenced by the rootstocks (Table 3). The following nutrients and rootstocks had the greatest amounts in the branches: N with 'IAC 766'; P with 'IAC 572'; Ca with 'IAC 572' and 'IAC 766'; S with 'IAC 572' and 'IAC 766'; Fe with '1103P'; and Mn with 'IAC 766' and '1103P'.

Table 3. Nutrient content in 'BRS Vitória' grapevine branches and bunches grafted onto two rootstocks across two harvest seasons.

Treatments	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
	g kg^{-1}						mg kg^{-1}				
Nutrient content in branches											
Rootstocks											
IAC 572	8.4 ab	1.1 a	5.9	5.1 a	1.2	0.7 a	9.1	7.8	38.1 b	69.9 b	28.0
IAC 766	8.9 a	1.0 b	5.5	4.8 a	1.2	0.7 a	9.4	7.9	42.4 b	108.6 a	30.2
1103P	8.0 b	1.0 ab	5.6	4.1 b	1.2	0.6 b	9.2	7.8	59.8 a	122.9 a	38.0
p-value	< 0.05	0.03	0.23	< 0.01	0.66	< 0.01	0.87	0.98	< 0.01	< 0.01	0.16
CV rootstocks	10.4	11.7	9.4	8.7	14.9	7.0	13.2	20.9	22.7	16.8	41.9
Seasons											
2021	9.1 a	1.0	5.4 b	4.4 b	1.1 b	0.8 a	6.6 b	9.5 a	63.4 a	86.8 b	31.0
2022	7.8 b	1.0	5.9 a	4.9 a	1.3 a	0.5 b	11.9 a	6.2 b	30.1 b	114.1 a	33.1
p-value	< 0.01	0.78	< 0.05	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.51
CV seasons	10.6	11.1	10.3	9.6	9.4	8.5	9.8	23.3	24.4	18.2	31.7
Mean	8.4	1.0	5.6	4.7	1.2	0.7	9.2	7.8	46.7	100.5	32.1
Nutrient content in bunches											
Rootstocks											
IAC 572	4.7	0.8	14.4 a	0.6 a	0.3	0.5	14.8ab	2.6 a	13.8 a	6.6 b	3.0
IAC 766	4.0	0.9	13.3ab	0.5 a	0.3	0.5	18.0 a	2.0 b	9.5 c	8.0 b	3.0
1103P	3.8	0.8	12.3 b	0.3 b	0.3	0.5	13.0 b	2.7 a	11.6 b	10.6 a	2.7
p-value	0.07	0.68	< 0.01	< 0.01	0.08	0.10	< 0.01	< 0.01	< 0.01	< 0.01	0.40
CV rootstocks	23.7	21.9	9.0	23.2	12.4	9.7	21.5	19.4	17.3	25.6	23.4
Seasons											
2021	3.8 b	0.8	14.3 a	0.4 b	0.3	0.7 a	14.1 b	1.8 b	4.3 b	5.7 b	3.1
2022	4.5 a	0.8	12.4 b	0.6 a	0.3	0.3 b	16.4 a	3.1 a	19.0 a	11.1 a	2.7
p-value	< 0.05	0.88	< 0.01	< 0.01	0.08	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.08
CV seasons	20.0	12.9	7.6	26.4	10.3	9.0	10.2	16.0	32.6	21.2	24.8
Mean	4.1	0.8	13.3	0.5	0.3	0.5	15.3	2.5	11.6	8.4	2.9

Different letters within a column for each factor (rootstocks and seasons) indicate a significant difference according to Tukey's test ($p < 0.05$). CV (%): coefficient of variation.

Nutrient levels in bunches also differed greatly according on the rootstock; vines grafted on 'IAC 572' had bunches with greater K, Ca, Cu, and Fe levels. Grown on 'IAC 766', vines only had greater levels of Ca and B. Conversely, the vines cultivated on the '1103P' rootstock exhibited elevated levels of Cu and Mn. Regarding the other elements assessed, namely N, P, Mg, S, and Zn, there was no discernible variation between the rootstocks with the concentrations found in the bunches (Table 3).

