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Productivity and Physicochemical Properties of the BRS Isis Grape on Various Rootstocks under Subtropical Climatic Conditions

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

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

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1. Introduction

The production of seedless grapes is an important contributor to the economy, producing a considerable number of jobs in viticulture-related businesses. With the rising worldwide demand for seedless grapes [1], business has the potential to expand, particularly in places with subtropical temperature conditions, where grapes with seeds such as 'Niagara Rosada' are planted. The major seed-grape cultivar grown in the state of São Paulo is 'Niagara Rosada' [2]. As a result, under these climatic conditions, the advent of seedless-grape growing plays a significant role in addressing an increasingly demanding consumer market.

Because of their good quality attributes [3], seedless grapes have gained in popularity as a result of customer acceptability. In this regard, Embrapa introduced the seedless grape 'BRS Isis' in 2013, the result of a hybrid between CNPUV 681-29 [Arkansas 1976 × CNPUV 147-3 ('Niagara White' × 'Vênus')] and 'BRS Linda'. This cultivar is resistant to downy mildew and adapts well to Brazil's many temperatures. 'BRS Isis' has a high bud fertility, a hard and crisp texture, big red berries, and a sugar content ranging from 16 to 22 °Brix [4].

Grafting is commonly used in worldwide viticulture to prevent phytosanitary issues that impact the plant's root system, as well as abiotic difficulties, and for adaptability to low-fertility soils, flooded soils, water shortage, saline soils, and other unfavourable condition effects [5]. The Agronomic Institute of Campinas (IAC) developed the main rootstocks used in Brazil, with the following being the most regularly used: IAC 313 'Tropical', which is primarily used in the São Francisco Valley [6]; IAC 766 'Campinas' and IAC 572 'Jales', which are currently among the most frequently employed in viticulture in the State of São Paulo [7]. In addition, regions employing Paulsen 1103 and SO4 rootstocks (*V. riparia* × *V. berlandieri*) and, to a lesser degree, Freedom and Harmony [C1613 (Solonis Othello) × Dogridge] have increased in recent years.

Numerous studies have indicated that more robust rootstocks enhance production while decreasing levels of phenolic compounds and soluble solids in grape berries [8–10]. However, the interaction between rootstock and scion variety is quite specific, as are adaptations to climatic conditions [11,12], which may result in non-uniform performance [10,13], as well as in the absorption, accumulation, and translocation of nutrients [14,15]. Cookson et al. (2012) [16] state that the unique compatibility and interaction between the scion cultivar and the rootstock can alter the vine's growth and vigour based on climatic and nutritional parameters, as well as the cultivar's bud fertility [17].

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

2. Materials and Methods

The experiment was conducted in a research vineyard located in the Experimental Farm of the School of Agriculture (FCA) at UNESP (22°46′35″ S and 48°34′08″ O; elevation 773 m) in São Manuel, São Paulo, Brazil, during the summer production cycles of 2021 and 2022. The climate is classified as Cfa (subtropical with hot summers) by Köppen. According to the Brazilian soil classification system, the soil is classed as a dystroferric Red Oxisol with a sandy texture [18]. The same soil is classed as Dystrophic Typic Hapludox using the USDA (United States Department of Agriculture) Soil Taxonomy [19].

