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Rootstocks and potassium fertilization on yield performance and quality of 'Niagara Rosada' grapevine under subtropical conditions

Daniel Callili [1*], Marlon Jocimar Rodrigues da Silva[1], Camilo André Pereira Contreras Sánchez[1], Letícia Silva Pereira Basílio[2], Bruno Marcos de Paula Macedo[1], Luiz Antonio Junqueira Teixeira[3], Giuseppina Pace Pereira Lima[2], Marco Antonio Tecchio[1]

[1]Universidade Estadual Paulista 'Júlio de Mesquita Filho', Faculdade de Ciências Agronômicas (FCA/UNESP), Departamento de Produção Vegetal, 3780 Universitária Avenue, 18610-034, Botucatu, SP, Brazil
[2]Universidade Estadual Paulista 'Júlio de Mesquita Filho', Instituto de Biociências (IB/UNESP), Departamento de Ciências Químicas e Biológicas, 250 Prof. Dr. Antônio Celso Wagner Zanin Street, 18618-689, Botucatu, SP, Brazil
[3]Instituto Agronômico de Campinas (IAC), Centro de Pesquisa e Desenvolvimento de Solos e Recursos Ambientais, 1481 Barão de Itapura Avenue, 13012-970, Campinas, SP, Brazil

***Corresponding author: daniel_callili@hotmail.com**

Abstract

The current study aimed to assess the influence of rootstocks ('IAC 572' and 'IAC 766') and potassium fertilization with different sources (KCl and K_2SO_4) and concentrations (0, 75, 150 and 300 kg ha^{-1} K_2O) regarding to yield performance and grape quality of 'Niagara Rosada', as well as the variation of K availability in soil. Thus, yield components; physical characteristics of bunches and berries; chemical composition, bioactive compounds, and antioxidant activity of grape berry; leaf K content; and variation of K availability in soil were evaluated in two consecutive seasons (2017 and 2018). Results showed no influence of rootstocks on yield performance of 'Niagara Rosada'; however, grapevines grafted on to 'IAC 766' produced berries with higher concentration of total flavonoids and anthocyanins. Furthermore, KCl provided higher concentration of total flavonoids and anthocyanins compared to K_2SO_4. In general, potassium sources had similar effects on the variation of K availability in soil. Results indicated that there was small effect between K doses with regards to production and qualitative parameters. We therefore estimated a fertilization rate of 150 kg ha^{-1} K_2O to maintain K concentration in soil after each production cycle.

Keywords: table grapes, grafting, physicochemical characteristics, antioxidant compounds, K replacement.

Introduction

The grape (*Vitis vinifera* L.) is one of the most important fruit in the Brazilian market. In 2018, Brazil produced around 1.6 million tons of grapes, with table grapes accounting for 53% of the total (OIV, 2019). Because Brazil is the size of a continent, viticulture stands out for the diversity of varieties and management practices that allow grapevines to be grown under different weather conditions. In Brazil's subtropical regions, 'Niagara Rosada' is one of the most often planted table grape cultivars. Such cultivar is a non-*vinifera* with a great cost-benefit production when compared to *Vitis viniferas* grapes; besides that, 'Niagara Rosada' presents high yields in both tropical and subtropical conditions (Tecchio et al., 2018). However, several factors can affect grapevine yield and grape quality, which include the use of rootstocks (Jin et al., 2016; Cheng et al., 2017; Silva et al., 2018).
Many studies have shown that more vigorous rootstocks increase yields despite lowering phenolic compounds and soluble solids levels in grape berries (Jones et al., 2009; Mota et al., 2009; Borges et al., 2013; Ibacache et al., 2016). Nevertheless, the compatibility between rootstock and scion is quite specific, even as the adaptations to climate conditions (Vrsic et al., 2015; Tecchio et al., 2020). In addition, rootstocks have different efficacy to nutrient absorption, accumulation, and translocation (Garcia et al., 2001; Fisarakis et al., 2005; Tecchio et al., 2011). Thus, the scion and growing conditions must be taken into consideration before making any rootstock recommendation (Keller et al., 2001).
Potassium fertilization, according to Mpelasoka et al. (2003), is an agricultural management that can directly influence the development and quality of grapes. Potassium (K) is an essential nutrient for grapevines, as it is the most abundant cation in grape berries at all stages of growth (Rogiers et al., 2006; Martins et al., 2012). K can affect the chemical and biochemical quality of grapes (Walker and Blackmore, 2012; Obenland et al., 2015), because it is involved in several physiological processes (Rogiers et al., 2017), such as anion neutralization, which is important for regulating cell membrane potential; enzymatic activation; translocation of assimilates; osmoregulation; protein and starch synthesis (Wang and Wu, 2013; Ahmad and Maathuis, 2014; Shabala and Pottosin, 2014).

Because potassium is mobile and susceptible to leaching losses, adequate potassium fertilization can help to maintain stable K levels in the soil. There are different K sources for agriculture employment, but potassium chloride (KCl) stands out due to its higher K_2O concentration and greater solubility (Oliveira, 2017), besides having a lower cost than other fertilizers. On the other hand, Kleinhenz (1999) stated that potassium sulphate (K_2SO_4) contains two important nutrients, presents lower salinity and less susceptibility to leaching when compared to KCl. Although it is widely accepted that fertilizer type, concentration, timing, and application frequency are essential criteria, the efficiency of the fertilizer should also be determined by the genotype of the rootstock and scion, as well as the microclimate and soil properties (Mpelasoka et al., 2003).

