Phenolic compounds profile and antioxidant activity of commercial tropical red wines (*Vitis vinifera* L.) from São Francisco Valley, Brazil

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Abstract
The aim of this study was to investigate the phenolic composition and antioxidant activity of commercial red wines produced from *Vitis vinifera* L. grapes grown in the São Francisco Valley (SFV), which is a tropical region in northeastern Brazil. All wines showed phenolic compound contents consistent with those of other traditional wine producing regions and high antioxidant activity. In total, 20 phenolic compounds were quantified by RP-HPLC-DAD-FD and the antioxidant activity was positively correlated with the content of syringic acid > peonidin 3-O-glucoside > p-coumaric acid > (+)-catechin, epigallocatechin gallate > cyanidin-3-O-glucoside > procyanidin A2 > (-)-epicatechin, highlighting the contribution of these bioactive compounds to the antioxidant potential of tropical wines. This study shows that it is possible to obtain wines with a good bioactive component and high antioxidant activity in tropical climates such as that of the SFV. The data reported herein contribute to our knowledge of the wine producing potential of new regions worldwide.

Practical applications
An important difference between the tropical viticulture practiced in the São Francisco Valley (SFV) and that of other traditional regions of the world is that in the SFV each vine can produce two harvests per year. Also, since this is a region with hot weather, high luminosity and abundant water for irrigation, wineries operate according to a particular scheme, according to the best period in which to harvest the grapes and to prune the vines. Also, the "step" system can be applied, where the harvesting is distributed within a certain period (e.g., one month, several months, or the whole year). Thus, it is possible to prepare wines throughout the year. This study contributes to gaining a better enological understanding of the wines produced in an atypical grape production region.

KEYWORDS
antioxidant capacity, bioactive compounds, tropical wines

1 INTRODUCTION

Grapes are grown for wine production all around the world and *Vitis vinifera* L. is used for the production of high-quality wines. However, in contrast to traditional wine producing countries, Brazil produces wines mainly from *Vitis labrusca* L. and hybrid grapes. At present, the domestic wine production is approximately 227 million liters per year, and of this total over 90% is produced with *Vitis labrusca* L. grapes (UVIBRA, 2014).

However, the submiddle region of the São Francisco Valley (SFV), located in northeastern Brazil and represented mainly by the municipalities of Petrolina (Pernambuco State) and Juazeiro (Bahia State), differs from other Brazilian wine producing regions, because it produces wines mostly from varieties of *Vitis vinifera* L. grapes. The climatic conditions in this region are distinct from those of other wine-producing areas in Brazil and around the world, since the SFV is situated between the southern hemisphere parallels of 8°–9° and at 350 m altitude, in a semiarid tropical climate.
TABLE 1  Description and basic characteristics of samples of commercial red wines (Vitis vinifera L.) from São Francisco Valley, northeastern Brazil

<table>
<thead>
<tr>
<th>Wine codes</th>
<th>Grape variety</th>
<th>Vintage</th>
<th>Maturation</th>
<th>pH</th>
<th>Alcoholic strength (% v/v)</th>
<th>Total acidity (mEq L⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASB</td>
<td>60% Cabernet Sauvignon, 30% Syrah, 10% Alicante Bouschet</td>
<td>2008</td>
<td>6 months in oak barrels</td>
<td>3.64</td>
<td>12.6</td>
<td>98.0</td>
</tr>
<tr>
<td>BAR</td>
<td>100% Barbera</td>
<td>2013</td>
<td>no maturity</td>
<td>3.60</td>
<td>13.0</td>
<td>87.3</td>
</tr>
<tr>
<td>TON</td>
<td>100% Touriga Nacional</td>
<td>2009</td>
<td>6 months in oak barrels</td>
<td>3.60</td>
<td>13.1</td>
<td>100.7</td>
</tr>
<tr>
<td>PVE</td>
<td>100% Petit Verdot</td>
<td>2012</td>
<td>No maturity</td>
<td>3.93</td>
<td>13.8</td>
<td>104.7</td>
</tr>
<tr>
<td>RCA</td>
<td>100% Ruby Cabernet</td>
<td>2013</td>
<td>No maturity</td>
<td>4.09</td>
<td>12.0</td>
<td>76.0</td>
</tr>
<tr>
<td>SYR</td>
<td>100% Syrah</td>
<td>2012</td>
<td>No maturity</td>
<td>3.71</td>
<td>13.6</td>
<td>83.3</td>
</tr>
<tr>
<td>TEM</td>
<td>100% Tempranillo</td>
<td>2013</td>
<td>No maturity</td>
<td>3.86</td>
<td>13.1</td>
<td>99.3</td>
</tr>
</tbody>
</table>

