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Training systems improved agronomic characteristics and quality of 'Niagara Rosada' table grapes

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ABSTRACT: Vines are highly responsive to agricultural management techniques, such as training systems. Three training systems, i.e., conventional, high, and double training, for the 'Niagara Rosada' vine were studied considering aspects related to the yield, physicochemical, and antioxidant characteristics of the grapes. The experiment was carried out during two seasons (2017 and 2018), and the vines grafted on IAC 572 Jales. The training systems did not influence the fruit production per vine and yield of the 'Niagara Rosada' table grape, but some improvements were observed, such as a greater number of berries per bunch in vines managed in the conventional training systems and a higher fresh mass of berries when cultivated in the high and double training systems. Grapes from the double training system had higher soluble solids contents, an important sensorial characteristic in table grapes. The high training system, in turn, provided 'Niagara Rosada' table grapes with a greater content of bioactive compounds (e.g., phenolic compounds, flavonoids, and anthocyanins) and antioxidant activity.

Key words: *Vitis* spp., vertical shoot positions, bioactive compounds, antioxidant activity.

INTRODUCTION

Grape production in Brazil in 2021 was 1.7 million tons, with a planted area of 75,086 hectares (IBGE 2022). Notably, of total grape production, 51% was destined for processing and 49% for table use, with 30% of the total volume of table grapes corresponding to 'Niagara Rosada' fruits (Carvalho et al. 2019). The vine is grown in several countries around the world, where *Vitis vinifera* L. (European grapes) and *Vitis labrusca* L. (American grapes) stand out. The 'Niagara Rosada' table grape, a mutation of the Niagara Branca grape, was described in Brazil as a result of a cross between Concord (*V. labrusca* L.) and Cassady (*V. labrusca* × *V. vinifera*) grapes. The genealogy of 'Niagara Rosada' presents 75% of *V. labrusca* L. and 25% of *V. vinifera* L. (Maia and Camargo, 2012) and is a table grape cultivar called rustic or common, as it is less demanding in terms of cultural practices, tolerant to fungal diseases and adapted to hot and humid climates (Callili et al. 2022).

Viticulture in Brazil, mainly the cultivation of 'Niagara Rosada', can show changes in the productive potential due to factors such as climate and management technologies. Because vines have a climbing habit, the use of support systems for plant branches is an essential factor in the production and quality of grapes. The choice of support system should allow intensive cultivation with severe pruning and definition of the plant's canopy architecture (Maia and Camargo, 2012), which directly interferes with the interception of solar rays, plant vigor, and canopy microclimate (Lira et al. 2017). In addition, the photosynthetic rate of leaves (Sanchez-Rodriguez et al. 2016) may vary, directly affecting the volume and quality of production (Leão and Chaves 2021).

There are several systems used to support the vine, and the choice must be based on the edaphoclimatic conditions, the topography of the area, economic aspect and profitability, rootstock/scion ratio, and production objective. Rustic or fine grapes grown in systems such as trellis and Y usually have higher fruit yield per vine and yield due to the greater vegetative canopy (Marcon et al. 2020). Although these systems enhance the vigor of the canopy, they can reduce the quality of the berries (Leão and Chaves 2021). The espalier is a vertical support system that was consolidated due to its simple construction and low cost, allowing greater planting density and vertical accommodation of the productive branches during their growth (Maia and Camargo 2012). Some variants of this system, such as high espalier and double espalier, caused by the spacing between wires, can also promote improvements in the productive aspects and quality of grapes and their by-products (Domingues Neto et al. 2023, Simonetti et al. 2021).

In addition to these mentioned factors, crop management can also change the content of bioactive compounds in grapes (Callili et al. 2022). 'Niagara Rosada' grapes have been described to contain compounds with antioxidant potential, mainly polyphenols. Peels and pulps have considerable contents of anthocyanins, phenolic acids and phenolic alcohol in fresh fruits and flour (Gomes et al. 2021, Monteiro et al. 2021).