The levels of bioactive compounds in grapes depend on biotic factors, such as genotype and abiotic, such as climate, fertilization and management practices. There is a paucity of literature describing the bioactive compounds in 'Niagara Rosada' (Monteiro et al., 2020; Gomes et al., 2021) and there is no research yet that relate the effect of potassium fertilization and phenolic compounds in such cultivar. Both flavonoids and anthocyanins have been described in 'Niagara Rosada' (Gomes et al., 2021); these secondary metabolites have been described as powerful antioxidants molecules that can eliminate free radicals from different stress types; consequently, increasing the resistance against biotic and abiotic factors; besides that, they are also related to aroma, flavour and colour (Gomez-Gomez et al., 2018). The consumption of phenolic compounds is associated with the following properties: anti-inflammatory, antihistamine and anti-aging. Also, anthocyanins contribute to the colourful appearance of grapes, and 3-glucoside is the most active anthocyanin antioxidant (Orak, 2007). Therefore, grapes that present higher antioxidant quality from cultural management practices may attract both producers' attention due to extended post-harvest life and consumers due to antioxidant properties.

In the context, the current study aimed (1) to assess the influence of rootstocks and potassium fertilization on the yield performance and antioxidant quality of 'Niagara Rosada' grapes and (2) the effect of potassium fertilization in the variation of K availability in soil.

Results

There was no significant interaction (p > 0.05) among rootstocks, K sources and doses for all evaluated variables. Therefore, the factors were analysed in separate.

Rootstocks

Results only showed a significant difference (p <0.05) between rootstocks for leaf K concentration (Table 1), since the grapes grafted on to 'IAC 572' showed 13.5% higher leaf K concentration than 'IAC 766' (16.81 g kg^{-1} and 14.81 g kg^{-1}, respectively).

However, there was no significant effect of the rootstocks regarding to the other variables. In general, the grapevines grafted on to rootstocks presented an average of 17 bunches per vine and 58 berries per bunches. The bunches presented 249.34 g fresh mass, 13.19 cm length and 7.48 cm wide. Besides that, grape berries presented 4.24 g fresh mass, 2.04 cm length and 1.87 cm wide. These characteristics provided an average production of 3.42 kg/vine, that is, an average yield of 14.13 t ha^{-1} in a plant density of 6,250 plants per hectare.

Table 2 indicates that was only a significant difference between rootstocks for total flavonoids and anthocyanins concentrations with regards to chemical composition of the grape must, bioactive compounds and antioxidant activity. Thus, grapevines grafted on to 'IAC 766' presented berries with a higher total flavonoid concentration (15.25 mg $100g^{-1}$) than those grafted on to 'IAC 572' (13.49 mg $100g^{-1}$). Berries from the grapevines grafted on to 'IAC 766' showed anthocyanin content 37% higher (6.34 mg 100 g^{-1}) than the ones grafted on to 'IAC 572' (4.62 mg 100 g^{-1}). Moreover, there were no significant differences between rootstocks for the other chemical and biochemical variables.

K sources

Table 3 shows that leaf K content, yield performance, and physical attributes of bunches and berries did not differ significantly between K sources (KCl and K_2SO_4). As a result, the average leaf K concentration between potassium sources was found to be 16.06 g kg^{-1}. Moreover, each vine displayed roughly 17 bunches per plant with the following average values: 249.34 g fresh mass, 13.19 cm length and 7.47 cm width. The bunches contained 58 grape berries on average, with the following averages: fresh mass of 4.24 g, length of 2.04 cm, and width of 1.87 cm. As a result of these features, the average yield was 14.12 t ha^{-1} and the average production was 3.53 kg/vine.

The KCl fertilizer induced higher content of total flavonoids and anthocyanins (15.03 mg 100 g^{-1} and 6.16 mg 100 g^{-1}, respectively) compared to K_2SO_4 (13.71 mg 100 g^{-1} and 4.80 mg 100 g^{-1}, respectively) (Table 4). However, both K sources did not promote any significant differences in the total phenol content (157.11 mg 100 g^{-1}) and antioxidant activity, which can be measured via DPPH (24.00 mg 100 g^{-1}) or FRAP (36.49 mM kg^{-1}). In addition, there was no significant difference between KCl and K_2SO_4 sources for pH (3.60), TA (0.86%), SS (15.68 °Brix) and maturation index (18.84).

In the samples taken from 0 - 20 and 20 - 40 cm after the first and second production cycle, both fertilizers (KCl and K_2SO_4) did not promote any significant variation of K availability in soil (ΔK) (Table 5). After the first production cycle, there was a decrease in K concentrations in samples taken from 0 to 20 cm, that is, a reduction of 0.17 $mmol_cdm^{-3}$ in soil fertilized by KCl and 0.22 $mmol_cdm^{-3}$ in soil fertilized by K_2SO_4. At the 20 to 40 cm depth, K concentration reduced for KCl (0.40 $mmol_cdm^{-3}$) and K_2SO_4 (0.38 $mmol_cdm^{-3}$).

After the second production cycle, at the 0 - 20 cm depth, soil K concentration decreased in relation to the initial concentration, that is, reduced to 0.32 $mmol_cdm^{-3}$ for KCl treatment and 0.33 $mmol_cdm^{-3}$ for K_2SO_4 treatment. At the 20 - 40 cm depth, soil K concentration remained neutral for KCl (ΔK = -0.05 $mmol_cdm^{-3}$), but there was an increase in 0.26 $mmol_cdm^{-3}$ for K_2SO_4.