Vines grafted on 'IAC 572' may have produced higher yields due to an inherent relationship between the increased concentration of nutrients in the bunches and branches, particularly the macronutrients K, N, and Ca. It is crucial to emphasize that every nutrient in viticulture has a distinct purpose. Certain characteristics, including yield, grape size, soluble solids content, organic acids, pH, and bioactive compounds, require the element K to be grouped (Hudina and Stampar, 2002; Amiri and Fallahi, 2007; Walker and Blackmore, 2012).

Given that research indicates a general correlation between plant vigor and N content, it is possible that the N content had a significant impact on the vines' vigor (Verdenal *et al*., 2019). Similar to how the low Ca levels in the vines grafted on '1103P' may have had a direct impact on the poor productivity and vigor (Tables 2 and 3), supporting the findings of Duan *et al*. (2022) that Ca is linked to plant development.

With the exception of P and Zn, it was confirmed that there was no discernible variation in the nutrient levels in the branches when comparing the cycles. The vines in the second cycle had greater levels of K, Ca, Mg, B, and Mn in the branches compared to the vines in the first cycle, which had higher levels of N, S, Cu, and Fe. Accordingly, in the bunches, larger concentrations of N, Ca, B, Cu, Fe, and Mn were noted in the second production cycle, whereas higher amounts of K and S were found in the first cycle (Table 3).

3.3.3. Extraction of nutrients by branches, bunches and total and absorption of nutrients by bunches

The extraction of all nutrients from the branches, with the exception of Mn, was significantly impacted by the rootstocks. The 'IAC 572' rootstock primarily yielded the greatest results for nutrient extraction by branches and bunches, whereas the rootstocks for P, Mn, and Zn had little effect on nutrient extraction by bunches (Table 4).

Table 4. Macro and micronutrients exported by pruned branches and harvested bunches of the 'BRS Vitória' grapevine grafted onto two rootstocks over two harvest seasons.

Treatments	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
	kg ha^{-1}						g ha^{-1}				
					Nutrient removal by branches						
Rootstocks											
IAC 572	26.1 a	3.6 a	18.6 a	16.2 a	4.0 a	2.3 a	29.5 a	24.1 a	116.6 a	228.3	89.8 a
IAC 766	18.1 b	2.0 b	11.5 b	10.0 b	2.6 b	1.4 b	20.1 b	15.5 b	73.1 b	227.0	62.1 ab
1103P	11.1 c	1.5 b	7.9 b	5.8 c	1.7 c	0.9 b	13.7 c	10.4 b	82.9 b	178.3	53.0 b
p-value	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.08	< 0.05
CV rootstocks	29.7	35.6	32.4	33.2	30.5	36.4	24.5	34.6	31.4	28.8	47.1
Seasons											
2021	17.0 b	2.0 b	10.2 b	8.5 b	2.2 b	1.6	12.0 b	17.7	105.8 a	147.8 b	54.1 b
2022	19.8 a	2.7 a	15.1 a	12.8 a	3.4 a	1.5	30.2 a	15.6	75.9 b	274.6 a	82.5 a

p-value	< 0.05	< 0.01	< 0.01	< 0.01	< 0.01	0.33	< 0.01	0.19	< 0.01	< 0.01	< 0.01
CV seasons	18.4	19.2	18.9	16.6	13.9	18.6	16.4	29.8	26.3	17.2	35.9
Mean	18.4	2.4	12.7	10.7	2.8	1.5	21.1	16.7	90.9	211.2	68.3
Nutrient removal by bunches											
Rootstocks											
IAC 572	38.1 a	6.9	112.8 a	5.7 a	3.1 a	4.1 a	118.2 ab	22.5 a	122.0 a	59.5	23.9
IAC 766	27.2 ab	6.0	86.9 b	4.1 b	2.5 ab	3.1 b	125.4 a	14.7 b	81.0 b	60.5	19.8
1103P	23.3 b	4.9	71.8 b	2.2 c	2.0 b	2.9 b	81.9 b	17.8 b	81.6 b	67.1	16.0
p-value	< 0.05	0.08	< 0.01	< 0.01	< 0.01	< 0.01	< 0.05	< 0.01	< 0.01	0.68	0.11
CV rootstocks	38.3	36.4	28.3	34.6	27.6	25.8	36.9	23.7	24.2	39.8	46.1
Seasons											
2021	19.0 b	4.3 b	71.0 b	2.0 b	1.7 b	3.4	70.5 b	9.3 b	21.3 b	27.3 b	15.6 b
2022	40.1 a	7.6 a	110.0 a	6.0 a	3.3 a	3.3	146.5 a	27.4 a	168.5 a	97.5 a	24.2 a
p-value	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.31	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
CV seasons	27.0	19.0	13.3	32.7	14.3	12.3	19.2	21.7	40.6	29.8	33.4
Mean	29.5	5.9	90.5	4.0	2.5	3.4	108.5	18.3	94.9	62.4	19.9