ASB = “60% Cabernet Sauvignon + 30% Syrah + 10% Alicante Bouschet”; BAR = “Barbera”; TON = “Touriga Nacional”; PVE = “Petit Verdot”; RCA = “Ruby Cabernet”; SYR = “Syrah”; TEM = “Tempranillo”.

Climate zone, with average temperatures of 26 °C, high sunlight intensity (3,000 h/year), and low annual rainfall (around 500 mm) (Teixeira, Scherer-Warren, Hernandez, Andrade, & Leivas, 2013). These climatic conditions, coupled with the absence of winter and the water for irrigation, make it possible to obtain two crops in the SFV in the same year, a typical scenario in tropical viticulture. Although this is a recently introduced practice, it has been previously carried out in Thailand, Venezuela, and India, where, as in Brazil, tropical wines began to be produced after developing the production of table grapes (Camargo, Pereira & Guerra, 2011; Lima, Leite, Sampaio, Viana, & Lima, 2015).

Wine production in the SFV was consolidated using classical Vitis vinifera L. grapes such as Syrah, Tempranillo, Cabernet Sauvignon, Alicante Bouschet, Sauvignon Blanc, Chenin Blanc, and Moscato Canelli. In addition, the use of Petit Verdot, Touriga Nacional, Grenache, and Verdejo grapes, among others, is expanding in the region.

In order to improve our knowledge regarding tropical wines, such as those produced in the SFV, there is a need to characterize these products to identify the specific qualities related to their region of origin. A notable aspect in this regard is the phenolic composition, which can be determined in order to assess the potential of a region to produce good quality wines.

Phenolic compounds not only reflect the characteristics of a region of origin, but are also related to the sensory properties of wine, particularly the stability, color, structure, and astringency of the drink. Furthermore, they can improve the nutritional characteristics of the product since they have a wide range of pharmacological effects associated with reduced risk of chronic-degenerative diseases, such as some cancers and cardiovascular diseases (Chiva-Blanch et al., 2013; Fagherazzi et al., 2014).

The production of wine in tropical regions is a relatively recent practice and thus the characterization of the phenolic compounds in these wines is of interest. In this context, the aim of this study was to evaluate the phenolic compounds profile and determine the in vitro antioxidant activity of tropical commercial red wines originating from the submiddle region of the San Francisco Valley, Brazil.

2 | MATERIALS AND METHODS

2.1 | Wine samples

Major commercial red wines produced in the SFV were selected for this study. Samples of seven different types of wine were collected, on the same day, directly from the five wineries located in the region and immediately analyzed. The samples were composed of mono-varietal wines, produced from the cultivars “Barbera,” “Touriga Nacional,” “Petit Verdot,” “Ruby Cabernet,” “Syrah,” and “Tempranillo” and a wine obtained from an Assemblage containing “Cabernet Sauvignon,” “Syrah,” and “Alicante Bouschet” varieties in the proportions of 60:30:10 (Table 1).