K doses

Results did not detect any significant effect between K doses for these traits (Table 6). In the average doses, leaves presented 15.81 g kg^{-1} K. The grapevines presented about 17 bunches with a production of 3.52 kg, thus, a yield of 14.13 t ha^{-1}. Regarding to the physical characteristics, the bunches had 58 berries, a fresh mass of 249.34 g, 13.19 cm length and 7.47 cm wide. The grape berries weighed 4.23 g with 2.03cm length and 1.87cm wide.

There was only a significant effect of K doses for total phenols and antioxidant activity of the grapes (Table 7). A quadratic polynomial model was adjusted to express the variation of total phenols in relation to K doses, in which the highest concentration of total phenols occurred in control treatment (177.10 mg 100 g^{-1}) and the lowest occurred in grape berries treated with 150 kg ha^{-1} K_2O, whose concentration reached 136.48 mg 100 g^{-1}.

With regards to the effect of K doses related to antioxidant activity, quadratic polynomial models were adjusted for both DPPH and FRAP methods; nevertheless, the untreated grape berries presented the greatest antioxidant activity.

There was no significant effect of K doses for the chemical variables, total flavonoids and monomeric anthocyanins concentrations. The average doses in the grape must presented the following outcomes: 3.60 pH, 0.85% TA, 15.68 °Brix SS and 18.84 (SS/TA). The levels of total flavonoids and anthocyanins were 14.37 and 5.47 mg 100 g^{-1}, respectively.

At both depths, after the first and second production cycle, there was a linear increase in soil K concentration with the increase in K doses (Table 8). After the first production cycle, at the 0 - 20 cm depth, soil K replacement occurred after treating with around 150 kg K_2O ha^{-1} ($\Delta K = 0.15$ $mmol_c dc^{-3}$). In contrast, at the 20 - 40 cm depth, soil K replacement occurred only after treating with approximately 240 kg ha^{-1} K_2O. After the second cycle, there was no decrease in soil K availability at the 0 - 20 cm depth by treating with about 150 kg ha^{-1} K_2O ($\Delta K = 0.17$ $mmol_c dc^{-3}$). However, soil K availability remained neutral with the application of 150 kg ha^{-1} K_2O ($\Delta K = -0.08$ $mmol_c dc^{-3}$).

Discussion

Rootstocks

'IAC 572' and 'IAC 766' rootstocks have been evaluated in combinations with several grape cultivars, such as clones of cv. 'Concord' (Borges et al., 2013), 'Isabel Precoce', 'BRS Carmem', 'BRS Cora', IAC 138-22 'Máximo' (Silva et al., 2018), 'BRS Ísis' (Leão et al., 2020a) and 'BRS Vitória' (Leão et al., 2020b). There are a great variation in these studies' outcomes, as well as this current study (Table 1), therefore, showing that the affinity and interaction between rootstocks and scion must be taken into account because of all particularities between them (Tecchio et al., 2020).

Furthermore, selecting rootstocks that are well adapted to climate variations must be considered, since the fluctuations in climate conditions had already affected the outcomes in studies with 'Niagara Rosada' grafted on to 'IAC 572' and 'IAC 766'. Tecchio et al. (2014), Angelotti-Mendonça et al. (2018) and Vedoato et al. (2020) evaluated the production performance of 'Niagara Rosada' grafted on the same rootstocks in a *Cwa* climate, which is similar to this study condition, and they found no significant effect of these relation; thus, corroborating with this study (Table 1).

However, Tecchio et al. (2011) found that 'Niagara Rosada' and 'IAC 766' increased the yield when compared to 'IAC 572' in a tropical climate (*Aw*). But Mota et al. (2009) observed the opposite in a *Cwb* climate, that is, 'Niagara Rosada' and 'IAC 572' enabled an increase in yield when compared to 'IAC 766'. Nevertheless, the compatibility and interaction between rootstock and scion must be considered (Vrsic et al., 2015), in addition to be well-adapted to climate of the respective growing area (Clingeleffer, 2010), as it could easily affect rootstock and scion (Leão et al. 2020a).

By growing 'Niagara Rosada' on to 'IAC 572' and 'IAC 766' rootstocks through vertical shoot position system, the average productions were 2.65 kg/vine (Tecchio et al., 2014), 1.26 kg/vine (Angelotti-Mendonça et al., 2018) and 1.63 kg/vine (Vedoato et al., 2020). These values are therefore lower than the average production obtained in this study (i.e. 3.42 kg/vine) (Table 1) which leads us to suggest that yield performance of 'Niagara Rosada' on to 'IAC 572' and 'IAC 766' can be considered good in a *Cfa* climate, that is, well-adapted to this climate condition.

Moreover, absorption and translocation of nutrients to the aerial part of grapevines grafted on to rootstocks can also influence grape traits (Kodur, 2011; Jogaiah et al., 2013). In this study, results showed that higher K concentration occurred in leaves of grapevines grafted on to 'IAC 572' (Table 1), since nutrients absorption via rootstocks is mainly affected by genetic factors (Ruhl, 1989), root system density and size (Kodur et al., 2010) and soil composition (Lambert et al., 2008). Also, such effect may have been caused by releasing K^+ into the xylem and, consequently, different translocation of the roots to the aerial part (Mpelasoka, 2003).

