Yield performance and quality of wine grapes (*Vitis vinifera*) grafted onto different rootstocks under subtropical conditions

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ABSTRACT: This study aimed to evaluate the productive performance and physicochemical traits of wine grape cultivars (Cabernet Sauvignon, Syrah, Cabernet Franc, Merlot, and Sauvignon Blanc) grafted on two different rootstocks (IAC 766 Campinas, and 106-8 Mgt) under subtropical conditions. The productive components (number of bunches, production per vine, yield, number of berries per bunch, fresh mass, length, and width of berries) and the grape must physicochemical composition (pH, titratable acidity, soluble solids, and maturation index) were determined after four consecutive harvest seasons. Results from analysis of variance and principal component analysis showed that Cabernet Franc and Syrah were generally more productive than the other ones. In addition to that, Cabernet Sauvignon presented the lowest production and the smallest grape berries of all. With regards to rootstocks, IAC 766 induced higher scions yield than 106-8 Mgt; besides that, IAC 766 had greater affinity with Cabernet Franc and Merlot, which was observed by the increase in the number of bunches per vine, larger and heavier bunches, as well as higher soluble solids content and pH value than the ones in 106-8 Mgt. Furthermore, IAC 766 also induced higher soluble solids content and pH value for Cabernet Sauvignon. Results showed similar effects for Syrah and Sauvignon Blanc, regardless of the rootstocks.

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

INTRODUCTION

Of the 1.6 million tons of grapes produced in the country in 2018, 47% were wine grapes (OIV 2019), including *Vitis vinifera* and non-*vinifera* cultivars. Among the *V. vinifera*, the following red cultivars are the most produced in the country, that is, Cabernet Sauvignon, Cabernet Franc, Syrah, and Merlot, as well the white Sauvignon Blanc (Tecchio et al. 2018). According to Silva et al. (2017), the soluble solids content of these cultivars ranged from 17.3 to 20.7 °Brix, pH values from 3.18 to 4.10 and titratable acidity from 0.66 to 1.03% under subtropical conditions. The determination of physicochemical attributes directly influences the final quality of the wines, but they are also may be affected by the weather and rootstocks (Leão et al. 2020).

In viticulture, the grafting technique allows vines to be protected against pathogens that can easily damage the roots, such as *Phylloxera* (Granett et al. 2001) and some soil nematodes (Anwar et al. 2002). Moreover, rootstocks also allow the vines by adapting them to be grown to adverse soil conditions, such as high salinity (Walker et al. 2014), water deficit

(Meggio et al. 2014), and low fertility soils (Lo'ay and El-Ezz 2021). In addition, several studies have already evidenced that rootstocks influence the productive performance of vines (Tecchio et al. 2020), grape must composition (Silva et al. 2018), the length of phenological stages (Tecchio et al. 2013), shelf life (Lo'ay and El-khateeb 2017), and antioxidant compounds content (Borges et al. 2013).

Therefore, IAC 766 Campinas and 106-8 Mgt are the main rootstocks used in state of São Paulo, Brazil, subtropical viticulture, because both present affinity with the main scion cultivars and have good adaptation to edaphoclimatic conditions (Tecchio et al. 2018). According to Tecchio et al. (2018), 106-8 Mgt has low vigour, but it adapts very well to different types of soil, especially in acidic soils. On the other hand, IAC 766 Campinas has high vigour and good adaptation in low fertility soils. Recently, these rootstocks have been evaluated in combinations with several grape cultivars (Silva et al. 2017, Tecchio et al. 2020, Simonetti et al. 2021). However, there is a wide variation between these studies' outcomes; thus, showing how important it is to consider the affinity and interaction between rootstocks, scion (Vrsic et al. 2015), and environment (Kidman et al. 2013).

The wine production has become an increasingly attractive activity for the productive sector, since the wine consumption in Brazil increased by 18% from 2019 to 2020 (OIV 2021). Therefore, some alternatives must be implemented to try to meet this growing demand, e.g., expanding to subtropical regions and using agronomic techniques that provide an increase in yield and quality of the grapes, i.e., suitable rootstocks. Considering that few information about the influence of rootstocks on wine grapes in subtropical conditions of the state of São Paulo, especially *V. vinifera*, further studies are needed to evaluate some combinations between rootstocks and scions. In this context, this current study aimed to evaluate the yield and physicochemical traits of wine grapes (*V. vinifera*) grafted on different rootstocks under subtropical conditions.