2.2 | Chemicals

Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid), 2,2-diphenyl-1-picrylhydrazyl (DPPH), and 2,2-azino-bis (3-ethylbenzthiazoline-6-acyl sulfonic acid) (ABTS) were obtained from Sigma-Aldrich (St. Louis, MO, USA). Potassium persulfate, ethanol, acetone, sodium carbonate, and Folin-Ciocalteu were obtained from Merck (Darmstadt, Germany). Methanol and acetonitrile (both HPLC grade) and orthophosphoric acid were supplied by Vetec Química Fina Ltda (Rio de Janeiro, Brazil), JT Baker (Phillipsburg, NJ), and Fluka (Switzerland), respectively. The water used in the study was purified in an Elga PURELAB option-Q (USA) purification system. The standards of ferulic, syringic, and queretin acids were obtained from Chem Service (West Chester, USA). p-Coumaric and gallic acids were obtained from Sigma-Aldrich (St. Louis, MO, USA). Kaempferol-3-O-glucoside, rutin, (+)-catechin, (+)-epicatechin, (+)-gallocatechin, (+)-epigallocatechin gallate, procyanidin A2, procyanidin B1, procyanidin B2, pelargonidin-3-O-glucoside, cyanidin-3-O-glucoside, malvidin-3-O-glucoside, delphinidin-
3-O-glucoside, peonidin-3-O-glucoside, and trans-resveratrol were obtained from Extrasynthese (Genay, France).

2.3 | Determination of total phenolic content and total monomeric anthocyanins

The total phenolic contents of the wines were determined spectrophotometrically at 765 nm (Biospectro, model SP-220, USA), after reacting with Folin-Ciocalteu reagent, according to the method described by Singleton and Rossi (1965). The results were obtained in comparison with a calibration curve using gallic acid as the standard, and expressed in mg L$^{-1}$ of gallic acid.

The total monomeric anthocyanins contents of wines were determined using the pH differential method proposed by Lee, Durst, and Wrolstad (2005). The samples were diluted in KCl solutions (0.025 M, pH 1.0) and in sodium acetate (0.4 M, pH 4.5). Readings were taken at 520 and 700 nm using a Biospectro spectrophotometer (SP model-220, USA). The pigment concentration in the wines was calculated and expressed as cyanidin-3-O-glucoside.

2.4 | Quantification of individual phenolic compounds by HPLC-DAD-FD

The analytical procedure was carried out under the chromatographic conditions described by Silva et al. (2015) using a HPLC Waters system (model Alliance e2695) couple to a diode array detector (DAD) (model 2998) and a fluorescence detector (FD) (model 2475). The data obtained were processed using the software program Empower™ (Milford, USA).

The wine samples were previously diluted in ultrapure water, filtered through a nylon membrane (0.45 μm), and a volume of 10 μL was injected. A Gemini-NX C18 column (150 mm × 4.60 mm × 3 μm) was used, protected by a Gemini-NX C18 column guard (4.0 × 3.0 mm), both manufactured by Phenomenex® (EU). The furnace temperature was maintained at 40°C, the flow at 0.6 mL min$^{-1}$ and the total run time was 65 min.

The elution gradient used was 0 min 100% A; 18 min 87.5% A, 2.5% B, 10.0% C; 30 min 83.5% A, 3.2% B, 13.3% C; 36 min 75.0% A, 5.0% B, 20.0% C; 48.5 min 65.0% A, 8.3% B, 26.7% C; 50 min 65.0% A, 8.3% B, 26.7% C and 65 min 100% A. The mobile phase consisted of a 25 mmol L$^{-1}$ solution of potassium dihydrogen phosphate with pH adjusted to 2.05 using phosphoric acid as solvent A, methanol as solvent B, and acetonitrile as solvent C.