Bearing in mind that leaf diagnosis serves as an important tool for assessing plant nutritional status to make further fertilization recommendations (Arrobas et al., 2014). Studies have already shown that leaf K concentration is strong correlated to chemical attributes of grape must and yield components (Amiri and Fallahi, 2007). Despite that, Ruhl (1989) affirmed there is a positive correlation between K and the pH of grape must, such fact did not occur in this study ($r = 0.02$, $p > 0.05$). Leak K concentration showed a high positive correlation with the number of bunches per plant ($r = 0.73$, $p < 0.05$) and berry length ($r = 0.75$, $p < 0.05$); but these physical parameters did not influence grapevines production performance (Table 1). The low positive correlation observed between leaf K concentration and yield ($r = 0.31$, $p > 0.05$) was like the one recorded by Tecchio et al. (2006) ($r = 0.42$). However, there was a high negative correlation between leaf K concentration with total flavonoids ($r = -0.75$, $p < 0.05$) and soluble solids ($r = -0.55$, $p > 0.05$) and low negative correlation with total phenolic compounds ($r = -0.44$, $p > 0.05$) (Pearson's correlation data not shown). Therefore, rootstocks with less K accumulation, in addition to lowering the pH (Walker and Blackmore, 2012), tend to provide higher levels of bioactive compounds and soluble solids. In this context, it is important to note that some rootstocks, such as *Vitis rupestris* and *Vitis berlandieri* have less K accumulation (Ruhl, 1989; Wolpert et al., 2005; Walker and Clingeleffer, 2009) and are quite promising; therefore, they require additional research attention (Rogiers et al., 2017).

The chemical and biochemical traits of the grape must were considered to evaluate the quality of grape; therefore, 'IAC 766' rootstock stood out, as presented the highest concentration of total flavonoids and anthocyanins (Table 2). Anthocyanins are flavonoids intrinsically related to fruit pigmentation and high levels of this compound makes the colour of the grape berries more intense, that is, berries become more attractive to consumers.

According to Mota et al. (2009), 'IAC 572' is more vigorous than 'IAC 766', Borges et al. (2013) stated that less vigorous rootstocks tend to induce greater accumulation of bioactive compounds as they provide better vegetative balance to the scion. In the context, Brighenti et al. (2011) also emphasized that vegetative and reproductive balance directly interferes

Table 1. Leaf K concentration, production components and physical characteristics of bunches and berries of the 'Niagara Rosada' vine grafted on to 'IAC 572 Jales' and 'IAC 766 Campinas' rootstocks.

Leaf K concentration, yield components and physical traits	Rootstocks		
	'IAC 572 Jales'	'IAC 766 Campinas'	*p*-value
Leaf K concentration (g kg^{-1})	16.81 ± 1.21 a	14.81 ± 1.68 b	< 0.01
Production (kg/vine)	3.44 ± 0.65	3.41 ± 0.51	0.39
Yield (t ha^{-1})	13.79 ± 2.61	14.47 ± 2.06	0.39
Number of bunches per vine	17.12 ± 3.00	16.63 ± 2.32	0.60
Number of berries per bunch	58.29 ± 7.67	57.47 ± 5.45	0.71
Bunch mass (g)	245.81 ± 17.96	252.87 ± 21.90	0.33
Bunch length (cm)	13.12 ± 0.48	13.26 ± 0.58	0.40
Bunch width (cm)	7.49 ± 0.28	7.47 ± 0.31	0.85
Berry mass (g)	4.20 ± 0.14	4.28 ± 0.13	0.11
Berry length (cm)	2.04 ± 0.03	2.04 ± 0.04	0.79
Berry width (cm)	1.89 ± 0.13	1.85 ± 0.02	0.27

Values are expressed as mean ± standard deviation (n = 16). Values followed by different letters on the same line differ significantly (Tukey test, $p < 0.05$).

Table 2. Chemical composition, bioactive compounds and antioxidant activity concentrations of berries of the 'Niagara Rosada' vine grafted on to 'IAC 572 Jales' and 'IAC 766 Campinas' rootstocks.

Chemical and biochemical traits	Rootstocks		
	'IAC 572 Jales'	'IAC 766 Campinas'	*p*-value
pH	3.60 ± 0.07	3.61 ± 0.03	0.75
Titratable acidity (%)	0.83 ± 0.05	0.87 ± 0.09	0.20
Soluble solids (°Brix)	15.62 ± 0.69	15.75 ± 0.69	0.45
Maturation index (SS/TA)	19.25 ± 1.84	18.43 ± 2.10	0.22
Total phenols (mg 100 g^{-1})	154.29 ± 32.52	159.93 ± 51.74	0.64
Total flavonoids (mg 100 g^{-1})	13.49 ± 0.98 b	15.25 ± 2.07 a	< 0.01
Anthocyanins (mg 100 g^{-1})	4.62 ± 1.13 b	6.34 ± 1.98 a	< 0.01
DPPH (mg 100 g^{-1})	25.68 ± 8.63	22.31 ± 12.53	0.24
FRAP (mM kg^{-1})	37.69 ± 13.98	35.29 ± 10.12	0.42

Values are expressed as mean ± standard deviation (n = 16). Values followed by different letters on the same line differ significantly (Tukey test, $p < 0.05$).

Table 3. Leaf K concentration, production components and physical characteristics of bunches and berries of the 'Niagara Rosada' vine fertilized with KCl e K_2SO_4.

