CROP PRODUCTION

Training systems, rootstocks and climatic conditions influence quality and antioxidant activity of 'BRS Cora' grape

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ABSTRACT. Environmental and production factors might affect grapevine physiology. Estimating these effects is essential for planning the harvest and predicting the quality of grapes. The aim of this study was to characterize the quality and antioxidant potential of 'BRS Cora' grapes with different training systems and rootstocks in production cycles of the second half of the year under tropical conditions. The experimental design was randomized blocks with sub-subdivided plots over time. Three training systems and two rootstocks were studied in production cycles referring to the second halves of 2017 and 2018. In 2017, the grapes of plants trained with lyre and vertical shoot positioning (VSP) had the highest soluble solids and sugars contents, and in 2018, this response occurred with the overhead trellis system. There was lower variation in titratable acidity between cycles of grapevines trained with VSP and lyre, as well as in those grafted onto 'IAC 572'. In 2018, lyre with 'IAC 572' promoted higher pigment accumulation. Climatic conditions in 2017 provided a higher accumulation of polyphenols and antioxidant activity in grapes of plants trained with lyre with 'IAC 766'. The efficiency of the training system within each cycle, associated with the effect of the rootstock, resulted in differentiated responses according to climatic conditions.

Keywords: hybrid grapes; phenolic compounds; principal component analysis; production system; tropical vitiviniculture.

Introduction

The Submedium São Francisco River Valley is one of the most important grape-producing regions in Brazil. According to Köeppen, the climate in that region is classified as Bswh, corresponding to a very hot semiarid region (Leão, Nunes, & Lima, 2016). Such climatic conditions distinguish this region from other grape-producing regions (Leão, Rego, Nascimento, & Souza, 2018). Due to the high incidence of solar radiation and high temperatures, grapevines do not undergo dormancy, which leads to continuous growth. This behaviour, when associated with irrigation, results in at least two harvests per year (Ribeiro, Lima, & Alves, 2012), with potential differences between them regarding grapevine yield and chemical composition of the berries.

Over the previous years, the juice-making segment has become quite important in this region, and the grape cultivars 'Isabel Precoce', 'BRS Cora', 'BRS Violeta', and 'BRS Magna' are the basis of its production (Leão et al., 2018). The 'BRS Cora' hybrid cultivar has been commonly used for elaboration and colour enrichment of juices, as it has an agreeable flavour, which is typical of *Vitis labrusca* L. grapes, and a strongly coloured must. With the great viticulture potential of the Submedium São Francisco River Valley, in addition to improving the important attribute of colour that contributes to grape juice quality, 'BRS Cora' also helps increase the contents of phenolic compounds and organic acids in juice (Ribeiro et al., 2012).

To improve grape quality and, consequently, the quality of grape products, several cultural practices, such as the correct choice of the training system and rootstock, are used to adjust the balance between the vegetative and productive parts of the plant. Therefore, vegetative canopy management allows for greater vineyard exposure to sunlight and aeration, thus offering a suitable microclimate for increased quality and phenolic composition of grapes (Leão et al., 2016).

The aim of this study was to characterize the quality and antioxidant potential of 'BRS Cora' grapes under tropical conditions with different training systems and rootstocks in production cycles of the second halves of two years (2017 and 2018).

Material and methods

Characteristics of the experimental area

The experiment was conducted in Petrolina, Pernambuco (09º09' S, 40º22' W, 376 m of altitude) at a vineyard that was created in December 2015. The climate in the region is tropical, semiarid, hot and dry, with a rainy season from January-April, mean annual rainfall of 503 mm, relative air humidity of 64%, mean temperature of 26.1°C, global solar radiation of 18 MJ m^{-2} day^{-1}, wind speed of approximately 2 m s^{-1}, and reference evapotranspiration of 7 mm day^{-1} (Embrapa Semiárido, 2015). Plants in the experimental area were trained with three training systems (overhead trellis, lyre, and vertical shoot positioning - VSP, all with 3.0 x 1.0 m spacing) and two rootstocks (IAC 572 and IAC 766). Cultural practices followed the recommendations for regional viticulture (Soares & Leão, 2009), with daily dripping irrigation and a varied irrigation rate according to meteorological data collected each day. Climatic data observed during the experimental period are shown in Table 1.

Table 1. Monthly meteorological data in the Experimental Field of Bebedouro/Embrapa Semiárido during the production cycles ranging from July 4 to October 25, 2017, and June 25 to October 9, 2018, referring to production cycles of the second half of the year, when the quality of 'BRS Cora' grape berries was studied under the influence of different training systems and rootstocks.

Month	T (°C)			RH	Rad.	Ws	Rainfall	ET0
	Mean	Max.	Min.	(%)	(MJ m^{-2} dia^{-1})	(m s^{-1})	(mm)*	(mm dia^{-1})
July to October 2017 (Production Cycle 1)								
July/2017	22.9	28.4	17.6	69.0	15.1	3.2	4.7	4.4
Aug/2017	25.1	31.8	19.1	64.7	21.5	2.7	0.6	5.7
Sep/2017	24.1	30.7	18.5	68.7	20.2	3.5	11.9	6.0
Oct/2017	27.9	34.9	21.7	65.6	25.3	3.5	0.0	7.6
Mean	25.0	31.45	19.2	67.0	20.5	3.2	4.3	5.9
June to October 2018 (Production Cycle 2)								
June/2018	25.4	32.4	19.4	72.6	19.1	2.2	0.7	4.6
July/2018	25.0	31.8	18.9	66.3	20.1	2.4	0.4	4.9
Aug/2018	26.0	33.3	19.5	62.0	23.8	2.5	0.0	5.9
Sep/2018	27.6	34.8	21.1	56.7	26.0	2.7	0.0	6.9
Oct/2018	28.5	35.9	22.8	62.6	25.7	2.2	9.1	6.7
Mean	26.5	33.6	20.3	64.0	22.9	2.4	2.0	5.8

Mean T. = mean temperature; T. Max. = maximum temperature; T Min. = minimum temperature; RH = relative humidity; Rad = global solar radiation; Ws = wind speed at a 2.0 m height; Rainfall = accumulated rainfall; ET0 = reference evapotranspiration. *Total monthly rainfall. Source: Agrometeorological Station of Bebedouro, Petrolina, Pernambuco State, Brazil - Embrapa Semiárido (2018).