This work aimed to characterize the 'Niagara Rosada' vine grown in training systems in an agronomic way, considering the productive aspects and the physicochemical and bioactive characteristics of the grapes.

MATERIAL AND METHODS

The grapevine 'Niagara Rosada' (*Vitis labrusca* L. × *Vitis vinifera* L.) grafted onto the IAC 572 Jales (*Vitis tiliaefolia* × [*V. riparia* × *V. rupestres*]) was assessed. The experiment was carried out in two seasons (2017/2018), in São Manuel, São Paulo, Brazil (22°44'S and 48°34'W, 740 m a.s.l.). The vineyard was implanted in 2014 by planting the rootstocks spaced at 0.8 m between vines and 2 m between rows (6,250 vines.ha^{-1}), trained on a bilateral cordon system. Fertilization was carried out according to soil analysis results and recommendations for the crop. The climate, according to the Köppen classification, is humid subtropical (Cfa). Rainfall is concentrated from November to April, with average annual precipitation and temperature of 1,465 mm and 20.8 °C, respectively (Alvares et al. 2013). The vines were irrigated using a drip system. The soil of the experimental unit was classified as dystrophic Red Yellow Latosol (Embrapa 2006).

The evaluations are carried out in two seasons, cycle I and cycle II. In cycle I, winter pruning was carried out in July and harvest in November, with the total duration of 130 days. In cycle II, production pruning occurred in July and the harvest in December, and the cycle is 145 total days.

The treatments consisted of three training systems: conventional training (Fig. 1a), high training (Fig. 1b), and double training (Fig. 1c). The experiment was carried out with a randomized block design, with three treatments and eight repetitions, totaling 24 plots, with six vines each. The conventional training system consists of three wires, placed at 0.9, 1.3, and 1.7 m above the ground. In the high shoot position, a wire was added at the end of the installation, i.e., 2.1 m above the ground. The double training consists of three wires placed at 0.9, 1.4, and 1.9 m above the ground.

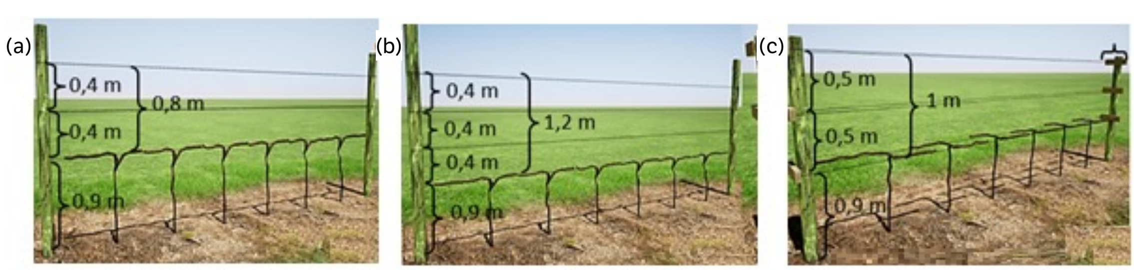

Figure 1. Types and dimensions of training systems for vines: (a) conventional training, (b) high training and (c) double training system.

At harvest, fruit yield per vine was determined by the mass of bunches in each plot, and the value divided by the number of plants, and the estimate of yield was expressed in t ha-1, from the product of fruit yield per vine by the density of plants per hectare.

Ten bunches from each experimental plot were used to determine the fresh mass (g), length (cm), and width (cm). In ten berries per bunch, the fresh mass, length, and width of the berries were determined. After removing all the berries from the bunches, the fresh mass, length, and width of the rachis were determined. The number of berries per bunch was determined by subtracting the mass of the bunch from the mass of the rachis and the value divided by the mass of the berry. The number of bunches per plant was estimated by counting the bunches on the vines before harvesting. In the must of 100 berries from each treatment, obtained by manual pressing, the contents of soluble solids (°Brix), pH, and titratable acidity (% tartaric acid·100 g^{-1} of grape) were determined (Zenebon et al. 2008). The maturation index was calculated by dividing the soluble solids content by the titratable acidity. The reducing sugar content was determined according to Nelson (1944) and expressed as a percentage.