MATERIALS AND METHODS

The experiment took place at an experimental vineyard, located in Jundiai, São Paulo, Brazil (at the following GPS coordinates: 23°06'S, 46°55'W; and an altitude of 745 m above sea level) over four successive harvest seasons (from 2011 to 2014). According to Köppen's classification, the climate is of the *Cfa* type, that is, subtropical with dry winter and hot summer, with average annual rainfall of 1,400 mm, average temperature of 19.5 °C and relative humidity of 70.6%. The soil in the area was classified as Cambisol Dystrophic Red (Embrapa 2018).

The vineyard was implanted in September 2009, with the rootstocks IAC 766 Campinas and 106-8 Mgt, by using a spacing of 2.5 m between rows and 1 m between vines (density of 4,000 vines per hectare). In July 2010, all the cultivars were grafted on to them. Vines were trained on a vertical shoot position (VSP) with unilateral cord, and the wires were located at 1, 1.3, 1.5 and 1.8 m above the ground. Also, microsprinklers were used for irrigation, and polyethylene mesh (18% shading rate) was used for protection against birds during ripening of the berries. Furthermore, some other cultural and phytosanitary managements were also performed according to the standard practices for local growers.

In 2011, 2012, 2013 and 2014, vines were pruned in late winter in August, and the bunches were harvested between December and January, featuring normal summer harvest season. In all seasons, vines were spur-pruned, and one bud was retained per spur, and, after pruning, 2.5% hydrogen cyanamide was applied to induce and stimulate a more uniform budburst.

A 5 × 2 factorial experiment in randomized complete block design (10 treatments) with five blocks and four vines per plot were conducted, totalling 200 vines. The factors consisted of five wine grape cultivars (Cabernet Sauvignon, Cabernet Franc, Syrah, Merlot, and Sauvignon Blanc) and two rootstocks – IAC 766 Campinas (106-8 Mgt × *V. caribaea*) and 106-8 Mgt [*V. riparia* x (*V. rupestris* × *V. cordifolia*)].

The determination of the grape harvest was according to the maturation curve, when soluble solids and titratable acidity contents stabilized in the interval between two samples.

At harvest, the number of bunches per vine was counted, and the production per vine (kg/vine) was weighted. The yield (t·ha^{-1}) was estimated as a function of production per vine and planting spacing, considering the density of 4,000 vines per hectare.

The physical characteristics of bunches, rachis and berries were evaluated as a function of their masses (g) on an analytical precision scale (± 0.01 g), length (cm), and width (cm) by using a graduated ruler. For these evaluations, 10 bunches were selected per plot, and 10 berries were collected from each bunch; thus, 100 berries per plot. In addition, the number of grape berries per bunches was counted.

Using the same berries, the chemical composition of the grape must be analysed by determining the soluble solids content (SS, expressed in °Brix), titratable acidity (TA, expressed as percentage of tartaric acid), pH value and maturation index (SS/TA). The SS content was determined by direct refractometry of the grape must in a digital refractometer (Reichert®, model r2i300, United States of America). TA was obtained by titration with 0.1 N NaOH to the equivalence point of pH = 8.2. The pH value was detected by direct reading in a Tecnal® potentiometer pH analyser, model r2i300.

Statistical analyses were performed through the average of four harvest seasons. Data were subjected to analysis of variance (Two-Way ANOVA) to determine the effect of rootstock and scion interaction. The comparison of the means of both factors was performed by using the Tukey test (5% probability) through the SISVAR® statistical program, version 5.6 (Lavras, MG, Brazil).

Data from 17 traits (number of bunches per vine [NBchV], yield per vine [YldV], productivity [Pdt], bunch mass [BchM], bunch length [BchL], bunch width [BchW], berry mass [BM], berry length [BL], berry width [BW], rachis mass [RM], rachis length [RL], rachis width [RW], number of berries per bunch [NBBch], soluble solids [SS], pH value [pH] titratable acidity [TA], maturation index [MI]) within 10 rootstocks and scion combinations were also analysed by principal component analysis (PCA) by using XLSTAT software, version 19.4 (Addinsoft, NY, United States of America). This software was also used to calculate Pearson's correlation.