Leaf K concentration, yield components and physical traits	Sources of K		
	KCl	K_2SO_4	*p*-value
Leaf K concentration (g kg^{-1})	15.50 ± 1.84	16.62 ± 1.68	0.20
Production (kg/vine)	3.36 ± 0.68	3.70 ± 0.42	0.09
Yield (t ha^{-1})	13.44 ± 2.73	14.81 ± 1.69	0.09
Number of bunches per vine	16.26 ± 3.33	17.49 ± 1.62	0.19
Number of berries per bunch	58.26 ± 8.41	57.49 ± 4.23	0.73
Bunch mass (g)	248.57 ± 19.52	250.11 ± 21.14	0.83
Bunch length (cm)	13.13 ± 0.58	13.25 ± 0.49	0.47
Bunch width (cm)	7.39 ± 0.21	7.56 ± 0.34	0.11
Berry mass (g)	4.24 ± 0.15	4.24 ± 0.14	0.96
Berry length (cm)	2.03 ± 0.04	2.04 ± 0.03	0.49
Berry width (cm)	1.88 ± 0.14	1.86 ± 0.02	0.49

Values are expressed as mean ± standard deviation (n = 16). Values followed by different letters on the same line differ significantly (Tukey test, $p < 0.05$).

Table 4. Chemical composition, concentration of bioactive compounds and antioxidant activity of berries of the 'Niagara Rosada' vine fertilized with KCl and K_2SO_4.

Chemical and biochemical traits	Sources of K		
	KCl	K_2SO_4	*p*-value
pH	3.60 ± 0.05	3.60 ± 0.06	0.90
Titratable acidity (%)	0.86 ± 0.08	0.85 ± 0.07	0.59
Soluble solids (°Brix)	15.68 ± 0.78	15.68 ± 0.70	0.99
Maturation index (SS/TA)	18.66 ± 2.01	19.02 ± 2.01	0.59
Total phenols (mg 100 g^{-1})	165.50 ± 48.58	148.72 ± 39.93	0.17
Total flavonoids (mg 100 g^{-1})	15.03 ± 2.22 a	13.71 ± 1.02 b	< 0.01
Anthocyanins (mg 100 g^{-1})	6.16 ± 1.92 a	4.80 ± 1.45 b	< 0.01
DPPH (mg 100 g^{-1})	22.96 ± 9.11	25.04 ± 12.33	0.46
FRAP (mM kg^{-1})	37.31 ± 13.14	35.68 ± 11.26	0.58

Values are expressed as mean ± standard deviation (n = 16). Values followed by different letters on the same line differ significantly (Tukey test, $p < 0.05$).

Table 5. Effect of KCl and K_2SO_4 fertilizers on the variation of K availability in soil (ΔK) after each production cycle at the 0 - 20 cm and 20 - 40 cm depths.

K soil concentration ($mmol_c dm^{-3}$)	Soil depth (cm)	Sources of K		
		KCl	K_2SO_4	*p*-value
(ΔK) after 1st season	0 - 20	-0.17 ± 1.11	-0.22 ± 1.31	0.82
(ΔK) after 1st season	20 - 40	-0.40 ± 0.58	-0.38 ± 0.67	0.84
(ΔK) after 2nd season	0 - 20	-0.32 ± 2.04	-0.33 ± 2.09	0.98
(ΔK) after 2nd season	20 - 40	- 0.05 ± 1.27	0.26 ± 1.53	0.40

Values are expressed as mean ± standard deviation (n = 16). Values followed by different letters on the same line differ significantly (Tukey test, $p < 0.05$).

Table 6. Leaf K concentration, production components and physical characteristics of bunches and berries of the 'Niagara Rosada' vine fertilized with different K doses.

Leaf K concentration, yield components and physical traits	Doses of K (kg ha^{-1} K_2O)				
	0	75	150	300	*p*-value
Leaf K concentration (g kg^{-1})	14.87 ± 1.50	16.41 ± 2.30	15.64 ± 1.61	16.33 ± 1.36	0.40
Production (kg/vine)	3.31 ± 0.87	3.62 ± 0.43	3.53 ± 0.60	3.65 ± 0.36	0.58
Yield (t ha^{-1})	13.25 ± 3.49	14.50 ± 1.74	14.16 ± 2.39	14.61 ± 1.43	0.58
Number of bunches per vine	15.53 ± 3.92	17.43 ± 2.02	16.65 ± 2.37	17.88 ± 1.55	0.67
Number of berries per bunch	60.45 ± 9.52	59.44 ± 3.42	56.01 ± 6.06	55.61 ± 5.60	0.58
Bunch mass (g)	252.52 ± 15.86	259.78 ± 21.61	245.30 ± 20.00	239.75 ± 19.95	0.69
Bunch length (cm)	13.04 ± 0.39	13.59 ± 0.51	13.17 ± 0.57	12.96 ± 0.49	0.10
Bunch width (cm)	7.48 ± 0.26	7.62 ± 0.37	7.44 ± 0.30	7.37 ± 0.22	0.52
Berry mass (g)	4.22 ± 0.11	4.25 ± 0.13	4.27 ± 0.17	4.21 ± 0.17	0.37
Berry length (cm)	2.03 ± 0.05	2.05 ± 0.03	2.03 ± 0.02	2.04 ± 0.03	0.80
Berry width (cm)	1.86 ± 0.02	1.87 ± 0.19	1.92 ± 0.02	1.85 ± 0.02	0.19

Values are expressed as mean ± standard deviation (n = 8).

Table 7. Chemical composition, concentration of bioactive compounds and antioxidant activity of berries of the 'Niagara Rosada' vine fertilized with different K doses.