Treatments and experimental design

'BRS Cora' grapevines were trained with three training systems (overhead trellis, lyre, and VSP) and grafted onto two rootstocks, 'IAC 572' and 'IAC 766'. Two production cycles were evaluated in the second halves of two years: cycle 1 - from July 4, 2017 (pruning) to October 25, 2017 (harvest); cycle 2 - from June 25, 2018 (pruning) to October 9, 2018 (harvest).

The experimental design was randomized blocks in plots that were sub-subdivided through time; the plots were represented by training systems, subplots corresponded to rootstocks, and sub-subplots corresponded to production cycles. Four replicates of five plants were used. Ten bunches were collected from each experimental plot for the analysis.

Analysis of quality components

The quality components evaluated were as follows: bunch weight (g); berry weight (g); berry resistance to compression (N); skin colour attributes, which were luminosity (L), a* (variations in red and green), and b* (variations in yellow and blue); titratable acidity (g of tartaric acid 100 mL^{-1}); soluble solid content (°Brix); and total soluble sugar content (g 100 g^{-1}).

Bunch weight was determined by the mean value of ten bunches measured using a semi-analytical precision scale model VI 2400 (Acculab, Florida, USA), and berry weight was the mean weight value of fifty berries sampled from these bunches using the same scale.

Skin colour attributes, L, a*, and b*, were measured using a digital colorimeter (Konika Minolta, model CR-400) in twenty representative berries collected from the upper, median, and lower regions of ten bunches from each experimental plot.

To measure berry resistance to compression, twenty berries were used, which were evenly detached from bunches making up the experimental unit. The required strength to cause compression to 20% of the berry volume was measured using an Extralab TA.XT.Plus texture analyser (Stable Micro Systems, Surrey, UK) with a P/75 pressure plate (Ribeiro et al., 2012).

The titratable acidity was measured as described by AOAC (2010) using a digital automatic titrater with a Metrohm potentiometer 113 Titrino plus 848. The soluble solid content was determined by an ATAGO, PAL-1 digital refractometer with automatic temperature compensation, using the juice extracted from grape pulp (AOAC, 2010). Total soluble sugar contents were determined with a UV-Vis spectrophotometer (Varian, Carry 50 Bio UV-Vis model) at 620 nm with anthrone reagent (Yemn & Willis, 1954).

Analyses of phenolic compound contents and antioxidant activity

Phenolic compound contents were evaluated using yellow flavonoid and total anthocyanin contents in grape skin (mg 100 g^{-1}) and total extractable polyphenol contents in skin and pulp together (mg gallic acid 100 g^{-1}). Conversely, to determine total antioxidant activity in skin and pulp, the ABTS$^{\bullet+}$ [(2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)] and DPPH$^{\bullet}$ (2,2-dyphenyl-1-picryl-hydrazyl) free-radical capture methods were used, expressed in μM trolox g^{-1} and g g^{-1} DPPH, respectively.

Yellow flavonoid and total anthocyanin contents in grape skin were determined using the method proposed by Francis (1982) with an extraction solution composed of ethyl alcohol (95%) and HCl (1.5 N) at an 85:15 ratio. The extracts were stored in a refrigerator overnight protected from light. Yellow flavonoids and total anthocyanins were quantified the next day using a UV-Vis spectrophotometer (Varian Cary 50 Bio) at 374 and 535 nm, respectively.

To determine the total extractable polyphenol contents and antioxidant activity using the ABTS$^{\bullet+}$ and DPPH$^{\bullet}$ methods, extracts prepared from ground skin and smashed pulp were used. Methyl alcohol at 50% was used as the first extraction solution, and 70% acetone was used as the second one. Polyphenol contents were determined with Folin-Ciocalteu reagent and 20% sodium carbonate at 700 nm using a UV-Vis Varian Cary 50 Bio spectrophotometer (Larrauri, Rupérez, & Saura-Calixto, 1997).

Antioxidant activity was determined at 734 nm using a UV-Vis Varian Cary 50 Bio spectrophotometer with the ABTS$^{\bullet+}$ method following the procedure described by Miller et al. (1993) and adapted by Rufino et al. (2010). Using DPPH$^{\bullet}$, the activity was measured at 515 nm using the same spectrophotometer according to the method reported by Sánchez-Moreno, Larrauri, and Saura-Calixto (1998) and adapted by Rufino et al. (2010).

Data analysis

A normal distribution of the data was evaluated using the Shapiro-Wilk test. Data that met the normality principle were subjected to an analysis of variance, comparing the mean values of isolated effects of plots, subplots, and sub-subplots, as well as possible interactions between them using Tukey's test (p ≤ 0.05). The skin colour attribute a* did not have a normal data distribution; however, it was adjusted via $\sqrt{(x + 1)}$ transformation and then subjected to analysis of variance and data interpretation. The data that did not show a normal distribution and that could not be adjusted to any transformation were analysed using descriptive statistics, using mean values and standard deviations. Data were also subjected to principal components analysis (PCA) to evaluate the behaviour of the treatments according to the variables.