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

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

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

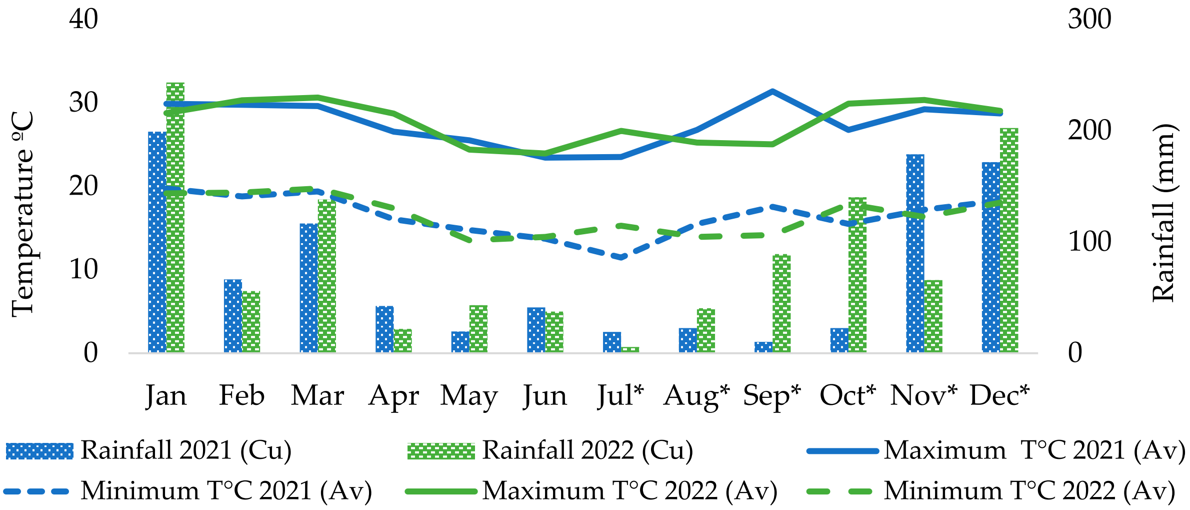

Figure 1. Maximum and minimum temperatures and precipitation between the 2021/22 and 2022/23 cycles. Source: Data provided by the Department of Soils and Environmental Resources, 2023. * Production period. The bars represent the total amount of rain, while the solid lines represent maximum temperatures and the dotted lines represent the minimum temperatures.

Phytosanitary control, fertilizing, debudding, defoliation, denetting, and branch and bunch thinning were all carried out in line with Ritschel et al.'s (2013) [4] recommendations.

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

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

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

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

The total phenolic component content of the peel and pulp was calculated using the Folin–Ciocalteu reagent [20] and represented in milligrams of gallic acid equivalent (GAE) per kilogram of peel and pulp (mg GAE 100 mg^{-1}). Popova et al. (2004) [21] developed a technique for determining total flavonoid content. The pH differential technique [22] was used to quantify the monomeric anthocyanin content, which was expressed as malvidin 3,5-diglucoside equivalents per 100 mg^{-1}.

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

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

3. Results and Discussion

3.1. Productivity Features

'BRS Isis' grown on 'IAC 572' and 'IAC 766' produced more bunches as well as more kg per plant than when grown on 'Paulsen 1103', with 37.4, 36.1, and 21.2 bunches per plant and 18.42, 18.05, and 11.99 kg per plant, respectively. As a result, production was higher when 'IAC 572' and 'IAC 766' were used, with 30.7 and 30.0 t per hectare, respectively (Table 1). Other table-grape cultivars that were grafted onto 'Paulsen 1103' [9], 'IAC 572', and 'IAC 766' [23], as well as grape cultivars for processing juices [10] and wines [24], showed a positive correlation between production and number of bunches.

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

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

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

Regardless of the rootstock utilized, the average yield of the two production cycles for 'BRS Isis' was assessed to be 26.9 t/ha/cycle. Ahmed et al. (2019) [1] reported a higher yield (36.5 t/ha/cycle) under subtropical circumstances utilizing the 'IAC 766' rootstock, with greater spacing and a low-altitude location. The yield observed in the current study, on the other hand, is like that reported by Ritschel et al. (2013) [4] of 26 t/ha/cycle and higher than that reported for this cultivar [6,25], representing a 7% increase over the average yield of 25 t/ha/cycle under semi-arid conditions. Because of their increased tolerance to subtropical environments, both 'IAC 766' and 'IAC 572' rootstocks offered higher yield in this research. Higher yields have been observed in vines for fresh consumption grafted onto 'IAC 572', such as 'Niágara Rosada' and 'Vênus', in subtropical high-altitude climates [26] and tropical climates [27]. The table grape 'BRS Maria Bonita' yielded more in a semi-arid tropical region when grown with the 'IAC 766' rootstock [28]. As a result, production is affected by rootstock as well as climate and cultivation circumstances. However, in terms of yield, 'IAC 766' appears to be a promising rootstock for usage in both subtropical and tropical climates.