For the determination of bioactive compounds, 100 g of berry flesh from each replicate was ground in liquid nitrogen. Samples were homogenized in acidified methanol 80:19:1 (v/v/v), vortexed for 1 min, and centrifuged at 4,500 rpm at 5 °C for 7 min.

Total phenolic compounds (mg of gallic acid equivalent to 100 g^{-1} grapes) were determined using Folin–Ciocalteu reagent (Singleton and Rossi 1965). The total flavonoid content (mg quercetin equivalent·100 g^{-1} grapes) was determined according to Popova et al. (2004). The total monomeric anthocyanin content (mg cyanidin 3-glucoside equivalent 100·g^{-1} grapes) was determined by the pH-differential method (Giusti and Wrolstad, 2001). The in-vitro antioxidant activity was analyzed by reduction of the 2,2-diphenyl-1-picrylhydrazyl radical (DPPH) and expressed in milligrams equivalent Trolox g^{-1} (Brand-Williams et al. 1995) and by Fe reduction (FRAP) (Benzie and Strain 1996) in mg Fe^{2+}·g^{-1}.

Data from the two seasons were submitted to analysis of variance (ANOVA) and means compared by Tukey's test at a 5% probability, using SISVAR program version 5.4. Principal component analyses (PCA) were performed using the XLSTAT software (version 2017; Addinsoft, France).

RESULTS AND DISCUSSION

A higher number of clusters per vine (13.22) was observed in the double training system, compared to the conventional (12.71) and high (12.53) training systems (Table 1). In grapevines, the number of bunches per vine varies between eight (Silva et al. 2018) and 25 (Sanchez-Rodriguez and Sposito 2020). In our study, the training system influenced the number of bunches, resulting in a greater vegetative canopy and more productive branches, also affecting the bud fertility (Botelho et al. 2006) and, consequently, the greater number of bunches per plant (Table 1).

Table 1. Productive characteristics of 'Niagara Rosada' cultivated on different training systems.

	Seasons	Vertical shoot position			
		Conventional	High	Double	p-value
Number of berries per bunch	I	67.27*	59.66	54.71	
	II	61.71	58.47	60.41	
	Mean	64.49 a	59.06 b	57.56 b	< 0.001
Number of bunches per vine	I	12.68	12.71	13.11	
	II	12.75	12.34	13.32	
	Mean	12.71 b	12.53 b	13.22 a	< 0.001
Fruit yield per vine (kg/vine)	I	3.84	3.57	3.55	
	II	3.51	3.56	3.57	
	Mean	3.68ns	3.57	3.56	0.2017
Yield (t·ha^{-1})	I	24.02	22.34	21.77	
	II	21.96	22.29	22.35	
	Mean	22.99^{ns}	22.32	22,06	0.3696

*Data are means from 2017 (I) and 2018 (II) seasons. Values followed by different letters in the within line differ significantly (Tukey test, $p < 0.05$); ns: not significant.

In the conventional training system, there was a greater number of berries per bunch compared to the other double training system (Table 1). The number of berries per bunch is an important parameter in the productive aspect of vines and can be influenced by several factors during plant management, including the training system (Simonetti et al. 2021).

Production per vine and yield were not affected using training systems (3.7 kg per vine and 23 t·ha^{-1}, respectively) (Table 1). Despite these results, the values are above the average yield of 'Niagara Rosada' cultivated in the region of Jundiaí, São Paulo, Brazil (14 to 15 t·ha^{-1}) (Maia and Camargo 2012). These results may be attributed to similar data found for the mass, length, and width of the bunch, length and width of the berry, and length and mass of the rachis (Table 2). In this study, we have noticed that the training system used did not influence the main physical characteristics of 'Niagara Rosada' bunches and berries.

Table 2. Physical characteristics of bunch, berry and rachis of 'Niagara Rosada' cultivated on different training systems.