Different letters within a column for each factor (rootstocks and seasons) indicate a significant difference according to Tukey's test ($p < 0.05$). CV (%): coefficient of variation.

In terms of the production cycles, there was no discernible variation in the nutrients extracted by the bunches only for S and by the branches for S and Cu. With the exception of Fe extraction by the branches, the other nutrients showed a significant difference in production cycles, with larger values being found in the second cycle (Table 4).

For branches, the sequence of nutrient extraction was N>K>Ca>Mg>P>Mn>Fe>Zn>B>Cu>S, and for bunches, K>N>P>Ca>Mg>B>Fe>Mn>Zn>Cu>S. Tecchio *et al*. (2011) and Tecchio *et al*. (2014) confirmed similar findings with 'Niagara Rosada', where N was the nutrient primarily exported to the branches and K to the bunches. Additionally, K was shown to be the most prevalent nutrient transferred to the bunches of 'Isabel Precoce' by Sato *et al*. (2016).

With the exception of Mn, the nutrients with the highest total extraction were K, N, Ca, and P, with the highest levels appearing in vines grafted onto 'IAC 572'. Furthermore, with the exception of S, overall nutrient extraction was greater in the second cycle (Table 5). Tecchio *et al*. (2019) obtained in a research using 'Vênus' that the sequence of total nutrient extraction was K>N>Ca>P>Mg>S>Mn>Fe>Zn>B>Cu.

Table 5. Nutrients exported (pruned branches + harvested bunches) by the 'BRS Vitória' grapevine grafted onto two rootstocks in two harvest seasons.

Treatments	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
	kg ha^{-1}						g ha^{-1}				
Rootstocks											
IAC 572	64.3 a	10.6 a	131.4 a	21.9 a	7.1 a	6.5 a	147.8 a	46.7 a	238.6 a	287.9	113.8 a
IAC 766	45.3 b	8.10 a	98.4 b	14.2 b	5.2 b	4.5 b	145.5 a	30.2 b	164.0 b	287.5	81.9 ab
1103P	34.5 b	6.4 b	79.8 b	8.1 c	3.8 c	3.8 b	95.7 b	28.2 b	154.7 b	245.5	69.1 b
p-value	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.05	< 0.01	< 0.01	0.25	< 0.05
CV rootstocks	29.5	33.3	26.7	26.0	23.9	24.8	32.5	24.1	14.8	26.7	43.0
Seasons											
2021	36.1 b	6.3 b	81.2 b	10.6 b	3.9 b	5.0	82.5 b	27.0 b	127.1 b	175.1 b	69.7 b
2022	60.0 a	10.4 a	125.2 a	18.9 a	6.8 a	4.8	176.8 a	43.1 a	244.5 a	372.2 a	106.8 a
p-value	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.16	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
CV seasons	18.4	13.6	11.4	13.4	10.0	10.1	15.5	18.1	25.6	15.4	28.9
Mean	48.0	8.4	103.2	14.7	5.4	4.9	129.7	35.0	185.8	273.6	88.3

Different letters within a column for each factor (rootstocks and seasons) indicate a significant difference according to Tukey's test ($p < 0.05$). CV (%): coefficient of variation.

The proportion of nutrient extraction by bunches as a function of total nutrients exported by 'BRS Vitória' was significantly affected by rootstocks and production cycles. The findings in Table 6 reveal that the export of nutrients to the bunches was greater in vines growing on the '1103P' rootstock for the majority of the macro and micronutrients tested, with the following values: 66% N; 76% P; 90% K; 54% Mg; 76% S; 85%B; 58% Cu; and 26% Mn. There was no significant variation in the nutrients Ca, Fe, and Zn, with an average of 26, 42, and 23%, respectively, amongst rootstocks.