These yield discrepancies might be attributed to the interspecific connection between the scion cultivar and the rootstock. Maia and Camargo (2012) [29] classify the rootstocks 'IAC 572' and 'IAC 766' as high-vigour, suggesting that both rootstocks are more suited to subtropical and tropical climatic conditions than 'Paulsen 1103'. The poor yield of 'Paulsen 1103' is attributable to the interaction with the scion cultivar, rootstock genotype, and its origin, since it is from a Mediterranean region with dry summers and wet winters [30]. Furthermore, 'BRS Isis' is a strong cultivar with exuberant growth that is better compatible with 'IAC' rootstocks [4].

3.2. Physical Features of the Bunch

Both the fresh bunch mass ($p > 0.05$) and bunch length ($p > 0.01$) of the 'BRS Isis' table grape differed significantly between rootstocks. Bunches from 'IAC 766' had the largest mass (502.58 g), followed by 'IAC 572' and 'Paulsen 1103', with 458.26 and 387.22 g, respectively. These findings outperform those reported by [4] for 'BRS Isis,' who reported 348.12 g under tropical circumstances on the 'IAC 572' rootstock and 292.53 g in semi-arid settings on the 'IAC 313' and 'SO4' rootstocks. Under tropical circumstances, 'IAC 572' had a substantial impact on the bunch length of 'BRS Isis' compared to 'Paulsen 1103', with, respectively, 18.4 and 16.99 cm (Table 2). When evaluating the influence of rootstocks under semi-arid circumstances, [23] found that 'BRS Isis' on 'IAC 572' had a larger curl length than on 'Paulsen 1103', a behaviour like that seen in the current study. More robust rootstocks often have a greater ability for water and nutrient absorption and translocation, which benefits scion performance [31].

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

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

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

The rootstocks utilized with 'BRS Isis' had no significant effect on the physical properties of the berry and stem (Table 2), yielding average values of 6.2 g of berry mass, 3.0 cm of length, 1.6 g of berry breadth, 1.8 cm of diameter, and 12.4 g of stem mass. In comparison to the current study, Ahmed et al. (2019) [1] discovered similar values for the physical properties of berries and bunches, with 6.5 g of fruit mass, 2.7 cm in length, 1.9 cm in diameter, and bunches weighing 521 g on average. It is vital to note that a minimum diameter of 1.2 cm is necessary for the commercialization of table grapes on the national and international markets [32], with implied averages between 1.4 and 1.7 cm to maximize the value and quality of bunches for export [33,34]. 'BRS Isis' achieved these values in this case, independent of the rootstock utilized, with berry diameter values of 1.79 cm.

Several authors, however, documented considerable impacts of the rootstock on the morphological properties of the fruit and stem across multiple table- and processing-grape varieties [9,10,35–37]. According to Bascunán-Godoy et al. (2017) [38], the amount of vigour transmitted to the scion by different rootstocks is a critical component in modifying the physical features of grapes. The rootstock's descendant genotype influences gene expression in the crown of grafted vines, indicating that rootstock interaction, even when subtle, is complex, manifesting itself with certain factors such as time and adaptability to soil conditions and climate [39,40]. The improved performance of 'BRS Isis' grafted onto 'IAC 572' and 'IAC 766' rootstocks is attributable to greater adaptation to the research site's edaphoclimatic conditions (Cfa climate and distroferric Red Latosol).

3.3. Chemical Properties of the Grape Must

The chemical properties of 'BRS Isis' grape berries grown on different rootstocks showed no significant variations ($p > 0.05$) (Table 3). Regardless of the rootstock employed, the titratable acidity in the grape must of 'BRS Isis' grapes ranged from 0.39 to 0.42% (Table 3). The average values are lower than those found by [1], i.e., 0.40 versus 0.70. They do, however, coincide with the range reported by [4] (0.34 to 0.55). Leão et al. (2020) [23]

reported that rootstocks had no effect on the titratable acidity of 'BRS Isis' must under semi-arid circumstances, with values lower than those found in this study (0.40 versus 0.38). Multiple factors, including genetic characteristics [41], physiological processes [42], temperature variation, light intensity, and rainfall [43], promote TA reduction during ripening, resulting in variation in vine metabolism, which can promote or hinder grape genetic potential [44].