RESULTS AND DISCUSSION

There was no significant interaction between rootstocks and scions ($p > 0.05$) for yield components and physical characteristics of grape berries; all factor analyses were therefore carried out on separate (Table 1).

Table 1. Fruit yield per vine, yield, and berries characteristics of *Vitis vinifera* grapes varieties grafted on different rootstocks*.

Scion	Fruit yield per vine (kg/vine)	Yield (t·ha⁻¹)	Berry mass (g)	Berry length (mm)	Berry width (mm)
Cabernet Sauvignon	0.55 ± 0.10 b	2.20 ± 0.41 b	1.43 ± 0.05 b	13.62 ± 0.18 d	13.01 ± 0.10 c
Cabernet Franc	1.01 ± 0.38 a	4.06 ± 1.51 a	1.88 ± 0.13 a	14.80 ± 0.40 c	14.44 ± 0.95 a
Merlot	0.72 ± 0.24 b	2.88 ± 0.96 b	1.68 ± 0.09 b	14.80 ± 0.35 c	13.50 ± 0.16 bc
Syrah	1.11 ± 0.24 a	4.44 ± 0.95 a	1.84 ± 0.13 a	15.36 ± 0.41 b	13.63 ± 0.30 b
Sauvignon Blanc	0.71 ± 0.23 b	2.84 ± 0.91 b	1.83 ± 0.07 a	15.87 ± 0.30 a	14.05 ± 0.30 ab
p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Rootstock					
IAC 766	0.91 ± 0.32 a	3.62 ± 1.27 a	1.78 ± 0.21 a	15.04 ± 0.87 a	13.87 ± 0.83 a
106-8 Mgt	0.74 ± 0.31 b	2.94 ± 1.23 b	1.68 ± 0.16 b	14.74 ± 0.75 b	13.58 ± 0.43 b
p-Value	0.011	0.011	< 0.001	< 0.001	0.026

*Values are expressed as mean ± standard deviation (*n* = 5). Data are means from four seasons. Values followed by different letters in the within column differ significantly (Tukey test, *p* < 0.05).

There was a significant effect (p < 0.05) for all productive and physical variables of berries, when scions analyses were done on separate (Table 1), since Cabernet Franc and Syrah were the most productive cultivars, i.e., 1.01 and 1.11 kg/vine, respectively. Therefore, the following outcomes mostly contributed to better productive performance of these cultivars, that is, they had high positive correlation (Pearson's correlation) with production components: bunch length (r = 0.81, p < 0.05), rachis fresh mass (r = 0.80, p < 0.05), berry fresh mass (r = 0.75, *p* < 0.05), and the number of bunches per vine (r = 0.70,

$p < 0.05$). Cabernet Sauvignon showed the lowest yield (0.55 kg/vine), the lowest berry fresh mass (1.43 g), the smallest berry width (13.62 mm) and length (13.01 mm) of all. Orlando et al. (2008) assessed the productive performance of Syrah and Cabernet Sauvignon under similar climate conditions, and they observed that Syrah was also more productive than Cabernet Sauvignon, regardless of the rootstock. The best productive performance of Syrah can be related to high vigour and great adaptation to tropical and subtropical conditions.

With regards to the grape berries' physical traits, Sauvignon Blanc and Syrah presented the greatest width (15.87 and 15.36 mm) and length (14.05 and 14.44 mm) of all, respectively (Table 1). According to Sabir (2015), the size of a berry is highly influenced by its number of seeds, as fruit development is regulated by hormones produced in it. Furthermore, the size of a berry is an important attribute, because of its involvement in the concentration of phenolic compounds present in skin berry, especially for red wine grapes (Rockenbach et al. 2011). When grape berries are larger, the pH is higher, while the titratable acidity is lower, according to Chen et al. (2018). However, there was no high positive correlation between grape berry's physical attributes and pH, as well as there was no high negative correlation with titratable acidity. Thus, it is emphasized that pH and acidity can be influenced by vegetative vigour, environmental and soil conditions such as temperature and potassium levels.