When the two production cycles were compared, it was discovered that there was no substantial difference between them for K, Mg, S, and Zn. For B, the maximum export of this vitamin to the bunches was found during the first production cycle (85 versus 82%). Other nutrients, such as N, P, Ca, Cu, Fe, and Mn, were exported more during the second production cycle (Table 6).

Studies in the literature demonstrate large variability in N, P, and K extraction by the vine, with values ranging from 15 to 100 kilogram N ha^{-1}, 2 to 15 kg P ha^{-1}, and 34 to 123 kg K ha^{-1} (Giovaninni *et al.*, 2001). 'BRS Vitória' vines exported 48.1 kg ha^{-1} of N, 8.4 kg ha^{-1} of P, and 103.3 kg ha^{-1} of K on average throughout the two cultivation cycles (48.1 kg ha^{-1}, 19.3 kg ha^{-1}, and 124.4 kg ha^{-1} of N, P_2O_5 and K_2O, respectively).

Table 6. Nutrient accumulation by bunch in relation to overall nutrient accumulation by the 'BRS Vitória' grapevine grafted onto two rootstocks across two harvest seasons.

Treatments	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
	%										
Rootstocks											
IAC 572	57 b	64 b	85 b	24	43 b	64 c	80 b	45 b	43	18 b	21
IAC 766	58 b	73 a	88 a	27	48 ab	68 b	85 a	47 b	39	18 b	25
1103P	66 a	76 a	90 a	26	54 a	76 a	85 a	58 a	44	26 a	24
p-value	< 0.05	< 0.01	< 0.01	0.77	< 0.01	< 0.01	< 0.05	< 0.01	0.06	< 0.01	0.46
CV rootstocks	11.6	6.8	3.0	30.8	14.3	6.7	5.4	11.2	14.6	20.8	31.5
Seasons											
2021	54 b	69 b	87	21 b	47	70	85 a	37 b	16 b	16 b	24
2022	66 a	73 a	87	31 a	50	69	82 b	63 a	68 a	26 a	23
p-value	< 0.01	< 0.01	0.95	< 0.01	0.08	0.47	< 0.01	< 0.01	< 0.01	< 0.01	0.81
CV seasons	11.1	6.3	2.7	27.7	9.6	6.7	3.9	15.6	16.9	20.8	36.6
Mean	60	71	87	26	48	69	83	50	42	21	23

Different letters within a column for each factor (rootstocks and seasons) indicate a significant difference according to Tukey's test ($p < 0.05$). CV (%): coefficient of variation.

The nutrient use efficiency (NUE) of the 'BRS Vitória' grapevine fertilization varied depending on the rootstock. The partial factor productivity (PFP) index revealed that 'IAC 572' produced more fruits per kg of treated N, P, and K, but '1103P' was less efficient in fertilizer usage. Meanwhile, 'IAC 766' has an intermediate NUE in comparison to the others. According to Dobermann (2007), PFP is crucial for producers since it combines the principles of nutrients use efficiency from fertilizers and soil reserve mobilization. In view of the high cost of fertilizers, adopting a rootstock that yields more fruits per unit of applied fertilizer is a technique to improve viticulture's sustainability. The 'IAC 572' rootstock had a 50% higher NUE reflected by the PFP in this example than the '1103P' (Table 7).

Table 7. Partial factor productivity (PFP) and partial nutrient balance (PNB) for N, P, and K applied each cycle in the fertilization of 'BRS Vitória' grapevine as a function of the rootstocks. These figures are averages of two production cycles.

Treatments	Partial factor productivity			Partial nutrient balance		
Rootstocks	N	P_2O_5	K_2O	N	P_2O_5	K_2O
	kg of fruits harvested kg fertilizer applied^{-1}			kg of nutrients removed kg fertilizer applied^{-1}		
IAC 572	331 a	276 a	149 a	0.43 a	0.14 a	0.48 a
IAC 766	258 b	215 b	116 b	0.30 b	0.10 ab	0.36 b
1103P	210 b	175 b	94 b	0.23 b	0.08 b	0.29 b
p-value	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
CV rootstocks	16.7	16.7	16.7	20.9	23.6	18.9

Mean	266	222	120	0.32	0.11	0.37

Different letters within a column for each factor (rootstocks and seasons) indicate a significant difference according to Tukey's test ($p < 0.05$). CV (%): coefficient of variation.