Results and discussion

Quality components

Among the quality components evaluated, bunch weight, berry weight, berry resistance to compression, and skin colour attribute b* did not have a normal distribution. In the first cycle, the highest mean value of bunch weight, 218.45 g, was obtained from plants trained with lyre and grafted onto 'IAC 766' (Table 2). In the second cycle, VSP associated with rootstock 'IAC 572' was differentiated due to its lower bunch weight, 112.12 g. It is worth noting that in plants trained with VSP and lyre, bunch weight values were higher in cycle 1 regardless of the rootstock. However, more stable values between cycles were observed with the overhead trellis system. Ribeiro et al. (2012) reported differences in bunch weight of 'BRS Cora' grapes harvested from plants trained with the overhead trellis in harvests within the same year, corresponding to different halves of the year, in Submedium São Francisco River Valley. In the period of milder temperatures,

they observed a bunch weight of 126 g, while the values were approximately 75 g in the following cycle (second half of the year).

According to the variations around mean values, differences in berry weight were observed between the rootstocks studied in cycle 1, with the overhead trellis exhibiting the highest values when associated with rootstock 'IAC 766' (Table 2). This higher yield was possibly related to the effectiveness of the overhead trellis in capturing incident light and using it via the photosynthetic pathway (Creasy & Creasy, 2009). Additionally, the influence of rootstocks on berry weight might be related to vigour, since more vigorous rootstocks such as 'IAC 572' might transmit excessive vegetative vigour to the canopy under optimal climate and soil conditions, thus negatively affecting yield and performance (Angelotti-Mendonça, Moura, Filho, Vedoato, & Tecchio, 2018). The higher yield in plants grafted onto 'IAC 766' was thus justified in the present study.

Table 2. Mean values and standard deviations of the variables bunch weight, berry weight, berry resistance to compression, skin colour attribute b*, total extractable polyphenols and antioxidant activity determined by evaluating the free radical DPPH• in 'BRS Cora' grapes, affected by the training system, rootstock, and production cycle, in the Submedium São Francisco River Valley[1].

Training system	July to October 2017 (Cycle 1)		June to October 2018 (Cycle 2)		CV (%)
	'IAC 572'	'IAC 766'	'IAC 572'	'IAC 766'	
	Bunch weight (g)				
VSP	167.37 ± 5.50	184.40 ± 8.75	112.12 ± 4.29	133.02 ± 7.15	
Lyre	201.43 ± 5.50	218.45 ± 5.50	133.13 ± 8.67	142.13 ± 12.31	5.26
OTS	132.32 ± 5.50	150.35 ± 5.50	127.39 ± 13.95	142.01 ± 13.44	
	Berry weight (g)				
VSP	2.91 ± 0.16	2.94 ± 0.24	2.80 ± 0.15	2.79 ± 0.07	
Lyre	2.81 ± 0.23	2.85 ± 0.16	2.78 ± 0.15	2.74 ± 0.19	5.76
OTS	3.15 ± 0.09	3.16 ± 0.37	2.80 ± 0.16	2.70 ± 0.19	
	Berry resistance to compression (N)				
VSP	10.64 ± 1.35	10.33 ± 1.68	10.88 ± 0.64	10.65 ± 0.43	
Lyre	11.05 ± 0.34	10.77 ± 0.61	11.02 ± 0.43	10.90 ± 0.67	5.34
OTS	11.35 ± 0.23	11.43 ± 0.37	10.30 ± 0.43	10.24 ± 0.21	
	b*				
VSP	-2.47 ± 0.79	-2.12 ± 0.56	-2.99 ± 0.53	-2.65 ± 1.15	
Lyre	-1.50 ± 0.96	-2.35 ± 0.51	-2.90 ± 0.18	-2.50 ± 0.81	23.32
OTS	-3.15 ± 0.40	-1.62 ± 0.02	-3.16 ± 0.46	-1.67 ± 0.02	
	Total extractable polyphenol content (mg gallic acid 100 g^{-1})				
VSP	129.43 ± 6.70	186.90 ± 8.96	324.32 ± 6.84	247.65 ± 8.35	
Lyre	186.90 ± 8.96	203.84 ± 9.54	282.21 ± 5.03	297.99 ± 4.10	3.20
OTS	177.33 ± 9.23	178.63 ± 9.51	293.79 ± 9.01	326.15 ± 7.10	
	Antioxidant activity by the DPPH• method (g g^{-1} DPPH)				
VSP	6117 ± 569	3408 ± 80	3649 ± 267	4034 ± 98	
Lyre	3587 ± 43	3723 ± 371	3682 ± 246	3503 ± 185	5.47
OTS	5781 ± 80	6155 ± 57	5278 ± 218	4309 ± 236	

[1]Data did not have a normal distribution with either their original values or after transformation. VSP = vertical shoot positioning; OTS = overhead trellis system; CV = coefficient of variation.