IAC 766 rootstocks provided greater production (0.91 *versus* 0.74 kg/vine), yield (3.62 *versus* 2.94 t·ha^{-1}), berry fresh mass (1.78 *versus* 1.68 g), berry width (15.04 *versus* 14.74 cm), and length (13.87 *versus* 13.58 cm) (Table 1) when compared to 106-8 Mgt. The best performance of the grafted vines on IAC 766 rootstock is probably due to great adaptation to the edaphoclimatic conditions of the study area (*Cfa* climate and Cambisol Dystrophic Red). In addition, studies have already showed that high vigour of IAC 766 tend to increase yield scions from *V. vinifera* and *V. labrusca* species (Souza et al. 2015, Dias et al. 2017). In general, high vigour rootstocks have greater capacity to absorb water and nutrients, as well as greater potential to produce growth-promoting substances, which directly contribute to scion development. However, we must emphasize that the rootstock influence on the grapevines' productive performance depends on the scion genotype (Tecchio et al. 2020).

There was a significant interaction ($p < 0.05$) between rootstocks and scions for all evaluated physical traits of bunches and rachis. In general, results have suggested that Cabernet Franc and Merlot presented greater affinity with IAC 766, while Syrah had it with 106-8 Mgt. In contrast, there were no effects of rootstock on physical traits of bunches and rachis of Cabernet Sauvignon and Sauvignon Blanc (Table 2).

The highest number of bunches per vine was shown by Cabernet Franc grafted on to IAC 766. However, the number of bunches per vine is intrinsically related to bud fertility, which is also affected by some abiotic factors, such as temperature, light intensity, photoperiod, mineral nutrition, and plant regulators application, as well as biotic factors, such as varietal characteristics and endogenous hormone levels (Keller 2015).

By analysing the effects of rootstocks in each cultivar, vines on IAC 766 had greater number of bunches per vine, bunch mass and length of bunch and rachis for Cabernet Franc and Merlot than on 106-8 Mgt. However, Syrah on 106-8 Mgt had higher bunch mass, number of berries per bunch, bunch length, rachis weight and length; thus, showing that the interaction between rootstock and scion is quite particular, i.e., it depends on the compatibility between genetic materials and adaptation to edaphoclimatic conditions (Vrsic et al. 2015). Regardless of the rootstock, Cabernet Sauvignon was one of the cultivars that had the lowest bunch mass (85.5 g). Moreover, this value was 76% lower than those detected by Rizzon and Miele (2002) under temperate conditions. However, it must be considered that Cabernet Sauvignon is one of the most produced and vigorous cultivars in the world, mainly in temperate regions (Tecchio et al. 2018).

There was a significant interaction between rootstocks and scions in all chemical attributes that were evaluated in this study (Table 3). Results indicated that rootstocks directly affect the chemical composition of the grape must, which is also corroborated by Jin et al. (2016), Silva et al. (2018) e Tecchio et al. (2020).

The IAC 766 rootstock induced higher soluble solids content in Cabernet Sauvignon, Cabernet Franc and Merlot (18.65, 18.27 and 18.49°Brix, respectively) when compared to 106-8 Mgt (16.76, 17.38 and 15.61°Brix, respectively). According to Koundouras et al. (2008), the effect of rootstocks on primary and secondary metabolites, which is about the quality of the grapes, is related to the photosynthetic activity and gas exchange of the leaf area. Rootstocks have different translocation abilities for water (Ozden et al. 2010) and nutrients (Dias et al. 2012) to the scion; thus, influencing the content of soluble solids present in grape berries.

Table 2. Bunches and rachis characteristics of *Vitis vinifera* grapes varieties grafted on different rootstocks*.