	Seasons	Vertical shoot position			p-value
		Conventional	High	Double	
Bunch mass (g)	I	303.87*	281.68	267.03	
	II	277.36	280.74	269.38	
	Mean	290.62^{ns}	281.21	268.20	0.0446
Bunch length (cm)	I	16.45	14.95	14.58	
	II	14.44	14.73	15.08	
	Mean	15.72^{ns}	14.84	14.83	0.2234
Bunch width (cm)	I	9.08	9.05	8.61	
	II	8.39	8.81	8.84	
	Mean	8.72^{ns}	8.93	8.73	0.4919
Berry mass (g)	I	3.94	4.20	4.31	
	II	4.02	4.25	3.97	
	Mean	3.98 b	4.21 a	4.14 ab	< 0.001
Berry length (cm)	I	2.08	2.12	2.09	
	II	2.09	2.11	2.00	
	Mean	2.08^{ns}	2.12	2.05	0.0399
Berry width (cm)	I	1.84	1.82	1.87	
	II	1.82	1.85	1.80	
	Mean	1.83^{ns}	1.84	1.86	0.8617
Rachis mass (g)	I	10.35	7.64	7.76	
	II	7.51	7.66	8.01	
	Mean	8.93^{ns}	7.65	7.88	0.0749
Rachis length (cm)	I	12,72	12,90	11,81	
	II	11,35	12,36	12,42	
	Mean	12.19^{ns}	12.70	12.06	0.2469
Rachis width (cm)	I	7,30	6,47	6,15	
	II	6,55	6,29	6,49	
	Mean	7.04 a	6.36 b	6.24 b	< 0.001

*Data are means from 2017 (I) and 2018 (II) seasons. Values followed by different letters in the within line differ significantly (Tukey test, $p < 0.05$); ^{ns}: not significant.

The conventional training system provided grapes with less berry mass (Table 2), considering that, in this system, the production branches are shorter compared to the other training systems, with fewer leaves and, consequently, less distribution of photoassimilates to fruits (Domingues Neto et al. 2023). On the other hand, in the conventional training system, the rachis was wider. The rachis is where the berries attach, and, consequently, the greater the rachis structure, the better the coverage distribution and efficiency in the application of phytosanitary products and plant regulators, which provide greater health quality to the bunches (Roberto et al. 2015).

As a table grape, the 'Niagara Rosada' grape must present a harmonious balance between sugars, pH, and acidity, as they are sensory quality indicators of the fruit and guarantee the appreciation of the consumer market (Maia and Camargo 2012). The treatments did not influence neither the pH, total acidity of the must or the maturation index, nor the reducing sugar content (Table 3). In the vines grown on a double training system, the soluble solids content (16.73 °Brix) was higher than that of the other conventional and high training systems and higher than recommended for the cultivar in Brazilian legislation, which determines values above 14 °Brix. The canopy volume influences the synthesis and assimilation of sugars (Sanchez-Rodriguez and Sposito 2020), and in this study, there was an influence on the soluble solids content of the grapes grown in a double training system. Although grapes grown on high training systems present a greater vegetative canopy, it is a system that requires higher amounts of sugars and water from the plant for vegetative development and may reduce the contents in the berries (Sabbatini et al. 2015).

Table 3. Physicochemical characteristics, bioactive compounds and antioxidant activity of 'Niagara Rosada' cultivated on different training systems.