Standard solutions were injected to obtain the retention time for each compound. In the DAD, the detection of the compounds was performed at: 220 nm for gallic acid, procyanidin B1, (−)-epicatechin gallate, and (−)-epigallocatechin; 320 nm for p-coumaric acid, ferulic acid, and trans-resveratrol; 360 nm for the flavonols kaempferol, rutin, and quercetin; and 520 nm for the anthocyanins delphinidin 3-O-glucoside, cyanidin 3-O-glucoside, pelargonidin 3-O-glucoside, peonidin 3-O-glucoside, and malvidin 3-O-glucoside. In the FD, the photon excitation was carried out at 280 nm and the emission at 320 nm for procyanidin B2 and A2, (−)-epicatechin, (+)-catechin, and syringic acid.

2.5 | Determination of in vitro antioxidant activity

The in vitro antioxidant activity was determined using the ABTS and DPPH free radical capture methods, following the methodologies proposed by Re et al. (1999) and Kim, Guo, and Packer (2002), respectively. The ABTS$^+$ radical was formed through the reaction of 7 mM ABTS in 140 mM potassium persulfate, with heating at ±25°C in the absence of light for 16 hr. The solution was then diluted in ethanol until an absorbance of 0.700 ± 0.05 at 734 nm was obtained. A total of 30 μL of sample was added to 2970 μL of the solution containing the radical. The absorbance was determined using a Biospectro spectrophotometer (Model SP-220, USA) at 734 nm after 6 min of reaction.

DPPH tests were performed considering the decay rate of the absorbance at 517 nm. The DPPH radical solution was prepared in ethanol and diluted up to an absorbance of 0.900 ± 0.050. For each sample, the absorbance of the DPPH solution was determined at time t = 0 min and 30 min after the addition of the sample (t = 30 min). The procedure consisted of mixing 0.1 mL of each sample of wine with 2.9 mL of a 100 μM ethanol solution of DPPH. The mixture was kept in the dark for 30 min and the absorbance was read at 517 nm on a Biospectro spectrophotometer (Model SP-220, USA).

In both methods, Trolox was the analytical standard used to construct the calibration curves and the results were expressed in millimoles of Trolox equivalents per liter of wine (mM TEAC L$^{-1}$).

2.6 | Statistical analysis

The data were subjected to analysis of variance (ANOVA) and the Tukey test (p ≤ 0.05). In order to correlate the phenolic compounds content with the antioxidant activity results, Pearson correlation analysis (p ≤ 0.05) was performed. Statistical analysis was performed using SAS® software (Statistical Analysis System, v. 9.3, SAS Institute, Cary, NC, USA).

3 | RESULTS AND DISCUSSION

3.1 | Individual phenolic compounds

3.1.1 | Flavanols

The description and basic characteristics of the wine samples studied in this research are shown in Table 1 and a typical chromatogram of a wine sample is presented in Figure 1.

The results obtained for the flavanols are shown in Table 2, where the total flavanols quantified by HPLC varied from 32.32 to 110.8 mg L$^{-1}$ for Barbera and Touriga Nacional wines, respectively. With regard to the individual phenolic compounds present, the highest values were found for catechin and procyanidins B1 and B2. The Touriga Nacional (53.9 mg L$^{-1}$), Assemblage (40.4 mg L$^{-1}$), and Syrah (22.6 mg L$^{-1}$) wines contained the highest amounts of catechin. In relation to procyani- din B1, the Tempranillo wines (26.3 mg L$^{-1}$) and Ruby Cabernet (22.3 mg L$^{-1}$) had notable amounts. The values observed for procyanidi- din B2 ranged from 13.5 to 37.6 mg L$^{-1}$, with the Touriga Nacional
and Ruby Cabernet wines having averages of 30.5 and 30.67 mg L$^{-1}$, respectively.

Leeuw, Kevers, Pincemail, Defraigne, and Dommes (2014) determined the phenolic profiles of 38 commercial red wines (Vitis vinifera L.) produced with classic cultivars derived from countries with a long tradition in the production of high quality wines, such as France, Italy, USA, Chile, Argentina, South Africa, and Australia. The results showed that the flavanol profile varied according to the cultivar and the region of origin. The cultivars with the highest concentrations of flavanols were Pinot Noir (France), Merlot (France), and Nero D’Avola (Italy). The catechin values ranged from 26.2 to 160.7 mg L$^{-1}$, procyanidin B1 from 29.7 to 295.7 mg L$^{-1}$, and procyanidin B2 from 19.4 to 239.4 mg L$^{-1}$.