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

Chemical Parameters of Grape Must	**Rootstocks**			
	IAC 572 Jales	**IAC 766 Campinas**	**Paulsen 1103**	***p*-Value**
Titratable acidity (%)	0.42 ± 0.05	0.39 ± 0.02	0.41 ± 0.06	0.46
pH	3.45 ± 0.03	3.45 ± 0.05	3.44 ± 0.06	0.69
Soluble Solids (°Brix)	16.43 ± 0.33	16.38 ± 0.39	16.71 ± 0.33	0.28
Maturation index (SS/AT)	46.81 ± 7.29	50.00 ± 3.14	45.66 ± 7.79	0.47

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

The pH of the 'BRS Isis' rootstock requirement was 3.45 (Table 3). The authors of [1,4] reported higher values ranging from 3.78 to 4.4. The concentrations of tartaric and malic acid, the primary acids present in vines, as well as the concentration of potassium (K) in the soil and must, are closely connected to the overall acidity of the grape [45]. The lower pH discovered in this study might be attributed to the lower concentration of minerals in the soil solution, particularly K, the type of soil, the quantities of nitrogen fertilizer applied, rainfall, and the vine's vegetative vigour [46].

The varied rootstocks had no effect on the soluble solids in the grape must in the two cycles studied. The average soluble solids of the rootstocks were 16.5 °Brix (Table 3). The current study's results outperformed those obtained by [1,23], which ranged from 14.2 to 16.4 °Brix. Ritschel et al. (2013) [4] found that 'BRS Isis' had a range of soluble solids concentration at complete maturity between 16 and 21 °Brix, which was comparable to what was discovered in the current study. The reactions in soluble solids content based on rootstock relate to aspects such as cultivar genetics, seasonal fluctuations, cultural management, and different vineyard management methods, with inconsistent results in the literature [23].

In terms of the ripening index, which is determined from the ratio of sugar to acidity contents (SS/TA), the low acidity obtained for 'BRS Isis' resulted in higher ripening index (47.5) values among the rootstocks. This result falls within the 'BRS Isis' range established by [4], which is between 38 and 48. The maturity index can suggest a grape cultivar's perfect balance of sugar and acidity for a specific location; however, it should normally be more than 18 [1].

3.4. Chemical Properties of the Grape Must

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

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

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

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

The total phenol concentration of the three rootstocks employed was greater than that reported by Ahmed et al. (2019) [1] for 'BRS Isis' grapes grafted onto 'IAC 766' in a tropical environment (26.1 mg 100 g^{-1}). Lower levels of total phenols were also reported in 'Redglobe' [47] and 'BRS Clara' [48] grapes grafted onto 'Paulsen 1103', namely 97.413 mg 100 g^{-1} and 81.39 mg 100 g^{-1}, respectively. These findings highlight the great diversity in the rootstock's effect on the biosynthesis and composition of these chemicals [49], as well as the direct influence of climatic factors such as temperature, light, and precipitation [1]. The optimal canopy, training method, and rootstock combination optimizes variety performance, resulting in climatic adaptability, high yield, and superior fruit quality [50]. The heightened accumulation of phenols, flavonoids, and anthocyanins in grapevines is intricately associated with the inadequate acclimatization of the rootstock to subtropical conditions, consequently leading to enhanced physiological stress in the vine and ultimately culminating in an augmented synthesis of these chemical constituents [50,51]. Studies have demonstrated that phenolic compounds can function as antioxidants that scavenge free radicals. Furthermore, the consumption of polyphenol-rich foods may be associated with a reduced risk of chronic diseases, such as cardiovascular diseases, cancer, and diabetes [31].