	Seasons	Vertical shoot position			p-value
		Conventional	High	Double	
Soluble solids (°Brix)	I	15.94*	15.89	16.68	
	II	16.14	15.94	16.78	
	Mean	16.04 b	15.92 b	16.73 a	< 0.001
pH	I	3.22	3.25	3.27	
	II	3.24	3.26	3.28	
	Mean	3.23^{ns}	3.24	3.26	0.2279
Titratable acidity (%)	I	0.90	0.93	0.98	
	II	0.99	0.96	1.05	
	Mean	0.95^{ns}	0.95	1.02	0.7635
Maturation index (SS/TA)	I	18.55	17.44	17.52	
	II	17.24	17.03	16.05	
	Mean	17.89^{ns}	17.24	16.78	0.8231
Reducing sugars (%)	I	14.95	14.73	15.15	
	II	14.78	14.42	15.30	
	Mean	14.86^{ns}	14.57	15.22	0.3282
Total phenolics (mg 100 g^{-1})	I	234.98	316.09	180.91	
	II	235.14	326.44	247.89	
	Mean	235.06 b	321.27 a	214.4 c	< 0.001
Total flavonoids (mg 100 g^{-1})	I	86.26	109.66	59.88	
	II	86.31	112.57	76.16	
	Mean	86.29 b	111.11 a	68.02 c	< 0.001
Total anthocyanins (mg 100 g^{-1})	I	10.52	13.50	7.13	
	II	11.76	13.68	10.36	
	Mean	11.14 b	13.59 a	8.75 c	< 0.001
Antioxidant activity FRAP (mg·g^{-1})	I	238.89	308.78	164.43	
	II	240.26	316.07	238.30	
	Mean	239.58 b	312.43 a	201.37 c	< 0.001
Antioxidant activity DPPH (mg·g^{-1})	I	17.38	19.11	12.78	
	II	17.66	19.15	17.41	
	Mean	17.52 b	19.13 a	15.09 c	< 0.001

*Data are means from 2017 (I) and 2018 (II) seasons. Values followed by different letters in the within line differ significantly (Tukey test, $p < 0.05$); ^{ns}: not significant; SS: soluble solids; TA: titratable acidity; FRAP: antioxidant activity; DPPH: antioxidant activity.

The double training system was the one that least favored the content of phenolic compounds in the berries. Double training systems have a doubling of the canopy, which may result in greater shading due to the greater vegetative canopy, affecting the synthesis of bioactive compounds and anthocyanin pigments in red grapes (Table 3). In grapes, the antioxidant activity is directly linked to the phenolic composition and may be influenced by genetic inheritance, as well as by the management carried out during the production cycle (Callili et al. 2022). In this study, the high training system positively influenced the level of phenolic compounds, including total flavonoids and total anthocyanins, reflecting on the antioxidant activity. The high training system also promoted greater antioxidant activity by the FRAP and DPPH methods in *V. labrusca* (cv. Isabel) and hybrid (cv. Bordô, IAC 138-22 Máximo and BRS Violeta) grape juices (Domingues Neto et al. 2023).

Fruits with higher levels of bioactive compounds have attracted the attention of consumers, and the results of this study may collaborate with producers who, in addition to increasing yield, may offer a product with higher antioxidant quality. 'Niagara Rosada' presents several phenolic compounds that influence not only the bioactive quality, but also help maintain post-harvest quality, as they eliminate free radicals produced by the oxidative stress that occurs during storage (Gomes et al. 2021).

To establish a descriptive model for grouping the results based on production data and yield as well as physicochemical, and biochemical characteristics of the 'Niagara Rosada' grapes as a function of the training system, PCA was applied to the dataset, which explained 100% of the data variance (Fig. 2). Fruit yield per vine and yield were grouped in PC1+ and PC2+, but they were not correlated with any of the training systems since there was no significant difference (Table 1). The loadings show that soluble solids, pH, reducer sugar, and total acidity were more associated with the double training system (PC1+, explaining 59.62% of the data).