Chemical and biochemical traits	Doses of K (kg ha^{-1} K_2O)				
	0	75	150	300	*p*-value
pH	3.59 ± 0.04	3.60 ± 0.06	3.61 ± 0.06	3.60 ± 0.06	0.52
Titratable acidity (%)	0.84 ± 0.06	0.86 ± 0.06	0.83 ± 0.05	0.88 ± 0.12	0.64
Soluble solids (°Brix)	15.90 ± 0.66	15.74 ± 0.57	15.67 ± 0.72	15.43 ± 0.81	0.96
Maturation index (SS/TA)	19.24 ± 1.44	18.76 ± 1.66	19.25 ± 1.89	18.11 ± 2.85	0.64
Total phenols (mg 100 g^{-1})	177.10 ± 40.95 (1)	143.09 ± 38.40	136.48 ± 43.20	171.79 ± 46.99	< 0.01
Total flavonoids (mg 100 g^{-1})	14.72 ± 1.70	14.40 ± 1.27	14.00 ± 2.15	14.36 ± 2.24	0.33
Anthocyanins (mg 100 g^{-1})	4.75 ± 1.64	6.03 ± 1.69	5.55 ± 1.86	5.58 ± 2.20	0.13
DPPH (mg 100 g^{-1})	30.60 ± 11.82 (2)	20.28 ± 8.98	21.39 ± 9.54	23.73 ± 10.71	< 0.05
FRAP (mM kg^{-1})	47.33 ± 11.87 (3)	34.03 ± 6.87	34.05 ± 11.22	30.56 ± 11.64	< 0.05

Values are expressed as mean ± standard deviation (n = 8). (1): $y = 0.0018x^2 – 0.5402x + 176.18$ ($R^2 = 0.99$); (2): $y = 0.0003x^2 – 0.1165x + 29.668$ ($R^2 = 0.83$); (3): $y = 0.0003x^2 – 0.1423x + 46.144$ ($R^2 = 0.89$).

Table 8. Effect of different doses on the variation of K availability in soil (ΔK) at the 0 - 20 cm and 20 - 40 cm depths after each production cycle.

K soil concentration (mmol$_c$dm^{-3})	Soil depth (cm)	Doses of K (kg ha^{-1} K_2O)				
		0	75	150	300	*p*-value
(ΔK) after 1st season	0 - 20	-1.60 ± 0.57 (1)	-0.60 ± 0.33	0.15 ± 0.36	1.26 ± 0.88	< 0.01
(ΔK) after 1st season	20 - 40	-0.91 ± 0.51 (2)	-0.61 ± 0.47	-0.23 ± 0.47	0.20 ± 0.44	< 0.01
(ΔK) after 2nd season	0 - 20	-2.46 ± 0.63 (3)	-0.87 ± 0.62	0.17 ± 0.54	1.85 ± 3.44	< 0.01
(ΔK) after 2nd season	20 - 40	-0.77 ± 1.62 (4)	-0.47 ± 0.44	-0.08 ± 0.36	1.75 ± 1.09	< 0.01

Values are expressed as mean ± standard deviation (n = 8). (1): $y = 0.0088x – 1.246$ ($R^2 = 0.92$); (2): $y = 0.0037x – 0.876$ ($R^2 = 0.98$); (3): $y = 0.014x – 2.16$ ($R^2 = 0.97$); (4): $y = 0.0086x – 1.016$ ($R^2 = 0.94$).

Table 9. Results of chemical soil analysis before running treatments, august 2016.

Soil Depth	OM[1]	pH	P[2]	K[2]	Ca[2]	Mg[3]	H+Al	V[(3)]
--- cm ---	---g kg^{-1}---		mg dm^{-3}	-------------------- mmol$_c$ dm^{-3} --------------------				---- % ----
0 - 20	20.1 (2.9)	5.5 (0.1)	67.6 (14.2)	4.2 (0.5)	37.6 (3.5)	13.6 (0.1)	21.6 (3.3)	71.8 (5.2)
20 - 40	12.3 (1.5)	5.6 (0.1)	25.3 (7.7)	2.5 (0.4)	31.0 (3.0)	13.8 (0.6)	20.5 (3.4)	70.1 (4.4)

(1) organic matter; (2) extracted by ion exchange resin; (3) base saturation. Values in parentheses: standard deviation (n = 4).

with the concentration of bioactive compounds in berries. The excess of vegetative vigour can cause greater shading to the bunches, a factor that can lower the concentrations of bioactive compounds, since excessive leaf area leads to water loss, fungal diseases and shading of the berries, forming a microclimate with high humidity and low radiation. We therefore noticed that there was a higher concentration of total flavonoids and anthocyanins in berries of grapevines grafted on to 'IAC 766' because this rootstock promotes less vegetative vigour to the canopies when compared to 'IAC 572'. Considering that the grape contains high levels of phenolic compounds and the consumption of foods rich in bioactive compounds are currently increasing due to the several health benefits and antioxidant activities, choosing the appropriate rootstock is very important because can enable a production of grapevines with greater biochemical quality.