Rootstocks had little effect on anthocyanin levels, which averaged 34.24 mg 100 g $^{-1}$. Ahmed et al. (2019) [1] reported 30 mg 100 g^{-1} in 'BRS Isis,' which is like the amount reported in the current study when the 'IAC 766' rootstock was utilized (32.84 mg 100 g^{-1}). These results, however, are lower than the combination of 'BRS Isis' and the 'Paulsen 1103' rootstock (43.04 mg 100 g^{-1}) (Table 4). The difference in anthocyanin concentration of 'BRS Isis' grapes between this study and [1] is attributable to the use of different rootstocks, as well as the effects of meteorological conditions and soil type. Furthermore, bunch thinning (load modification) has been shown to increase the formation of certain phenolic compounds [52]. Ahmed et al. (2019) [1] noticed a higher yield and lower concentration of bioactive compounds in 'BRS Isis' compared to those reported in this work, which could be explained by the negative correlation of production variables, productivity, and number of bunches per plant in relation to total anthocyanins, which was r = −0.9, ($p > 0.01$) (Table 5).

Rootstocks that favour the accumulation of these compounds can enhance the market value of grapes, especially if they are intended for the production of antioxidant-rich red wines [31]. Furthermore, the health benefits associated with consuming grapes rich in phenolics and flavonoids can be a significant marketing factor for producers. Therefore, careful rootstock selection is crucial for optimizing the quality and value of 'BRS Isis' grapes in the market. In addition to phenolic acids, grape pulp also contains primary metabolites such as organic acids and sugars [53]. Glucose, fructose, and tartaric and malic acids are the compounds that most contribute to the sweetness and acidity of grapes [46]. These characteristics significantly influence their organoleptic quality [1,54].

Table 5. Pearson dynamic analysis between all variables.

Traits	YldV	Pdt	NBchV	BchM	BchL	BchW	BM	BL	BW	RM	BD	NBBch	SS	pH	TA	MI	TPC	TF	TMA
YldV	1	1.0	1.0	0.9	1.0	1.0	0.9	1.0	0.7	0.9	−0.1	0.9	−0.5	0.9	−0.1	0.6	−1.0	−0.5	−0.9
Pdt	1.0	1	1.0	0.9	1.0	1.0	0.9	1.0	0.7	0.9	−0.1	0.9	−0.5	0.9	−0.1	0.6	−1.0	−0.5	−0.9
NBchV	1.0	1.0	1	0.9	1.0	1.0	0.9	1.0	0.7	0.9	−0.1	0.9	−0.5	0.9	−0.1	0.6	−1.0	−0.4	−0.9
BchM	0.9	0.9	0.9	1	0.9	0.9	1.0	1.0	0.9	1.0	−0.5	1.0	−0.8	1.0	−0.5	0.9	−0.9	−0.8	−0.7
BchL	1.0	1.0	1.0	0.9	1	1.0	0.9	1.0	0.7	0.9	−0.1	0.9	−0.5	0.9	−0.1	0.6	−1.0	−0.5	−0.9
BchW	1.0	1.0	1.0	0.9	1.0	1	0.9	1.0	0.7	0.9	−0.1	0.9	−0.5	0.9	−0.1	0.6	−1.0	−0.4	−0.9
BM	0.9	0.9	0.9	1.0	0.9	0.9	1	1.0	0.9	1.0	−0.4	1.0	−0.7	1.0	−0.3	0.8	−1.0	−0.7	−0.8
BL	1.0	1.0	1.0	0.9	1.0	1.0	1.0	1	0.8	0.9	−0.2	1.0	−0.7	1.0	−0.2	0.7	−1.0	−0.6	−0.9
BW	0.7	0.7	0.7	0.9	0.7	0.7	0.9	0.8	1	0.9	−0.7	1.0	−1.0	0.9	−0.7	1.0	−0.7	−0.9	−0.4
RM	0.9	0.9	0.9	1.0	0.9	0.9	1.0	0.9	0.95	1	−0.5	1.0	−0.8	1.0	−0.5	0.9	−0.9	−0.8	−0.7
BD	−0.1	−0.1	−0.1	−0.5	−0.1	−0.1	−0.4	−0.2	−0.7	−0.5	1	−0.5	0.9	−0.4	1.0	−0.8	0.1	0.9	−0.2
NBBch	0.9	0.9	0.9	1.0	0.9	0.9	1.0	0.9	0.9	1.0	−0.5	1	−0.8	1.0	−0.5	0.9	−0.9	−0.8	−0.7
SS	−0.5	−0.5	−0.5	−0.8	−0.5	−0.5	−0.7	−0.7	−1.0	−0.8	0.9	−0.8	1	−0.8	0.9	−1.0	0.5	1.0	0.2
pH	0.9	0.9	0.9	1.0	0.9	0.9	1.0	1.0	0.9	1.0	−0.4	1.0	−0.8	1	−0.4	0.9	−0.9	−0.8	−0.7
TA	−0.1	−0.1	−0.1	−0.5	−0.1	−0.1	−0.3	−0.2	−0.7	−0.5	1.0	−0.5	0.9	−0.4	1	−0.8	0.1	0.9	−0.3
MI	0.6	0.6	0.6	0.9	0.6	0.6	0.8	0.7	1.0	0.9	−0.8	0.9	−1.0	0.9	−0.8	1	−0.6	−1.0	−0.3
TPC	−1.0	−1.0	−1.0	−0.9	−1.0	−1.0	−1.0	−1.0	−0.7	−0.9	0.1	−0.9	0.5	−0.9	0.1	−0.6	1	0.5	0.9
TF	−0.5	−0.4	−0.4	−0.8	−0.5	−0.4	−0.7	−0.6	−0.9	−0.8	0.9	−0.8	1.0	−0.8	0.9	−1.0	0.5	1	0.1
TMA	−0.9	−0.9	−0.9	−0.7	−0.9	−0.9	−0.8	−0.8	−0.4	−0.7	−0.2	−0.7	0.2	−0.7	−0.3	−0.3	0.9	0.1	1