Grape cultivars for juice making with lower berry resistance to compression are more easily separated from the pedicel, which allows for a higher yield in the crushing process (Ribeiro et al., 2012). However, in the present study, berries in cycle 1 had high resistance to compression, with values ranging from 8.65 N, in grapes of plants trained with VSP and grafted onto 'IAC 766', to 11.80 N in grapes of plants trained with the overhead trellis and grafted onto 'IAC 572' (Table 2). In cycle 2, values ranged from 9.87 N in grapes of plants trained with the overhead trellis and grafted onto 'IAC 572', to 11.52 N in VSP with 'IAC 572' treatment. Ribeiro et al. (2012) reported values ranging from 2.3 to 5.08 N in different cycles for the same cultivar. Leão et al. (2016) observed values ranging from 1.87 to 2.36 N in different harvests of the 'Syrah' wine grape cultivar; the values obtained for this variable in the present study were higher than those previously reported for grapes intended for juice and wine production.

In both productive cycles, skin colour attribute b* showed variability in mean values and standard deviations according to the rootstocks. With the overhead trellis, grapes harvested from plants grafted onto 'IAC 572' had a relatively bluer coloration than those harvested from the treatment with rootstock 'IAC 766' in both productive cycles (Table 2). When rootstock 'IAC 572' was adopted, the values varied

from -2.75 to -3.55 in cycle 1 and from -2.70 to -3.62 in cycle 2. This range of values encompasses the variation observed in nearly all treatments with VSP and lyre combined for both rootstocks in both production cycles; therefore, similar responses of colour attribute b* were observed in this group of treatments. This colour attribute is indicative of the intensity of blue/violet pigmentation. Strong violet coloration is one of the most important characteristics of grape juice, and since the 'BRS Cora' cultivar was intended for this segment, more negative values were desirable for colour attribute b*. Canopy architecture in the overhead trellis system associated with the effect of rootstock 'IAC 572' on the grapevine possibly provided a higher accumulation of bluish pigments in both cycles compared to 'IAC 766', resulting in the stronger violet coloration of grape skin in this study.

Colour skin attribute L was significantly affected by training systems and production cycles separately. Berries trained with the overhead trellis were brighter (30.04) than those harvested from plants trained with the lyre (Table 3). Berries derived from the second productive cycle were brighter, with a mean value of 30.65 (Table 4). Ribeiro et al. (2012) reported berries of 'BRS Cora' grapes with a skin luminosity of 24.98 in the productive cycle referring to the second half of the year. According to the authors, low L values might result from more epicuticular wax (bloom) on berries. It is worth emphasizing that as this is a grape cultivar intended for juice making, and the skin becomes a residue after processing, the L value in the skin is not as important as it is for cultivars for *in natura* consumption.

Table 3. Luminosity skin colour attribute of 'BRS Cora' grapes in three training systems in the region of the Submedium São Francisco River Valley[1].

Vertical shoot positioning	Lyre	Overhead trellis system	CV (%)
29.53 ab	28.98 b	30.04 a	3.04

[1]Means followed by the same letter do not differ from each other using Tukey's test (p ≤ 0.05). CV = coefficient of variation.

Table 4. Luminosity (L) and a* skin colour attributes of 'BRS Cora' grapes in two different productive cycles in the region of the Submedium São Francisco River Valley[1].

	July to October 2017 (Cycle 1)	June to October 2018 (Cycle 2)	CV (%)
L	28.38 b	30.65 a	3.04
a*[2]	1.14 a	0.68 b	11.50

[1]Means followed by the same letter in the rows do not differ from each other using Tukey's test (p ≤ 0.05). [2]Variable analysed under data transformation $\sqrt{x+1}b$; CV = coefficient of variation.

There was an influence of the productive cycle on skin colour attribute a*, which refers to the intensity of red coloration; in cycle 1, the value was higher (1.14), indicating stronger red coloration of the berries (Table 4). The high incidence of solar radiation is a climatic factor that directly contributes to the increased red coloration of berries. Another factor affecting berry coloration was relative air humidity, which interferes with the synthesis of red (anthocyanic) pigments. In the presence of low relative air humidity, there is a deficit of vapor pressure, resulting in a reduction of transpiration and photosynthesis, which affects the events associated with growth and, subsequently, the accumulation of these compounds (Vogt, Pollak, Taryln, & Taylor, 1994). This assumption could confirm the reduced intensity of red coloration of berries in cycle 2, characterized by a lower relative air humidity during the maturation phase.

The soluble solid content and total soluble sugar content were affected by the interaction between training systems and production cycles (Table 5). The lyre and VSP training systems provided higher soluble solid contents in the first productive cycle of 21.8 and 21.3 °Brix, respectively, while the highest contents were observed in berries trained with the overhead trellis in the second productive cycle (21.6 °Brix). Silva et al. (2018) determined the soluble solid content of 15.9 °Brix in 'BRS Cora' grapes in an experiment in Votuporanga, São Paulo State, Brazil, a tropical climate region with a dry winter. Therefore, climatic conditions in the region of the Submedium São Francisco River Valley allow for the acquisition of grapes with high soluble solid contents, which might be differentiated when cultivated with a training system that is suitable for a given period.

The total soluble sugar contents were higher in berries trained with the lyre and VSP, with values of 20.58 and 19.67 g 100 g^{-1}, respectively, in the first productive cycle (Table 5), whereas in the second cycle, the highest value for this variable was obtained in berries cultivated with the overhead trellis. As total soluble sugars are the major constituents of soluble solids, these variables have corresponding responses. Changes in canopy structure due to training systems influence the response of the grapevine to climatic

factors that affect photoassimilate synthesis (Martínez-Lüscher et al., 2016). High temperatures and a high incidence of solar radiation might increase photosynthetic rates and carbohydrate accumulation, reflecting increased soluble solid contents and, consequently, increased total soluble sugars (Greer & Weedon, 2012). Even in a tropical semi-arid region, where high temperatures also induce increases in photorespiration, the results of this study suggest a positive photosynthesis balance. Therefore, canopy management strategies, such as the adoption of a suitable training system to promote exposure to sunlight, might help provide a suitable temperature in this portion of bunches for adequate sugar accumulation in the berries (Martínez-Lüscher et al., 2016).