Scion/Rootstocks	Number of bunches per vine		Number of berries per bunch	
	IAC 766	106-8 Mgt	IAC 766	106-8 Mgt
Cabernet Sauvignon	7.96 ± 0.97 bA	6.36 ± 1.70 abA	58.9 ± 6.1 cA	57.1 ± 7.1 bcA
Cabernet Franc	11.79 ± 2.20 aA	7.31 ± 1.79 abB	63.8 ± 5.7 bcA	60.9 ± 7.3 bcA
Merlot	7.79 ± 1.27 bA	4.77 ± 1.04 bB	80.6 ± 8.3 aA	68.2 ± 9.9 bB
Syrah	7.39 ± 1.41 bA	8.21 ± 1.46 aA	71.0 ± 5.2 abA	87.5 ± 3.1 aB
Sauvignon Blanc	8.51 ± 2.86 bA	7.76 ± 1.93 abA	55.0 ± 7.2 cA	54.6 ± 4.3 cA
p-Value	0.012		< 0.001	
Scion/Rootstocks	Bunch width (cm)		Rachis mass (g)	
	IAC 766	106-8 Mgt	IAC 766	106-8 Mgt
Cabernet Sauvignon	5.37 ± 0.11 cA	5.29 ± 0.22 cA	4.58 ± 0.54 bA	4.57 ± 0.48 cA
Cabernet Franc	6.87 ± 0.42 aA	6.17 ± 0.31 bB	4.56 ± 0.59 bA	4.47 ± 0.25 cA
Merlot	7.40 ± 0.34 aA	7.05 ± 0.61 aA	7.40 ± 0.87 aA	6.38 ± 0.77 bB
Syrah	5.92 ± 0.09 bA	6.22 ± 0.22 bA	7.28 ± 0.30 aB	8.96 ± 0.44 aA
Sauvignon Blanc	5.18 ± 0.16 cA	5.09 ± 0.29 cA	3.92 ± 0.45 bA	3.83 ± 0.41 cA
p-Value	0.011		< 0.001	
Scion/Rootstocks	Rachis length (cm)		Rachis width (cm)	
	IAC 766	106-8 Mgt	IAC 766	106-8 Mgt
Cabernet Sauvignon	7.74 ± 0.47 cA	7.39 ± 0.64 bcA	3.18 ± 0.25 bcA	3.19 ± 0.23 cA
Cabernet Franc	9.27 ± 0.46 aA	8.09 ± 0.60 bB	5.00 ± 0.50 aA	4.45 ± 0.21 abB
Merlot	8.34 ± 0.73 bcA	6.97 ± 0.41 cB	5.51 ± 0.40 aA	4.77 ± 0.51 aB
Syrah	8.66 ± 0.37 abB	9.55 ± 0.41 aA	3.60 ± 0.18 bA	3.90 ± 0.26 bA
Sauvignon Blanc	5.84 ± 0.65 dA	5.51 ± 0.57 dA	2.95 ± 0.34 cA	2.97 ± 0.27 cA
p-Value	< 0.001		0.004	

*Values are expressed as mean ± standard deviation (*n* = 5). Data are means from four seasons. Values followed by different letters, lowercase in column and uppercase in a row differ significantly (Tukey test, *p* < 0.05).

Table 3. Chemical attributes of *Vitis vinifera* grape berry varieties grafted on different rootstocks*.

Scion/Rootstocks	Soluble Solids (°Brix)		pH	
	IAC 766	106-8 Mgt	IAC 766	106-8 Mgt
Cabernet Sauvignon	18.65 ± 0.3 aA	16.76 ± 0.8 bcB	3.50 ± 0.06 bA	3.45 ± 0.02 bcB
Cabernet Franc	18.27 ± 0.4 aA	17.38 ± 1.1 bB	3.67 ± 0.05 aA	3.61 ± 0.04 aB
Merlot	18.49 ± 0.4 aA	15.61 ± 1.0 cB	3.54 ± 0.02 bA	3.43 ± 0.06 cB
Syrah	16.71 ± 0.7 bA	16.43 ± 0.1 bcA	3.51 ± 0.02 bA	3.50 ± 0.02 bA
Sauvignon Blanc	18.88 ± 0.4 aA	18.77 ± 0.2 aA	3.31 ± 0.02 bA	3.32 ± 0.01 dA
p-Value	< 0.001		< 0.001	
Scion/Rootstocks	Titratable acidity (%)		Maturation index (SS/TA)	
	IAC 766	106-8 Mgt	IAC 766	106-8 Mgt
Cabernet Sauvignon	0.96 ± 0.06 aB	1.05 ± 0.06 aA	19.72 ± 1.2 bA	16.31 ± 1.7 cB
Cabernet Franc	0.66 ± 0.06 bA	0.66 ± 0.03 cA	29.17 ± 1.4 aA	27.12 ± 2.9 aA
Merlot	0.70 ± 0.02 bB	1.00 ± 0.10 abA	26.54 ± 1.1 aA	17.34 ± 2.4 bcB
Syrah	0.92 ± 0.08 aA	0.92 ± 0.03 bA	19.08 ± 1.6 bA	18.17 ± 0.6 bcA
Sauvignon Blanc	0.95 ± 0.04 aA	1.00 ± 0.07 abA	20.44 ± 1.0 bA	19.76 ± 1.3 bA
p-Value	< 0.001		< 0.001	