Another critical feature of grape production that should be considered for sustainability is the nutrient export compared to the supply through fertilization. While not including all outputs such as erosion or nutrients leakage in the soil-plant system, the partial nutrient balance (PNB) acts as an indication of soil fertility sustainability (Fixen *et al*., 2015).

The PNB for the 'BRS Vitória' grapevine was consistently less than 0.5 when evaluated for N, P, and K based on different rootstocks (Table 7). This data is important since PNB levels greater than one are considered unsustainable, suggesting that the output is likely depleting the soil's nutrient stores. Alternatively, extremely low PNB levels may indicate an excessive fertilizer application, posing environmental and economic problems. In this case, the PNB for phosphorus (P) for all rootstocks was approximately 0.1. Given that the area's P availability is already extremely high (> 80 mg dm^{-3}), the phosphorus injection may be excessive. The PNB for K varied from 0.37 to 0.48 kg of K removed per kilogram of K applied. The fact that the grape grafted on 'IAC 572' had a 60% higher PNB value than the grape grafted on '1103P' implies that utilizing a rootstock that is more effective at collecting K requires careful monitoring and replenishment of K in the soil. In the experimental region, there was a decline in soil K availability between the first and second harvest (Table 1).

3.4. CONCLUSIONS

Rootstocks hampered the productive performance and biomass buildup of 'BRS Vitória,' with 'IAC 572' offering better vigor and, as a result, greater output to the vines than 'IAC 766' and '1103P'.

The rootstocks had varying nutrient extraction and absorption capabilities, with the contents in bunches and branches in most nutrients being greater in vines grafted on 'IAC 572'. However, vines growing on '1103P' exported more nutrients to the bunches.

The nutrients extracted from 'BRS Vitória' were extracted in the following order: N>K>Ca>Mg>P>Mn>Fe>Zn>B>Cu>S in the branches and K>N>P>Ca>Mg>B>Fe >Mn>Zn>B>Cu>S in the bunches.

'BRS Vitória' grafted onto 'IAC 572' was more efficient in the utilization of N, P, and K fertilizers than 'IAC 766' and '1103P'.

Given the necessity of utilizing rootstocks that promote high production and have a high nutrient absorption and extraction capability, the results indicate that the 'IAC 572' rootstock is best suited for use with the 'BRS Vitória' vine under subtropical circumstances.

It should be highlighted that, when combined with soil analysis, these results can help to rationalize mineral fertilization of the 'BRS Vitória' vine while also highlighting the need for study tailored to local conditions. Furthermore, because fertilization is one of the most significant components of production costs and has a high influence on the productivity and quality of the grape, knowledge of the demand for nutrients by the vines is essential for adequate replacement through fertilization.

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CONSIDERAÇÕES FINAIS

Considerando que a escolha do porta-enxerto ideal é um fator primordial para o sucesso do vinhedo, estudos sobre porta-enxertos são importantes para a viticultura brasileira pois podem servir como recomendações aos produtores, indicando de forma direta qual o porta-enxerto adequado para utilizar em determinadas condições e em combinações com determinadas cultivares.

Com relação aos porta-enxertos estudados, o ‘IAC 766’ apresentou resultados intermediários. Por sua vez, apesar do ‘Paulsen 1103’ ter proporcionado produtividade inferior, induziu maior precocidade no ciclo de produção e frutos com boa qualidade, com altos teores de sólidos solúveis e compostos bioativos. Entretanto, os resultados sugerem que, nas condições de cultivo do presente estudo, isto é, clima subtropical e latossolo vermelho, o ‘IAC 572’ é mais indicado em combinação com a videira ‘BRS Vitória’ pois este porta-enxerto apresentou maior eficiência na utilização da fertilização mineral e, principalmente, promoveu maior produtividade às videiras.

Os resultados do presente estudo também permitiram identificar que o cultivo da ‘BRS Vitória’ em áreas subtropicais é bastante viável devido, principalmente, à alta produtividade e boa qualidade dos frutos. Assim, o aumento do cultivo nessas regiões, como no Estado de São Paulo, trata-se de uma ótima alternativa para suprir crescente demanda por uvas sem sementes.

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