In 73 samples of red wine (Vitis vinifera L.) originating from Argentina, Chile, and Brazil, the main wine-producing countries of South America, prepared with classic varieties, the catechin values ranged from 64.4 to 149.1 mg L$^{-1}$ (Granato, Katayama, & De Castro, 2011). The authors also reported that the Merlot and Cabernet Sauvignon wines from Chile and the Pinot Noir and Cabernet Sauvignon from Argentina presented the highest concentrations of this flavanol.

The values for the main flavanols found in tropical wines from the SFV were lower than those reported by Leeuw et al. (2014) and Granato et al. (2011) for wines prepared from Vitis vinifera L. in traditional wine producing regions with temperate climates. This highlights the importance of characterizing the products of this new region in relation to these compounds, since the profiles can affect the distinct characteristics of these tropical wines. These data therefore aid the search for a geographical identity.

According to Monagas, Gómez-Cordovés, Bartolomé, Laureano, and Silva (2003), the main flavanols present in grapes and wines are the dimers B1 and B2, which corroborates the results obtained in this study, since procyanidin B2 was the most abundant compound of the flavanols analyzed.

In wines, procyanidins are compounds of interest because they are related to the loss of flavors, astringency, bitterness, oxidative browning, and color stability. They are also associated with a range of beneficial effects on the health of the consumers, offering good antioxidant and anti-inflammatory potential (Garrido & Borges, 2013; Kennedy, 2008; Vauzour, Rodriguez-Mateos, Corona, Oruna-Concha, & Spencer, 2010).

3.1.2 | Anthocyanins

The values obtained for the total monomeric anthocyanins are shown in Table 3, where the variation was from 36.2 to 351.3 mg L$^{-1}$. The Ruby Cabernet wine had the highest average value (351.3 mg L$^{-1}$), followed by the Petit Verdot (222.5 mg L$^{-1}$), Assemblage (211.6 mg L$^{-1}$), Touriga Nacional (145.6 mg L$^{-1}$), Barbera (57.8 mg L$^{-1}$), Tempranillo (48 mg L$^{-1}$), and Syrah (36.17 mg L$^{-1}$) wines.

The total monomeric anthocyanins concentrations obtained for the red wines produced in the SFV are in agreement with those reported in the literature for Vitis vinifera L. wines in various regions worldwide, with mean reported values ranging from 12.9 to 344.7 mg L$^{-1}$ (Granato et al., 2011; Gris et al., 2013; Mulero, Pardo, & Zafra, 2010; Plavša, Jurinjak, Antunović, Persurić, & Ganić, 2012).

For the individual anthocyanins, the total amounts quantified by HPLC show a heterogeneous profile for each cultivar, where the lowest value was 6.5 and the highest 141.7 mg L$^{-1}$ for the Tempranillo and Ruby Cabernet varieties, respectively (Table 2). The three major
anthocyanins present, in decreasing order of concentration, were malvidin-3-O-glucoside, pelargonidin-3-O-glucoside, and peonidin-3-O-glucoside. Notably, malvidin-3-O-glucoside represented approximately 82% of the total anthocyanins in all SFV wine samples.

The values for total anthocyanins quantified by HPLC in the SFV wines are in agreement with those for wines from several traditional wine-producing regions, with reported values ranging from 12 to 342 mg L$^{-1}$ (Gris et al., 2013; Leeuw et al., 2014; Plavsa et al., 2012).

The prevalence of malvidin-3-O-glucoside in the SFV wine samples is consistent with values reported for wines from almost all of the traditional wine-producing regions, and it is widely known that in Vitis vinifera L. varieties this anthocyanin is the main pigment present (He et al., 2010).