Table 5. Soluble solid content, total soluble sugar content, titratable acidity and antioxidant activity determined by the free radical ABTS[•+] of 'BRS Cora' grapes cultivated under three training systems in two production cycles in the region of the Submedium São Francisco River Valley[(1)].

Training system	July to October 2017 (Cycle 1)	June to October 2018 (Cycle 2)	CV (%)
Soluble solid content (ºBrix)			
Vertical shoot positioning	21.33 aA	20.38 bB	
Lyre	21.80 aA	20.68 bAB	4.23
Overhead trellis system	19.82 bB	21.60 aA	
Total soluble sugar content (g 100 g^{-1})			
Vertical shoot positioning	19.67 aA	18.63 aB	
Lyre	20.58 aA	19.17 bAB	5.88
Overhead trellis system	18.15 bB	20.17 aA	
Titratable acidity (g tartaric acid 100 mL^{-1})			
Vertical shoot positioning	0.95 aB	1.02 aA	
Lyre	1.03 aB	1.05 aA	12.97
Overhead trellis system	1.41 aA	1.12 bA	
Antioxidant activity by ABTS[•+] (µM trolox g^{-1})			
Vertical shoot positioning	14.36 aB	15.61 aB	
Lyre	18.14 aA	15.88 aB	13.97
Overhead trellis system	14.47 bB	19.15 aA	

[(1)]Means followed by the same lowercase letter in the row or uppercase letter in the column comparing production cycles and training systems, respectively, do not differ from each other using Tukey's test (p ≤ 0.05).

Titratable acidity was influenced by the interaction between training systems and production cycles, as well as by the interaction between rootstocks and production cycles (Tables 5 and 6). A lower variation in titratable acidity was observed between production cycles in berries trained with VSP and lyre, with mean values up to 0.70 g of tartaric acid 100 mL^{-1}. Berries cultivated with the overhead trellis had a higher titratable acidity in the first production cycle (Table 5). Solar radiation and temperature are factors that also influence the degradation of organic acids because they cause an increase in respiration, leading to decreased titratable acidity (Etienne et al., 2013). The relationship between these climatic factors and the accumulation of sugars and some pigments, as well as the degradation of organic acids, might be explained by the positive regulation of structural genes, such as those encoding chalcone synthase (CHS), flavonoid *O*-methyl transferase 2 (OMT2), and glutathione-S-transferase (GST), and others that are regulatory, namely, some genes in the MYB family, such as MYBA1 and MYBF1 (Martínez-Lüscher et al., 2016).

Grapevine berries grafted onto rootstock 'IAC 572' showed a lower variation in titratable acidity between cycles when compared to those grafted onto 'IAC 766' (Table 6). Rootstock 'IAC 572' associated with the climatic conditions of the first productive cycle provided berries with lower titratable acidity: 1.06 g of tartaric acid 100 mL^{-1}. Ribeiro et al. (2012) observed a titratable acidity of 1.23 g of tartaric acid 100 mL^{-1} in 'BRS Cora' grapes in the productive cycle from the second half of the year in the region of the Submedium São Francisco River Valley. However, the authors reported that this phenomenon might have been due to signs of wilting in berries that could have caused higher concentrations of different components in the pulp. In Votuporanga, São Paulo State, Brazil, Silva et al. (2018) observed that the same cultivar showed a titratable acidity of 1.30 g of tartaric acid 100 mL^{-1}. High titratable acidity is a characteristic of 'BRS Cora' grapes. However, the climatic conditions in the Submedium São Francisco River Valley, associated with the training systems lyre and VSP and the rootstock 'IAC 572', potentially resulted in higher degradation of organic acids, thus providing specific characteristics to the grapes produced in this region. Additionally, for grape cultivars intended for juice

making, the importance of defining factors pertaining to the production system considering soluble solid accumulation potential as well as organic acid degradation is related to flavour and shelf life.

Table 6. Titratable acidity and antioxidant activity determined by determining the free radical ABTS$^{\bullet+}$ of 'BRS Cora' grapes cultivated under two different rootstocks in two production cycles in the region of the Submedium São Francisco River Valley[1].

Rootstock	July to October 2017 (Cycle 1)	June to October 2018 (Cycle 2)	CV (%)
	Titratable acidity (g tartaric acid 100 mL^{-1})		
'IAC 572'	1.06 aB	1.09 aA	12.97
'IAC 766'	1.21 aA	1.03 bA	
	Antioxidant activity by ABTS$^{\bullet+}$ (µM trolox g^{-1})		
'IAC 572'	14.39 bB	18.56 aA	13.97
'IAC 766'	16.92 aA	15.20 aB	

[1]Means followed by the same lowercase letter in the row or uppercase letter in the column, comparing production cycles and rootstocks, respectively, do not differ from each other using Tukey's test (p ≤ 0.05).