Trait abbreviations: number of bunches per vine [NBchV], yield per vine [YldV], productivity [Pdt], bud fertility [BdF], bunch mass [BchM], bunch length [BchL], bunch width [BchW], berry mass [BM], berry length [BL], berry width [BW], rachis mass [RM], berry diameter [Bd], number of berries per bunch [NBBch], soluble solids [SS], titratable acidity [TA], maturation index [MI], total phenolic compounds [TPC], total flavonoids [TF], total monomeric anthocyanins [TMA].

3.5. Principal Component Analysis (PCA)

Principal component analysis (PCA) revealed that the first two principal components (PCs) explained 100% of the variation and these were utilized to visualize the data in a two-dimensional format (Figure 2). PC1 accounted for 78.15% of the overall data variability, encompassing factors such as bioactive substances, productive properties, and morphological features of the bunch, berries, and stalk. The PC1 study showed that it was successful in separating the rootstocks, primarily 'Paulsen 1103' and 'IAC 766'.

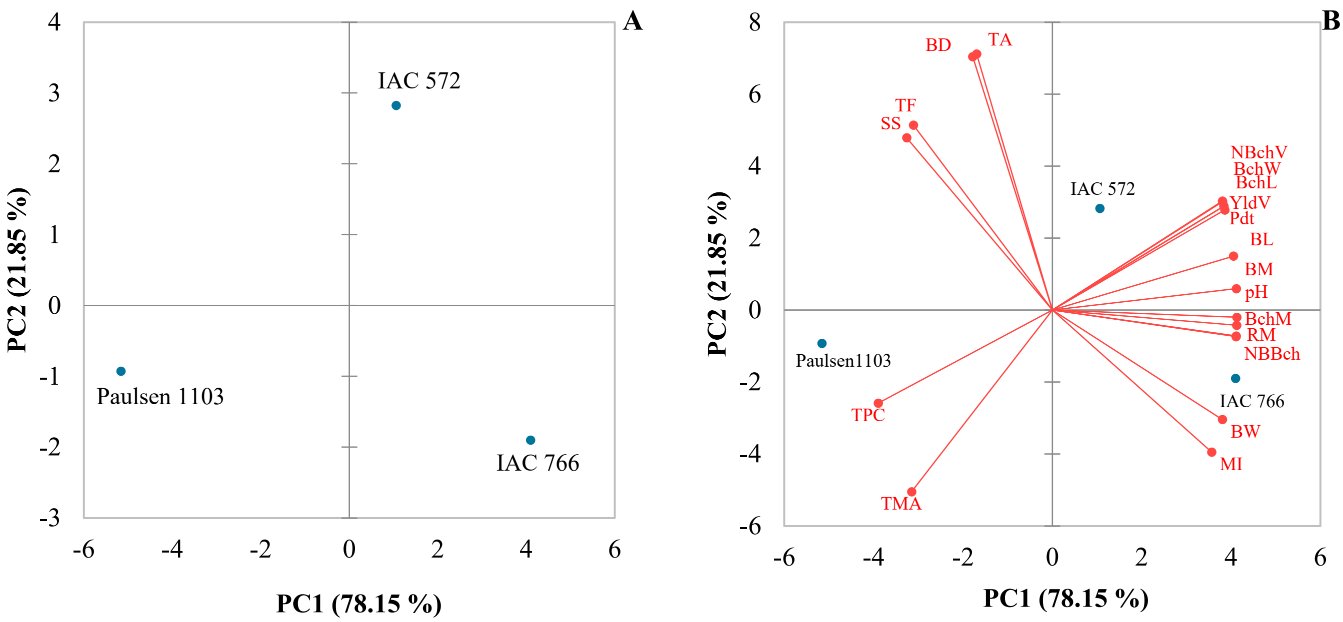

Figure 2. Principal component analysis of 20 yield components and physicochemical traits in 3 scion–rootstock grapevine combinations. Scores plot (**A**) and loadings plot (**B**). Scion–rootstock combinations: 'BRS Isis'; 'IAC 766', 'IAC 572', and 'Paulsen 1103' rootstocks. See Table 5 for trait labels.

Clustering was found to be caused by yield per vine [YldV], productivity [Pdt], number of bunches per vine [NBchV], bunch mass [BchM], bunch length [BchL], bunch width [BchW], fresh berry mass [BM], berry length [BL], berry width [BW], fresh stem mass [RM], number of berries per bunch [NBBch], pH, and maturation index [MI] based on PC1 loads (Figure 2B). These characteristics all have strong positive loadings (>0.70). PC1 scores and loadings indicated that 'BRS Isis' had higher yields than 'IAC 572' and had greater bunch and stem masses, number of berries per bunch, berry breadth, and fruit maturation index when employing 'IAC 766'. In contrast, the application of 'Paulsen 1103' resulted in poorer yield, smaller clusters, and smaller fruit size, corroborating the negative factors among the analyses (Table 5).