### 3.1.3 Phenolic acids

The results obtained for phenolic acids quantified by HPLC are shown in Table 2. The total phenolic acids in the wines studied ranged from...
TABLE 3  Total phenolic content of the wines and total monomeric anthocyanin content

<table>
<thead>
<tr>
<th>Wine sample</th>
<th>Total phenolic content (g GAE L(^{-1}))(^a)</th>
<th>Total monomeric anthocyanin (mg L(^{-1}))(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASB</td>
<td>2645 ± 30</td>
<td>211.6 ± 3.9</td>
</tr>
<tr>
<td>BAR</td>
<td>2459 ± 30</td>
<td>57.8 ± 0.6</td>
</tr>
<tr>
<td>TON</td>
<td>2281 ± 30</td>
<td>145.6 ± 2.6</td>
</tr>
<tr>
<td>PVE</td>
<td>2144 ± 50</td>
<td>222.5 ± 3.9</td>
</tr>
<tr>
<td>RCA</td>
<td>2220 ± 10</td>
<td>351.3 ± 1.9</td>
</tr>
<tr>
<td>SYR</td>
<td>1992 ± 40</td>
<td>36.2 ± 1.6</td>
</tr>
<tr>
<td>TEM</td>
<td>2454 ± 90</td>
<td>48.0 ± 0.3</td>
</tr>
</tbody>
</table>

ASB = "60% Cabernet Sauvignon, 30% Syrah, 10% Alicante Bouschet"; BAR = "Barbera"; TON = "Touriga Nacional"; PVE = "Petit Verdot"; RCA = "Ruby Cabernet"; SYR = "Syrah"; TEM = "Tempranillo". Values are expressed as mean of triplicate determination ± standard deviation.

\(^a\)Total phenolic content measured with Folin-Ciocalteau expressed as gallic acid equivalents (GAE).
\(^b\)Total monomeric anthocyanins quantified by the technic of difference of pH and expressed as equivalent to cyanidin 3-glucoside.

8.3 to 112.3 mg L\(^{-1}\), and the Assemblage, Touriga Nacional, and Syrah wines showed the highest values. The phenolic acids profiles varied depending on the cultivar used for the wine production, but the main compounds present were syringic and gallic acids (2.7 to 56.4 mg L\(^{-1}\) and 1.1 to 45.9 mg L\(^{-1}\), respectively).

The Assemblage wine presented the highest total value for phenolic acids (112.34 mg L\(^{-1}\)) compared to the other samples, mainly represented by syringic, gallic and \(\rho\)-coumaric acids (56.4, 45.9 and 9.3 mg L\(^{-1}\), respectively). The Touriga Nacional wine also had a notable content of total phenolic acids (42.9 mg L\(^{-1}\)), syringic acid having an average value of 39.3 mg L\(^{-1}\). The higher phenolic acids contents in the Assemblage and Touriga Nacional wines can be attributed to the fact that they were produced by the same winery and aged for 6 months in French oak barrels. Hernández (2002) reported an increased incorporation of phenolic acids in wine with aging in oak barrels.

The prevalence of syringic acid in the Assemblage and Touriga Nacional wine samples could be associated with the time for which they were kept in the bottle, since they are older wines (see Table 1). According to Garrido and Borges (2013), under anaerobic conditions of wine storage, chemical reactions can result in the degradation of monomeric anthocyanins such as malvidin-3-O-glucoside, yielding syringic acid.

The total phenolic acids contents of the tropical wines originating from the SFV are within the values for wines from different regions around the world, with reported values ranging from 4.0 to 161.4 mg L\(^{-1}\) (Granato et al., 2011; Leeuw et al., 2014; Plavša et al., 2012).