Phenolic compounds and antioxidant activity

Significant interactions were observed between training systems, rootstocks, and production cycles for the yellow flavonoid contents and total anthocyanins in skin (Table 7). As a result of the three-way interaction analysis regarding yellow flavonoid contents, grapes trained with VSP differed between production cycles when grafted onto 'IAC 572', with 47.19 mg 100 g^{-1} in cycle 1 and 38.57 mg 100 g^{-1} in cycle 2. The same behaviour was observed in grapes trained with the lyre and grafted onto 'IAC 572', and the highest contents were recorded in cycle 2. Regarding the overhead trellis system, both rootstocks caused a significant difference in the accumulation of these compounds in grapes between cycles. However, 'IAC 572' associated with the overhead trellis provided greater yellow flavonoids accumulation in the skin of the scion cultivar in cycle 1, while in cycle 2, the highest content was observed in rootstock 'IAC 766'. It is worth noting that the highest yellow flavonoid contents were quantified in grapes trained with the overhead trellis and VSP and grafted onto 'IAC 572' in cycle 1, with values of 47.49 and 47.19 mg 100 g^{-1}, respectively. In cycle 2, grapes trained with the lyre and grafted onto the same rootstock demonstrated the highest accumulation of these compounds of 48.09 mg 100 g^{-1}.

Table 7. Yellow flavonoid content and total anthocyanins in skin of 'BRS Cora' grapes with respect to production cycles, training systems and rootstocks, in the region of the Submedium São Francisco River Valley[1].

Training system	July to October 2017 (Cycle 1)		June to October 2018 (Cycle 2)	
	IAC 572	IAC 766	IAC 572	IAC 766
	Yellow flavonoid content (mg 100 g^{-1})			
Vertical shoot positioning	47.19 *a*Aa	38.76 *a*Ab	38.57 *b*Ba	44.65 *a*Aa
Lyre	40.39 *b*Aa	41.01 *a*Aa	48.09 *a*Aa	45.39 *a*Aa
Overhead trellis system	47.49 *a*Aa	34.50 *b*Ab	36.74 *b*Bb	45.51 *a*Aa
CV (%)	10.15			
	Total anthocyanin content (mg 100 g^{-1})			
Vertical shoot positioning	426.45 *a*Aa	367.42 *b*Ab	339.51 *b*Cb	424.02 *a*Ba
Lyre	265.12 *b*Bb	329.88 *b*Ba	514.43 *a*Aa	403.10 *a*Bb
Overhead trellis system	278.94 *b*Ba	300.79 *b*Ba	428.45 *a*Bb	468.40 *a*Aa
CV (%)	5.19			

[1]Means followed by the same lowercase letter in italics in the row, comparing production cycles within each training system interacting with each rootstock, and uppercase letters in the column, comparing training systems within each production cycle interacting with each rootstock, do not statistically differ from each other using Tukey's test (p ≤ 0.05). In the rows, means followed by the same lowercase letter, comparing rootstocks within each production cycle interacting with each conduction system, do not differ from each other using Tukey's test (p ≤ 0.05).

Solar radiation alone can only regulate the biosynthesis of phenolic compounds (Carbonell-Bejerano et al., 2014) and, in fact, is believed to be largely responsible for improvements in grape composition attributed to good exposure to light (Teixeira, Eiras-Dias, Castellarin, & Geros, 2013). However, temperatures approximately 35°C might degrade some phenolic compounds such as flavonoids (Oliveira, Mercenaro, Del Caro, Pretti, & Nieddu, 2015). Therefore, the production system, determined by a specific training system and rootstocks, affects the grape composition due to the level of exposure of bunches to solar radiation and temperature, which affects the synthesis and accumulation of phenolics.

Regarding the total anthocyanin contents in skin, grapes trained with VSP and grafted onto rootstock 'IAC 572' demonstrated a higher accumulation in cycle 1 (Table 7). In cycle 2, the highest

accumulation occurred in grapes grafted onto 'IAC 766'. With lyre, climate conditions in cycle 2 provided higher contents of these compounds (514.43 mg 100 g^{-1}) when the rootstock adopted was 'IAC 572'. Conversely, grapes trained with the overhead trellis in cycle 2, unlike those trained with lyre, had the highest contents of these compounds when they were grafted to rootstock 'IAC 766'. It is worth noting that in cycle 1, grapes trained with VSP and grafted onto both rootstocks had a higher accumulation of these compounds compared with the other systems. In cycle 2, the combination of lyre with rootstock 'IAC 572' resulted in a higher accumulation, whereas grapes of plants trained with the overhead trellis had the highest accumulation values with 'IAC 766'. Increases in total anthocyanin contents are related to positive regulation caused by light of proteins involved in the biosynthetic pathway of these compounds (Wang, Ma, Xi, Wang, & Li, 2015). Solar radiation promotes the biosynthesis of anthocyanins, an effect that might be mediated by the positive regulation between radiation and the gene MYBF1, which induces a response of the gene CHS responsible for the synthesis of precursors of an array of flavonoids, including anthocyanins (Martínez-Lüscher et al., 2016). Therefore, the vegetative canopy architecture resulting from the training system and rootstock adopted is of utmost importance to ensure the exposure of bunches to optimal solar radiation for the biosynthesis and accumulation of anthocyanins in berries.

The data for the total extractable polyphenol content did not have a normal distribution. Higher mean total extractable polyphenol contents were observed in the second productive cycle (Table 2). Phenolic compounds in grapes tend to be affected by external stimuli such as solar radiation and temperature (Badhani, Sharma, & Kakkar, 2015). The highest temperature and higher incidence of solar radiation during ripening in cycle 2 may have positively affected the synthesis and accumulation of polyphenols in 'BRS Cora' grapes. In cycle 1, the lyre associated with rootstock 'IAC 766' provided the highest accumulation of total extractable polyphenols, leading us to infer that it allowed a higher bunch exposure to solar radiation and temperature. However, in cycle 2, the overhead trellis associated with rootstock 'IAC 766' and the VSP associated with rootstock 'IAC 572' treatments provided the highest accumulation of these compounds in 'BRS Cora' grapes. These findings emphasize that the canopy architecture, resulting from the association of the training system and rootstock, affects the exposure of grapes to solar radiation, interfering with the synthesis/accumulation or degradation of these compounds.