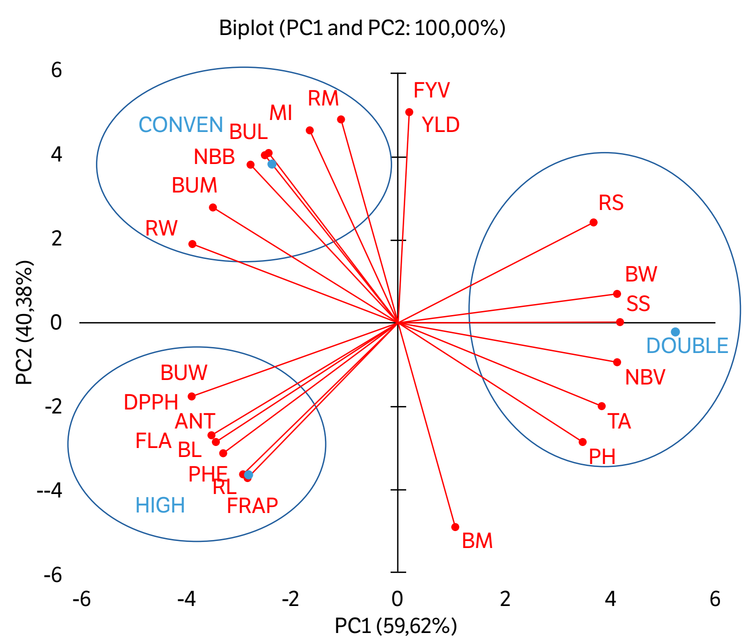

Figure 2. Two-dimensional projection and scores from BUM: bunch mass. BUL: bunch length. BUW: bunch width. BM: berry mass. BL: berry length. BW: berry width. RM: rachis mass. RL: rachis length. RW: rachis width. NBB: number of berries per bunch. NBV: number of bunches per vine FYV: fruit yield per vine. YLD: yield. SS: soluble solids. pH: pH. TA: titratable acidity. MI: maturation index. RS: reducing sugar. ANT: anthocyanins. PHE: total phenolic compounds. DPPH: antioxidant activity. FRAP: antioxidant activity. FLA: total flavonoids of 'Niagara Rosada' cultivated in conventional training system (CONVEN), high training system (HIGH) and double training system (DOUBLE).

Fruits from the conventional training system that presented higher bunch mass, number of berries per bunch, bunch length, and rachis width were grouped in PC1- and PC2+. Bioactive compounds (phenolics, flavonoids, anthocyanins, and antioxidant activity), as well as bunch width, berry length, and rachis length, were grouped in PC1- and PC2- and are results of the high training system. The vine is a liana with a climbing habit, requiring guidance. Although the conventional training system is the most used vertical support in 'Niagara Rosada' vines, the results of this study show the potential of other options (e.g., high, and double training systems), mainly in the quality and bioactive composition of the berries.

CONCLUSION

The training systems (conventional training, high training, and double training) did not influence the production per vine and yield of the 'Niagara Rosada' table grape. The conventional training system provided more berries per bunch, which is an interesting result for commercialization. The high and double training systems result in bunches with a greater mass of berries, emphasizing that the double training provides sweeter berries, and a high training system is the best to produce fruits with high antioxidant quality.

AUTHORS' CONTRIBUTION

Conceptualization: Pimentel Júnior, A. and Tecchio, M. A.; **Data curation:** Pimentel Júnior, A., Domingues Neto, F. J. and Monteiro, G. C.; **Formal analysis:** Pimentel Júnior, A., Lima, G. P. P. and Tecchio, M. A.; **Funding Acquisition:** Lima, G. P. P. and Tecchio, M. A.; **Investigation:** Pimentel Júnior, A., Domingues Neto, F. J. and Monteiro, G. C.; **Methodology:** Monteiro, G. C., Lima, G. P. P. and Tecchio, M. A.; **Project Administration:** Pimentel Júnior, A. and Tecchio, M. A.; **Resources:** Lima, G. P. P. and Tecchio, M. A.; **Visualization:** Pimentel Júnior, A.; Basílio, L. S. P.; Lima, G. P. P. and Tecchio, M. A.; **Writing – Original Draft:** Pimentel Júnior, A., Domingues Neto, F. J., Lima, G. P. P. and Basílio, L. S. P.; **Writing – Review and Editing:** Basílio, L. S. P., Lima, G. P. P. and Tecchio, M. A.

DATA AVAILABILITY STATEMENT

All dataset were generated and analyzed in the current study.

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