Potassium fertilization

One of the hypotheses raised in this study was whether the KCl and K_2SO_4 fertilizers would present significant differences regarding to yield, grape quality, K loss in soil and replacement K. However, the only significant difference was related to total flavonoids and anthocyanins concentrations (Tables 3, 4 and 5). We expected significant differences between fertilizers on yield performance, because KCl presents high content of chlorine and, consequently, high salinity; therefore, higher KCl doses can negatively effect on grapevines. According to Baby et al. (2016), salinity decreases in leaf area, root and shoot mass; in addition to reducing CO_2 assimilation (photosynthesis), transpiration rate and stomatal conductance; thus, decreasing in yield. On the other hand, K_2SO_4 has a high content of sulphur (S) in the composition (18%). S mainly provides disulfide bonds between amino acids within proteins; thus, playing an important role in plant growth due to the involvement in some metabolic pathways (Amâncio et al., 2009). However, Table 3 shows that KCl and K_2SO_4 fertilizers did not affect development and production performance of the grapevines. Regarding the chemical and biochemical characteristics of the grapes, Kleinhenz (1999) mentioned that K_2SO_4 can promote greater benefits to fruit quality, but results shows that KCl promoted higher content of total flavonoids and anthocyanins in grapes than K_2SO_4 (Table 4). Possibly, an abiotic stress may have appeared due to high salinity in the content of KCl, which may have increased the concentration of bioactive substances. It is known that biotic or abiotic stresses can increase the concentration of bioactive compounds. According to Mohammadkhan et al. (2013) and Mohammadkhan (2018), abiotic stresses such as salinity increase the activity of the enzyme phenylalanine ammonia lyase (PAL) and, then, contributing to a greater accumulation of bioactive compounds. It is highly important to consider that fertilizers are also responsible for K loss and replacement in soil. Kleinhenz (1999) mentioned that chloride is more susceptible to leaching in soil than sulphate; besides that, KCl leaches more easily than K_2SO_4. However, both fertilizers kept similar soil K concentrations after first and second cycles at both soil depths (Table 5). Therefore, the effect of both fertilizers was similar as K leaching highly depends on soil properties. In this study, soil presented a clayey texture and high CTC, that is, K leaching is lower than sandy and well-drained soils with low CTC (Raij, 2011). The literature and this study confirmed through the outcomes that fertilizer can cause positive or negative effects, especially KCl. Such effects are intrinsically related to doses, crop tolerance to salinity and soil properties. Nevertheless, KCl will only promote positive effects whether it is used in a rational manner and all these attributes are taken taking into account. There was a significant effect of K doses on few qualitative variables (Tables 6 and 7), because soil K concentration in the beginning of the experiment was considered high at the 0-20cm depth and medium at the 20-40 cm depth (Table 9), according to Raij (1997). The small effect of potassium fertilization can also be attributed to the slow response that perennial crops, such as grapevines, have in relation to mineral fertilization. In addition, grapevines may respond differently to specific soil K concentrations depending on cultivar, vigour, and agricultural production (Mpelasoka et al., 2003). Ciotta et al. (2021) assessed different K doses (i.e. 0, 50, 100, 150 e 200 kg ha^{-1} K_2O) and did not observe any significant effects on the production and chemical composition of grape must in 'Cabernet Sauvignon'. In terms of K replacement in soil, Table 8 shows that the 150 kg ha^{-1} K_2O is the ideal dose for maintaining the soil K level after each production cycle, which is in line with recommendations made by Terra et al. (1997) for grapevines. However, Ciotta et al. (2021) verified the adequate dose of 100 kg ha^{-1} K_2O to maintain K availability in 'Cambisolo Humico' soil after each production cycle. Therefore, once more is emphasized that recommendations must be made according to previous soil analysis, soil properties, crop conditions and management practices adopted. Thus, using adequate K doses will reduce common matters that easily affect grapevine production, such as leaching, the lack of K (< 1.6 $mmol_c dm^{-3}$) and the excess of K (> 6.0 $mmol_c dm^{-3}$). K deficiency impacts on the formation of smaller bunches and berries, greater acidity, and less soluble solids content. (Morris and Cawthon, 1982; Kliewer et al., 1983; Fráguas and Silva, 1998), while K in excess promotes a nutritional imbalance that can cause dryness of the rachis due to less absorption of calcium and magnesium (Tagliavini et al., 1996). In addition, inadequate potassium fertilization raises the cost of production and can cause greater environmental damage.

Materials and methods

Experimental location and growing conditions

The current study was conducted in an experimental vineyard in Botucatu, São Paulo, Brazil (latitude 22° 50'S, longitude 48°26'W at 790 m above sea level) during two consecutive seasons (2016 and 2017). According to the Köppen classification, the climate is type *Cfa*, i.e., humid subtropical climate. Throughout the study, the average minimum temperature dropped down to 16.4 degrees Celsius, while average maximum temperature went up to 26.2 degrees Celsius. Moreover, average rainfall was 1712 mm, but the precipitation tended to get more concentrated during summertime. The soil in the experimental area was classified as Nitossolo Vermelho (Embrapa, 2018). Soil chemical analysis was conducted for the area initial's characterization, before running the current experiment (Table 9). In September 2013, grapevine seedlings grafted on to rootstocks were planted at a spacing of 2.0 m between rows and 0.8 m between plants, that is, a density of 6,250 plants per hectare. The plants were conducted through an vertical shoot position system with three wire strands that were located at 1.0, 1.3 and 1.6 m above the ground. Furthermore, the inverted micro sprinklers were used every 2.5 meters and 50 cm from the ground for irrigation. Also, a plastic netting made of polyethylene (HDPE) with 18% sunshade was installed against birds. Besides that, other cultural and phytosanitary management practices were carried out according to the local standard practices. In 2016 and 2017, production pruning happened in July and harvests in December. Therefore, one to two buds were kept per spur in every production pruning and, then, 2.5% hydrogen cyanamide was applied to induce sprouting by providing a uniform budding. After sprouting began, 10 to 12 production bunches were selected per plant to standardize the grapevines.