Kyraleou et al. (2015), in an experiment conducted in a region with a Mediterranean climate, observed a higher accumulation of phenolic compounds in 'Xinomavro' grapes trained with lyre. However, in the present study, the accumulation of these compounds was affected not only by the training system but also by environmental factors such as solar radiation and temperature. Additionally, the training system associated with a specific rootstock might aid in providing suitable exposure of bunches to these factors, thus hampering or promoting the synthesis of phenolic compounds. According to Pedro Júnior, Hernandes, and Moura (2018), grapevines trained with lyre demonstrate a higher accumulation of polyphenols, as this system exposes the canopy to radiation and thus triggers moderate stress in the grapevine and a greater increase in these compounds in grape berries.

Regarding antioxidant activity determined by the ABTS$^{\bullet+}$ radical capture method, there was a significant interaction between the training system and productive cycle, between rootstock and productive cycle, and between training system and rootstock (Tables 5, 6, and 8). Based on the interaction between the training system and productive cycle, we observed that in cycle 1, the highest antioxidant activity occurred in grape berries trained with lyre, with a value of 18.14 μM trolox g^{-1}, while in cycle 2, the overhead trellis provided a higher mean value of 19.15 μM trolox g^{-1} (Table 5). However, the VSP system showed lower variation between cycles for this variable, with antioxidant activity of 14.36 μM trolox g^{-1} in berries in cycle 1 and 15.61 μM trolox g^{-1} in berries in cycle 2.

The interaction between rootstock 'IAC 572' and cycle 2 provided berries with higher antioxidant activity for ABTS$^{\bullet+}$, 18.56 μM trolox g^{-1}. However, there was no significant difference between productive cycles in grapes grafted onto rootstock 'IAC 766' (Table 6). Thus, this rootstock showed a higher stability of antioxidant activity between productive cycles, with 16.92 μM trolox g^{-1} in cycle 1 and 15.20 μM trolox g^{-1} in cycle 2. Rootstock 'IAC 572', associated with the overhead trellis and lyre,

provided higher antioxidant activity in 'BRS Cora' grapes, with values of 18.11 and 17.47 µM trolox g^{-1}, respectively (Table 8). Conversely, grapes grafted onto rootstock 'IAC 766' had a reduced antioxidant potential compared with 'IAC 572' when the training system adopted was the overhead trellis.

Table 8. Antioxidant activity determined by determining the free radical ABTS$^{•+}$ content in 'BRS Cora' grapes cultivated under different training systems and rootstocks in the region of the Submedium São Francisco River Valley[1].

Training system	Rootstock		CV (%)
	'IAC 572'	'IAC 766'	
Vertical shoot positioning	13.85 aB	16.12 aA	
Lyre	17.47 aA	16.56 aA	13.97
Overhead trellis system	18.11 aA	15.51 bA	

[1]Means followed by the same lowercase letter in the row or uppercase letter in the column, comparing rootstocks and training systems, respectively, do not differ from each other using Tukey's test (p ≤ 0.05).

The synthesis and accumulation of phenolic compounds are known to be directly affected by climatic conditions, such as temperature, solar radiation, rainfall, and the hydrothermal coefficient, and temperature and solar radiation are considered to be major factors (Downey, Dokoozlian, & Krstic, 2006). In addition to phenolic compound contents in grapes, these factors also change the antioxidant properties; therefore, the choice of a suitable production system is of utmost importance. An accurate decision might ensure a vegetative canopy architecture that causes increased antioxidant activity based on the accumulation of several different groups of phenolic compounds. Such a response is justified by the regulation of phenylalanine ammonia-lyase activity by light. This enzyme is primarily responsible for the synthesis of single phenylpropanoids, which are precursors of major phenolic compounds (Camm & Towers, 1973; Wang et al., 2015).

Data on antioxidant activity, determined by the DPPH$^{•}$ radical capture method, did not show a normal distribution (Table 2). In cycle 1, the mean values varied from 3328 g g^{-1} DPPH, the highest antioxidant activity in grapes trained with VSP combined with rootstock 'IAC 766', to 6686 g g^{-1} DPPH, the lowest antioxidant activity observed in cultivars also trained with VSP but grafted onto 'IAC 572'. In cycle 2, the mean values varied from 3318 g g^{-1} DPPH, the highest antioxidant activity, in grapes trained with lyre grafted onto 'IAC 766', to 5496 g g^{-1} DPPH, representing the lowest antioxidant activity in cultivars with an overhead system grafted onto 'IAC 572' (Table 2). Importantly, the results of the present study revealed the lowest antioxidant activity in grapes harvested from plants trained with the overhead trellis in both production cycles.

ABTS$^{•+}$ and DPPH$^{•}$ radical capture methods for determining antioxidant activity are commonly used in grapes (Dinis et al., 2016). However, the present study suggests that the ABTS$^{•+}$ method reveals an impact of each treatment on the final antioxidant ability.