*Values are expressed as mean ± standard deviation (*n* = 5). Data are means from four seasons. Values followed by different letters, lowercase in column and uppercase in a row differ significantly (Tukey test, *p* < 0.05).

There was no significant rootstock effect on level of soluble solids of Syrah and Sauvignon Blanc berries, which presented the following average values of 16.57 and 18.81°Brix, respectively. Simonetti et al. (2021) also showed that there was no significant difference between these rootstocks for Sauvignon Blanc grape (18.3 °Brix). Tecchio et al. (2020) also evaluated these same rootstocks in combinations with hybrids cultivars, and they reported that there was also no significant difference in the soluble solids content of the BRS Violeta, IAC Madalena and BRS Lorena hybrid cultivars. However, in the present study, IAC 766 rootstocks induced higher soluble solids to Isabel, Bordô and IAC 138-22 Máximo, while 106-8 Mgt induced higher soluble solids to IAC 116-31 Rainha. Thus, the effect of rootstocks on soluble solids content is also associated with the scion's genetic material, vegetative and reproductive balance, climate conditions, and vineyard management practices (Leão et al. 2020).

By isolating the effect of scions on each rootstock, we noticed that Syrah grape had the lowest soluble solids content (i.e., 16.71°Brix) when grafted on to IAC 766. In this context, the low sugar content can be attributed to dilution effect by berry mass. By using 106-8 Mgt, the lowest soluble solids content was obtained in Merlot (15.61°Brix) and the highest in Sauvignon Blanc (18.77 °Brix). It is important to emphasize that high levels of soluble solids are desirable because the sugar content in grapes is related to the quality (alcoholic potential) of the grape must for winemaking.

Regarding the pH values, IAC 766 also provided higher values in Cabernet Sauvignon, Cabernet Franc and Merlot when compared to 106-8 Mgt. This disparity could be explained by the ability of the rootstocks to absorb and transport potassium. This element is inextricably linked to the pH of the grape must (Walker and Blackmore 2012). Thus, the rootstocks can indeed influence K absorption and therefore the pH of the grapes (Dias et al. 2012).

By analysing the cultivars grafted on each rootstock on separate, Cabernet Franc obtained the highest pH in relation to the other cultivars in both rootstocks, that is, 3.67 on IAC 766 and 3.61 on 106-8 Mgt. Furthermore, Sauvignon Blanc and Merlot presented the lowest pH values when grafted on 106-8 Mgt, i.e., 3.32 and 3.43, respectively. According to Yamamoto et al. (2015), the most appropriate pH values for wine grapes should be 3.2 to 3.4, especially red grapes. This attribute is directly related to the anthocyanin's stability and, consequently, to the red wine colour intensity.

There were only rootstock effects on titratable acidity for Cabernet Sauvignon and Merlot, which 106-8 Mgt induced higher acid concentration than IAC 766. By comparing the scions in each rootstock, we noticed that Cabernet Franc and Merlot grafted on IAC 766 presented the lowest acid content (around 0.70%). However, when grafted on 106-8 Mgt rootstock, Cabernet Franc showed lower acidity (0.66%) among all cultivars. Only maturation index of Merlot and Cabernet Sauvignon were increased by IAC 766. The highest maturation index was found in Cabernet Franc grafted onto both rootstocks followed by Merlot grafted onto IAC 766. In contrast, the lowest maturation index was obtained in Cabernet Sauvignon, Merlot and Syrah grafted on 106-8 Mgt.

PCA delineated most of the variance in the first two principal components, which explained 80.31% of the variance and were used to plot the data in two-dimensional space (Table 4 and Fig. 1). The main component 1 represented 49.51% of the data total variability, and the variables with the greatest contribution were yield per vine, productivity, bunch mass, bunch length, and rachis length. Principal component 2 accounted for 21.41% of the total variance and it was mainly associated with berry width, berry mass, and soluble solids.