Treatments and experimental design

This study was developed, using an experimental design in randomized blocks, factorial scheme 4 x 2 x 2 (16 treatments), with 2 blocks and 5 plants per plot, i.e. 160 plants. The factors consisted of four potassium doses of K (0; 75; 150 and 300 kg ha^{-1} K2O), two potassium fertilizers (KCl and K_2SO_4) and two rootstocks ('IAC 572 Jales' and 'IAC 766 Campinas'). 'Niagara Rosada' was the chosen scion, that is, a mutant from cv. Niagara Branca, obtained from a cross between Concord and Cassady cultivars, the genealogy presents 75% *Vitis labrusca* and 25% *Vitis vinifera*. The rootstocks came from Agronomic Institute of Campinas (IAC), they were originated from the following crosses: 'IAC 572 Jales' (*Vitis caribaea* × [*Vitis riparia* × *Vitis rupestris* 101-14]) and 'IAC 766 Campinas' (Riparia do Traviú × *Vitis caribaea*). In this study, KCl and K_2SO_4 were used as potassium sources, they present about 60 and 51% K_2O in their compositions, respectively. K doses followed fertilization recommendations for grapevines in the specific region (Terra et al., 1997). Furthermore, treatments consisted of without fertilization (control), half of the recommended dose (75 kg ha^{-1} of K_2O), recommended dose (150 kg ha^{-1} of K_2O) and twice the recommended dose (300 kg ha^{-1} of K_2O). The fertilizer was proportionally weighed according to plot areas (8m^2 per plot) and applied via topdressing in 40 cm range beside the grapevines. In each production cycle, fertilization was divided into two plots, that is, half of the dose applied one week after production pruning and the remainder at the beginning of the bunches maturation.

Characteristics evaluated

Grape harvest was determined according to the maturation curve, when there was stabilization in the content of soluble solids and titratable acidity in the interval between two samples.

At harvest, the number of bunches per vine was counted and, then, the mass, production per plant (kg/vine) was obtained. Besides that, yield (t ha^{-1}) was estimated as a function of production per vine and planting spacing, considering a density of 6,250 plants per hectare.

The physical characteristics of bunches and berries were evaluated according to their masses (g) on an analytical precision scale (± 0.01 g), in addition to length (cm) and width (cm) by using a graduated ruler. Also, the number of berries per cluster was counted. For these evaluations, 10 bunches were selected per plot and 10 berries were collected from each bunch, that is, a total of 100 berries per plot. In grape must, the chemical characteristics were analysed through the content of soluble solids (SS, expressed in °Brix), titratable acidity (TA, expressed as percentage of tartaric acid), pH and maturation index (SS/TA).

SS was determined by direct refractometry of the grape must in a digital refractometer (Reichert®, Buffalo, NY, EUA). TA was obtained by adding 0.1 NaOH from buret to pH 8.2 endpoint. The pH was detected by direct reading in potentiometer (Tecnal®, Piracicaba, SP, Brazil).

The total phenolic compounds, total flavonoids, monomeric anthocyanins, and antioxidant capacity were analysed in both pulp and peel.

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

The antioxidant activity was measured by two methods, that is, using 2,2-diphenyl-1-picrylhydrazyl (DPPH), according to Brand-Williams et al. (1995), with results expressed in mg of Trolox per 100 g. The second method was the FRAP (Ferric Reducing Ability of Plasma), described by Benzie and Strain (1996) and results expressed in mM $FeSO_4$ per kg.

During the full-bloom of grapevines, the leaves were collected for leaf diagnosis by selecting the first ripe leaf from apex to base, which coincides with the opposite to the first bunch. Therefore, 10 leaves were collected per experimental plot. After sample preparation, the leaf potassium concentration was measured in g kg^{-1}, following the methodology described by Malavolta et al. (1997).

To check the variation of K availability in soil to estimate K replacement after each production cycle, ΔK was calculated in $mmol_c dm^{-3}$ at the following depths 0-20cm and 20-40cm, through the equation: ΔK = exchangeable K content after the production cycle - exchangeable K content before the production cycle. The chemical analyses of the soil were carried out following the methodology proposed by Raij et al. (2001).

Statistical analysis

Statistical analyses were performed with averages between two production cycles (2016 and 2017). Data were subjected to analysis of variance (three-way ANOVA) to determine the effects of rootstocks, K sources, K doses and their interactions. For rootstocks and K sources, the average comparison was performed using Tukey test at 5% probability. To quantify the effects of K doses, the regression analysis was performed. For this, statistical program used was the SISVAR®, version 5.6 (Lavras, MG, Brazil).

Conclusions

'IAC 572 Jales' and 'IAC 766 Campinas' rootstocks enabled great yields to 'Niagara Rosada' grapevine in subtropical conditions. However, 'IAC 766 Campinas' can be recommended as it provided a higher concentration of total flavonoids and anthocyanins, that is, better grape quality.

KCl provided a higher concentration of total flavonoids and anthocyanins to the grapes in relation to K_2SO_4 and did not cause any toxicity to the grapevines until the dose of 300 kg ha^{-1} K_2O. Furthermore, KCl and K_2SO_4 showed a similar effect with regards to maintaining K availability in soil.

In a soil with high K availability, potassium fertilization did not influence the production performance of the grapevines. Annual fertilization with approximately 150 kg ha^{-1} K_2O is estimated to maintain K availability in soil after each production cycle.

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