Principal Components Analysis (PCA)

According to the PCA, the bunch weight variable contributed best to distinguishing the combinations of lyre with rootstock 'IAC 572' in cycle 1 (LR1C1), lyre with 'IAC 766' in cycle 1 (LR2C1), VSP with 'IAC 572' in cycle 1 (VSPRIC1), and VSP with 'IAC 766' in cycle 1 (Figure 1). The variables of berry weight and berry resistance to compression helped distinguish the combination of the overhead trellis with 'IAC 572' in cycle 1 (OTSR1C1) and the overhead trellis with 'IAC 766' in cycle 1 (OTSR2C1). Antioxidant activity, determined using the ABTS$^{•+}$ radical capture method, was the variable that best contributed to distinguishing combinations of overhead trellis with 'IAC 572' in cycle 2 (OTSR1C2), overhead trellis with 'IAC 766' in cycle 2 (OTSR2C2), and lyre with 'IAC 766' in cycle 2 (LR2C2). However, colour b* distinguished the treatment combinations VSP and 'IAC 572' in cycle 2 (VSPR1C2), VSP and 'IAC 766' in cycle 2 (VSPR2C2), and lyre and 'IAC 572' in cycle 2 (LR1C2). Importantly, LR1C1, lyre associated with 'IAC 572' in cycle 1 (LR2C1), LR2C2, VSPR1C1, VSPR2C1, OTSR1C1, and OTSR2C1, were positioned in one component of the graph, while LR1C2, VSPR1C2, VSPR2C2, OTSR1C2, OTSR2C2, and LR2C2 were in another component, which revealed a marked distinction between these treatment combinations in productive cycles of the same half of the year.
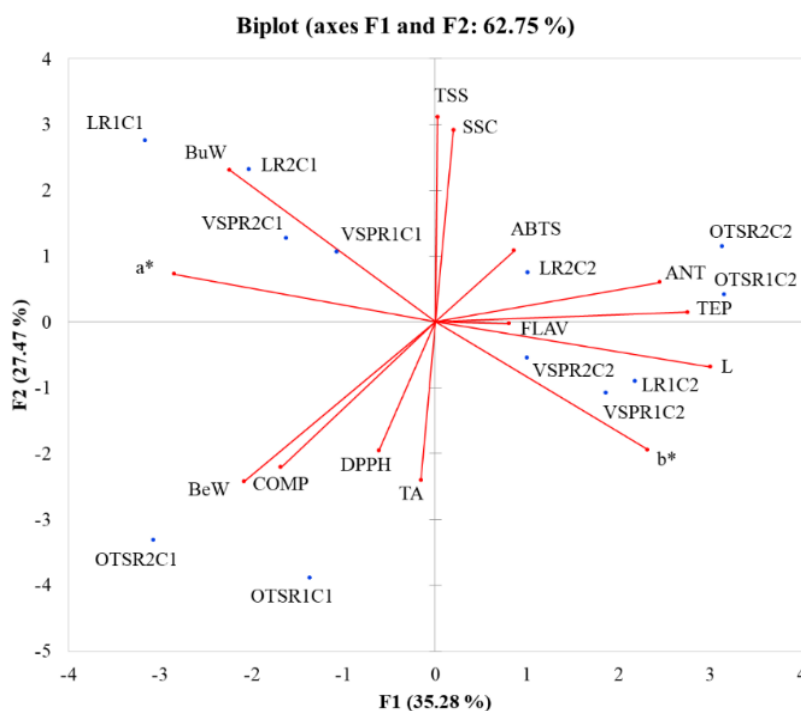
Figure 1. Principal components analysis of the variables determining the quality and antioxidant potential of 'BRS Cora' grapes, affected by the training system, rootstock, and production cycle in the region of the Submedium São Francisco River Valley. Variables: The bunch weight (BuW), berry weight (BeW), soluble solid content (SSC), total soluble sugar (TSS), titratable acidity (TA), berry resistance to compression (COMP), yellow flavonoids in skin (FLAV), total anthocyanins in skin (ANT), total extractable polyphenols (TEP), antioxidant activity by capturing methods of free radical ABTS $^{\bullet+}$ and DPPH$^{\bullet}$, luminosity (L), a* e b* skin colour attributes. Treatments: OTSR1C1 = overhead trellis system with rootstock IAC 572 in productive cycle from July to October, 2017; OTSR2C1 = overhead trellis system with rootstock IAC 766 in productive cycle from July to October, 2017; LR1C1 = lyre with rootstock IAC 572 in productive cycle from July to October, 2017; LR2C1 = lyre with rootstock IAC 766 in productive cycle from July to October, 2017; VSPR1C1 = vertical shoot positioning with rootstock IAC 572 in productive cycle from July to October, 2017; VSPR2C1 = vertical shoot positioning with rootstock IAC 766 in productive cycle from July to October, 2017; OTSR1C2 = overhead trellis system with rootstock IAC 572 in productive cycle from June to October, 2018; OTSR2C2 = overhead trellis system with rootstock IAC 766 in productive cycle from June to October, 2018; LR1C2 = lyre with rootstock IAC 572 in productive cycle from June to October, 2018; LR2C2 = lyre with rootstock IAC 766 in productive cycle from June to October, 2018; VSPR1C2 = vertical shoot positioning with rootstock IAC 572 in productive cycle from June to October, 2018; VSPR2C2 = vertical shoot positioning with rootstock IAC 766 in productive cycle from June to October, 2018.

Conclusion

In production cycles of the second halves, the efficiency of training systems associated with rootstocks influenced 'BRS Cora' grape quality, derived mostly from the capture of solar radiation provided by the canopy architecture. The suitable combination of training system and rootstock increased luminosity and a* in skin, soluble solid content, soluble sugars, yellow flavonoids, anthocyanins, and antioxidant activity. Grapes harvested from plants under overhead trellis grafted onto 'IAC 766' had the highest anthocyanin and extractable polyphenol contents in cycle 2. The use of overhead trellis in cycle 2 and lyre in cycle 1 provided higher soluble solids and antioxidant activity.

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