3.1.4 | Flavonols and trans-resveratrol

The values obtained for total flavonols are shown in Table 2 (ranging from 3.4 to 11.5 mg L\(^{-1}\)) and the highest contents were observed for the Syrah and Tempranillo wines. Rutin was predominant in the Touriga Nacional (3.1 mg L\(^{-1}\)), Assemblage (2.3 mg L\(^{-1}\)), and Barbera (2.1 mg L\(^{-1}\)) wines while Kaempferol 3-O-glucoside was predominant in the Tempranillo (8.9 mg L\(^{-1}\)), Petit Verdot (4.7 mg L\(^{-1}\)), and Ruby Cabernet (3.1 mg L\(^{-1}\)) wines.

The highest content of quercetin was found in the Syrah wine (5.0 mg L\(^{-1}\)). Sen and Tokatli (2014) also found that quercetin was the predominant flavonol in Syrah tropical wines produced in Turkey, where average temperatures range from 23.4 to 31.1 °C, suggesting that in hot climates there is a predominance of this flavonol for the Syrah cultivar.

The values obtained for kaempferol, quercetin, and rutin in the SFV wines are consistent with those found in the commercial wines of several Vitus vinifera L. cultivars originating from regions which traditionally produce high-quality wines, such as France, Italy, Argentina, Chile, and the United States (Leeuw et al., 2014).

The concentrations of trans-resveratrol present in the SFV red wine samples ranged from 0.33 to 3.0 mg L\(^{-1}\) (Barbera and Touriga Nacional varieties, respectively). In the case of the Tempranillo wine, this stilbene was not quantified (i.e., the value was below the quantification limit of the method).

The trans-resveratrol values found in the SFV wines are consistent with those quantified in wines from the south of Brazil (temperate climate region), Argentina, and Chile (1.02–4.30 mg L\(^{-1}\)) (Granato et al., 2011). However, Lucena et al. (2010) reported that the resveratrol present in the SFV wines is predominantly in the cis form, which suggests that in the wines analyzed in this study the values for this stilbene may be even higher. Other authors have also suggested that grape by-products produced in tropical regions are potential sources of resveratrol (Katalinić et al., 2010) and that under high temperature and luminosity conditions, such as those in the SFV, this compound is present in the cis form due to its greater chemical stability.

The results of several studies suggest various positive effects of resveratrol on human health including anti-inflammatory, cardioprotective, and antioxidant properties and aiding the fight against cancer (Vauzour et al., 2010). This reinforces the importance of characterization of this compound in new wine regions such as the SFV.

3.2 | Total bioactive content and antioxidant activity

The total phenolic content of red wines produced in the SFV (expressed as the equivalent in mg L\(^{-1}\) gallic acid) varied between 1992 and 2645 mg L\(^{-1}\) (Table 3), the highest value being obtained for the Assemblage wine and the lowest for the Syrah wine. Overall, the total phenolics values obtained in this study are consistent with those reported in literature for 111 samples of commercial wine (Vitis vinifera L) from the major wine producing regions of the old and new worlds, including France, Italy, United States, Argentina, Chile, and Australia, with values of 948–3526 mg L\(^{-1}\) (Granato et al., 2011; Leeuw et al., 2014). In wines produced in the Serra Catarinense (high-altitude wines), southern Brazil, the total phenolics in red wines produced from several Vitus vinifera L. cultivars were 2287–2814 mg L\(^{-1}\) (Gris et al., 2013).

The antioxidant activity of the wines (AOX) was expressed as millimols of Trolox equivalents per liter of wine (mM TEAC L\(^{-1}\)) and the results are shown in Figure 2. According to the ABTS method, the Assemblage wine had the highest AOX (30.65 mM TEAC L\(^{-1}\)), while the Petit Verdot and Syrah wines showed the lowest values (19.06 and 18.57 mM...
On applying the DPPH method, the antioxidant activity showed similar results to those obtained with the ABTS method, the highest AOX being obtained for the Assemblage wine (28.9 mM TEAC L⁻¹) and the lowest for the Syrah wine (19.3 mM TEAC L⁻¹).