PC2 accounted for 21.85% of the overall variance and was mostly associated with the chemical properties of the berries. The most important factors contributing to PC2 were titratable acidity [TA], berry diameter [BD], soluble solids [SS], total polyphenols [TPC], total flavonoids [TF], and total anthocyanins [TMA] according to the PC2 loading graph (Figure 2B). When the notes and loadings of this component were analysed, the 'BRS Isis' grapes on the 'Paulsen 1103' rootstock had the greatest levels of total phenolic compounds [TPC] and total anthocyanins [TMA], as well as the greatest diameter of berries [BD] on 'IAC 572'. There was a negative correlation between phenolic chemicals and bunch physical features (r = −1.0) (Table 5), which also confirmed the concentration of these compounds when 'Paulsen 1103' was employed (Table 4). 'BRS Isis' grapes grown on the 'IAC 572' rootstock had better titratable acidity and berry diameter [BD].

4. Conclusions

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

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

The findings presented in this study offer practical implications for grape producers in real-world scenarios. Producers can make informed decisions regarding rootstock selection based on specific objectives. For instance, for those seeking increased yield and larger bunches, employing rootstocks such as IAC 572 'Jales' and IAC 766 'Campinas' is recommended. Alternatively, if the aim is to enhance the content of phenolic compounds and total flavonoids in grapes, the utilization of the Paulsen 1103 rootstock is suggested. Thus, these results provide valuable guidance to grape producers for the selection of the most suitable rootstock in alignment with their specific objectives.

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