The scatter plot of treatments and evaluated characteristics observed in Fig. 1 showed a tendency to group treatments according to production, being effective when analysed separately the cultivars Cabernet Franc and Syrah in both rootstocks and Merlot on IAC 766 rootstock, which had higher averages for yield. On the other hand, the cultivar Sauvignon Blanc in both rootstocks showed higher soluble solids content. In this case, principal component 1 corroborated the mean test, in which it was shown that Cabernet Franc and Syrah were the most productive cultivars: Sauvignon Blanc was the cultivar with the highest soluble solids content and the lowest bunches, rachis and berries, and Cabernet Sauvignon presented more acidic grapes. Furthermore, it was shown that the combination between Merlot and 106-8 Mgt is also closely related to the highest titratable acidity.

Principal component 2 data also corroborated the mean test, in which it was observed that Syrah grafted on 106-8 Mgt had the highest number of berries and the highest rachis mass, while Cabernet Franc grafted on IAC 766 obtained the highest number of bunches per vine. Thus, we consider that the PCA was very efficient in confirming the results presented in this study.

Table 4. Factor loadings, eigenvalues, and proportion of variation associated with nine principal components (PC) of the principal components analysis of 17 yield components and physicochemical traits in 10 scion-rootstock grapevine combinations.

Traits	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
NBchV	0.551	0.654	-0.064	-0.417	0.138	0.265	0.037	0.005	-0.001
YldV	0.908	0.159	0.280	-0.260	-0.045	0.047	-0.003	-0.024	0.002
Pdt	0.908	0.159	0.280	-0.260	-0.045	0.047	-0.003	-0.024	0.002
BchM	0.853	-0.268	0.412	0.117	0.116	-0.051	0.015	0.002	0.007
BchL	0.903	-0.328	-0.058	-0.254	-0.048	-0.070	-0.004	0.040	-0.016
BchW	0.717	-0.328	-0.270	0.502	0.037	0.220	-0.053	0.013	-0.029
BM	0.649	0.559	0.428	0.173	-0.200	-0.103	-0.047	0.004	0.007
BL	0.297	0.499	0.750	0.307	0.012	-0.063	-0.037	-0.007	-0.002
BW	0.537	0.769	0.076	0.151	-0.276	0.111	0.041	0.034	-0.002
RM	0.557	-0.710	0.391	0.025	0.172	-0.034	-0.033	0.007	-0.010
RL	0.813	-0.378	-0.180	-0.399	-0.049	-0.012	-0.026	-0.030	-0.017
RW	0.728	-0.203	-0.399	0.498	0.036	0.134	-0.005	-0.029	0.024
NBBch	0.693	-0.601	0.278	0.055	0.263	-0.002	0.087	0.020	0.024
SS	-0.077	0.791	-0.123	-0.085	0.584	-0.033	-0.067	0.011	-0.001
pH	0.748	-0.111	-0.587	-0.214	-0.153	-0.088	-0.079	0.023	0.032
TA	-0.786	-0.318	0.442	-0.163	-0.039	0.231	-0.065	0.009	0.029
MI	0.667	0.520	-0.477	0.182	0.093	-0.120	0.032	-0.010	0.010
Eigenvalue	8.417	3.979	2.362	1.310	0.633	0.253	0.035	0.007	0.005
Variability (%)	49.511	23.405	13.893	7.705	3.723	1.488	0.206	0.042	0.028
Cumulative (%)	49.511	72.915	86.808	94.513	98.236	99.724	99.930	99.972	100.000