The AOX values obtained for the SFV wines are relatively high, since in many commercial wines of classic varieties such as Cabernet Sauvignon, Syrah, Merlot, Malbec, Pinot Noir, and San Giovese, originating from the world’s leading wine producing regions, the antioxidant activities ranged from 3.71 to 7.67 mM TEAC L⁻¹, as measured by the DPPH method (Leeuw et al., 2014). AOX values measured with the ABTS method for wines from the Merlot cultivars Vranec and Ulugbey Karasi, produced in Macedonia and Turkey, ranged from 4.72 to 13.5 mM TEAC L⁻¹ (Budak & Guzel-Seydim, 2010; Kostadinović et al., 2012). The AOX red wines from the south of Brazil, where the climate is temperate, measured by the ABTS and DPPH methods in a study carried out by Gris et al. (2011), ranged from 11.2 to 23.17 mM TEAC L⁻¹, values which are lower than those found in this study.

Based on the AOX results obtained for the SFV wines, there is evidence that this region may favor the production of wine with high antioxidant activity, which could be linked to the climate conditions (high temperature and luminosity), which can promote the synthesis of phenolic compounds with high AOX (Lucena et al., 2010).

### 3.3 Correlation between antioxidant activity and individual phenolic compounds

The Pearson correlation coefficients between individual phenolic compounds and the antioxidant activity of red wines of the SFV are shown in Table 4. Considering the ABTS results, the phenolic compounds that showed a positive r value and significant p value (p ≤ 0.05) were: syringic acid (r = 0.82), peonidin-3-O-glucoside (r = 0.77), p-coumaric acid (r = 0.65), catechin (r = 0.62), cyanidin-3-O-glucoside (r = 0.59), procyanidin A2 (r = 0.53), and epicatechin (r = 0.52).

On the other hand, based on the DPPH results, the correlations between the phenolic compounds and antioxidant activity showed that the phenolic compounds with a positive r value and significant p value (p ≤ 0.05) were: p-coumaric (r = 0.76) and syringic (r = 0.68) acids, the anthocyanin peonidin-3-O-glucoside (r = 0.62), and the flavonol epigallocatechin gallate (r = 0.61).

The correlations between the total phenolic compounds and the AOX were also positive and significant (p = 0.001 and r = 0.89), as reported by other authors (Lima et al., 2014; Lucena et al., 2010).

An analysis of the correlation between the phenolic compounds content and antioxidant activity is an important aid in the characterization of grape-derived beverages, highlighting possible substances which contribute more specifically to the nutraceutical potential due to their bioactive potential (Lima et al., 2014). However, the major phenolic compound in wine does not always have the strongest correlation with the antioxidant activity, and the antioxidant capacity of the beverage is mainly related to the class and structure of the phenolic compounds present (Di Majo et al., 2008) as observed in this study.
4 | CONCLUSIONS

This is the first study in which the phenolic content of commercial red wines from a tropical region (the SFV, northeast Brazil) was extensively analyzed. The HPLC-DAD-FD analysis permitted the quantification of various bioactive compounds of enological interest and the results showed that the predominant compounds were malvidin-3-O-glycoside, (+)-catechin, procyanidin B2, gallic acid, syringic acid, kaempferol-3-O-glycoside, and rutin. The antioxidant activity of the wines assessed was high and was positively correlated with the compounds syringic acid,peonidin-3-O-glycoside, p-coumaric acid, (+)-catechin, epigallocatechin gallate, cyanidin-3-O-glycoside, procyanidin A2, and (-)-epicatechin. This study shows that it is possible to obtain wines with a good bioactive component and high antioxidant activity in tropical climates such as that in the SFV. The data contribute to an improved knowledge of the wine producing potential of new regions worldwide.

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CONFLICT OF INTEREST

The authors declared that they have no conflict of interest

REFERENCES


Sen, I., & Tokatlí, F. (2014). Authenticity of wines made with economically important grape varieties grown in Anatolia by their phenolic profiles. Food Control, 46, 446–454.