NBchV: number of bunches per vine; YldV: yield per vine; Pdt: productivity; BchM: bunch mass; BchL: bunch length; BchW: bunch width; BM: berry mass; BL: berry length; BW: berry width; RM: rachis mass; RL: rachis length; RW: rachis width; NBBch: number of berries per bunch; SS: soluble solids; TA: titratable acidity; MI: maturation index [MI].
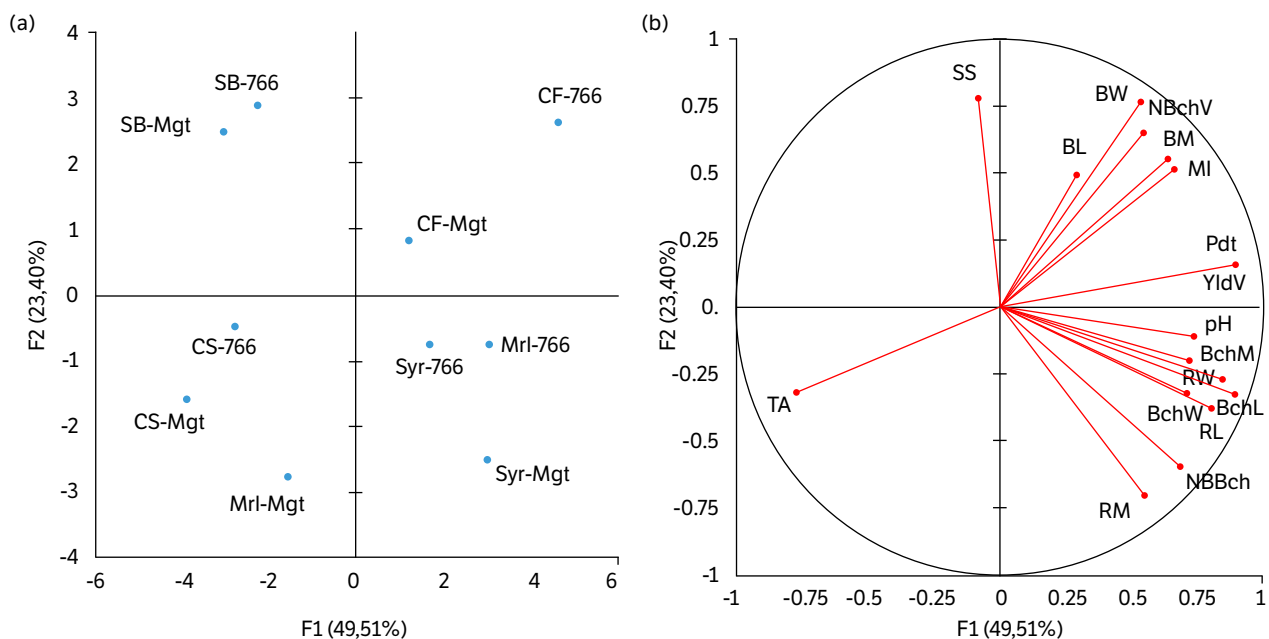

Figure 1. Plots of the principal component analysis of 17 yield components and physicochemical traits in 14 scion-rootstock grapevine combinations. (a) Scores plot and (b) loadings plot. Scion-rootstock combinations: Sauvignon Blanc (SB), Cabernet Franc (CF), Cabernet Sauvignon (CS), Syrah (Syr), Merlot (Mrl) IAC 766 rootstocks (766) and 106-8 Mgt rootstock (Mgt). See Table 4 for trait labels.

CONCLUSION

The red wine grape cultivars Cabernet Franc and Syrah were the most productive. The IAC 766 rootstock provided higher yield for all cultivars when compared to 106-8 Mgt. Moreover, IAC 766 had greater affinity with Cabernet Franc and Merlot cultivars, because it provided greater number of bunches per vine, larger and heavier bunches, as well as higher soluble solids content and pH in relation to 106-8 Mgt, as well as it promoted higher values for soluble solids, pH and maturation index for Cabernet Sauvignon.

AUTHORS' CONTRIBUTION

Conceptualization: Tecchio, M. A.; **Methodology:** Tecchio, M. A., Silva, M. J. R. and Moura, M. F..; **Investigation:** Silva, M. J. R. and Vedoato, B. T. F.; **Writing – Original Draft:** Silva, M. J. R., Sanchez, C. A. P. C. and Callili, D.; **Writing – Review and Editing:** Tecchio, M. A., Silva, M. J. R., Sanchez, C. A. P. C. and Callili, D.; **Funding Acquisition:** Tecchio, M. A. **Resources:** Tecchio, M. A.., Hernandes, J. L. and Moura, M. F..; **Supervision:** Tecchio, M. A.

DATA AVAILABILITY STATEMENT

All dataset were generated and analyzed in the current study.

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