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Research Article

The training system of 'Cabernet Sauvignon' grapevine in high altitude region influences wine chemical and phenolic composition

Sistema de condução da videira 'Cabernet Sauvignon' cultivada em região de altitude influencia a composição química e fenólica dos vinhos

Douglas Würz *[1](ORCID 0000-0001-6109-9858), **Alberto Fontanella Brighenti** [2](ORCID 0000-0002-6498-8826), **Leo Rufato** [3](ORCID 0000-0001-9545-7035), **José Luiz Marcon Filho** [4](ORCID 0000-0001-8198-378X)

[1]Instituto Federal de Santa Catarina, Canoinhas, SC, Brazil. *Author for correspondence: douglas.wurz@ifsc.edu.br
[2]Universidade Federal de Santa Catarina, Florianópolis, SC, Brazil.
[3]Universidade do Estado de Santa Catarina, Lages, SC, Brazil.
[4]Profissional autônomo, Campo Largo, PR, Brazil.

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ABSTRACT

The vine training system can influence the grape and wine composition. In this context, the objective of this study was to evaluate the effect of two training systems on the chemical and phenolic composition of 'Cabernet Sauvignon' wines grown in a high-altitude region of Santa Catarina. This study was conducted during the 2012 to 2015 vintages, in three commercial vineyards, located in the municipalities of Painel (1200 m), São Joaquim (1300 m) and Urubici (1150 m). The experimental design used was a randomized block design, with five plants per replicate, comparing the Y-trellis and VSP training systems. The chemical and phenolic composition of the wines were evaluated. The data were compared by analysis of variance, performing the F test ($p < 0.05$). The anthocyanin and polyfhenols content was the only chemical variable in the wine that allowed us to state that there was an effect of the training system on the wines. The other variables (pH, total total acidity, color intensity and color tone) do not allow us to conclude that there was an effect of the training systems, given the variation in response between location and year. Wines made with grapes from the Y-trellis have higher resveratrol levels, while the VSP increases the levels of flavonols quercetin and kaempferol in Cabernet Sauvignon wines. The results of this study show that Y-trellis is an alternative for use in the high-altitude regions of Santa Catarina, since it does not compromise the quality of the wine, due to its potential for greater yield.

KEYWORDS: *Vitis vinifera* L. Resveratrol. Anthocyanins. Vertical shoot position trellis (VSP). Y-trellis.

RESUMO

O sistema de condução da videira pode influenciar a composição da uva, e consequentemente no vinho. Nesse contexto, tem-se como objetivo deste trabalho avaliar o efeito de dois sistemas de condução na composição química e fenólica dos vinhos 'Cabernet Sauvignon' cultivada em região de altitude de Santa Catarina. O presente trabalho foi conduzido durantes as safras 2012 a 2015, em três vinhedos comerciais, localizados nos municípios de Painel (1200 m), São Joaquim (1300 m) e Urubici (1150 m). O delineamento experimental utilizado foi o de blocos ao acaso, com cinco plantas por repetição, comparando-se os sistemas de condução Y e espaldeira. Os dados foram comparados pela análise de variância, realizando-se teste F ($p < 0.05$). O teor de antocianinas e polifenóis foram as variáveis química do vinho possível de se afirmar que houve um efeito do sistema de condução nos vinhos, uma vez que, as demais variáveis (pH, polifenóis totais, acidez total, intensidade de cor e tonalidade de cor) não permitem concluir efeito dos sistemas de condução, tendo em vista a variação de resposta entre local e ano. Os vinhos elaborados com uvas provenientes do sistema de condução Y apresentam maiores valores de teores de resveratrol, enquanto sistema espaldeira aumenta os teores de flavonóis quercetina e campferol nos vinhos de 'Cabernet Sauvignon'. Os resultados deste estudo evidenciam que o sistema

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de sustentação “Y” é uma alternativa de utilização nas regiões de altitude de Santa Catarina, visto que não comprometem a qualidade do vinho, em função do seu potencial para maiores produtividades.
PALAVRAS-CHAVE: *Vitis vinifera* L. Resveratrol. Antocianinas. Espaldeira. Manjedoura.

INTRODUCTION

One of the most essential aspects of grapevine cultivation is the training system applied in the vineyard, with several systems being used (ZOHAR et al. 2024), with the aim of developing and maintaining the grapevine structure with a specific shape and architecture of the canopy (LEÃO & CHAVES 2021), significantly influencing the productive performance of the vine and the quality of the grape and wine (GAMBETTA et al. 2021).

Among the training systems, the vertical shoot positioning (VSP) (GUTIÉRREZ-GAMBOA et al. 2021) stands out, being one of the most popular training systems, while the Y-shaped has been used recently (MUSACCHI et al. 2021), and has been proposed as suitable alternatives due to its ability to keep the clusters under a diffuse light regime and reduce direct radiation (YU et al. 2022). Training systems should provide a greater leaf area exposed to solar radiation in relation to the total leaf area, reducing excessive vegetative growth, which can result in incomplete maturation, in addition to improving the microclimate of the canopy in the cluster region (DEL ZOZZO & PONI 2024).

The use of divided canopy training systems can improve the vineyard microclimate, in addition to providing an increase in the interception of solar radiation (LEÃO & CHAVES 2021) and resulting in an increase in productive indices (PEDRO JÚNIOR et al. 2007). In 'Cabernet Sauvignon', 'Sauvignon Blanc', 'Syrah' grapevines, the Y-trellis promoted increases in yield compared to the VSP (FAVERO et al. 2010, PEDRO JÚNIOR et al. 2015, WÜRZ et al. 2019, MARCON FILHO et al. 2021). Furthermore, divided canopy systems, such as Y-trellis, can improve the vegetative-productive balance, improving cluster architecture and the microclimate of the canopy (SMART et al. 2017, MARCON FILHO et al. 2021).

In vineyards planted in the high-altitude region of Santa Catarina, a pattern is observed in relation to the training system, with 84.7% of the area in the VSP system, Y-trellis with 10.17% of the area, Tendone in 1.71%, Lyre in 0.11% and other training systems in 3.26% (VIANNA et al. 2016). However, the use of VSP generally results in excessive vegetative growth in the vineyards (BEM et al. 2016). These features, with the choice of vigorous rootstocks, result in excessive vegetative growth in the vineyards (MARCON FILHO et al. 2021), making it necessary to adopt cultivation techniques that provide an adequate vegetative-productive balance, providing adequate levels of ripening, resulting in higher quality wines (WÜRZ et al. 2017, WÜRZ et al. 2019).

Changing training systems can be interesting because it has the potential to adapt the production system without changing the variety cultivated and, in some cases, without the need to replant and restructure the entire vineyard, determining the interception of light and the solar exposure of the cluster, thus completing maturation (XYRAFIS et al. 2023). In addition, the training system also affects the

vegetative development and yield of the vine (REYNOLDS &VANDEN HEUVEL 2009).

A study carried out by ETCHEBARNE et al. (2015) observed that the minimum pruning system presented greater aromatic and qualitative potential in wines compared to the VSP, indicate that training systems can influence the content of polyphenols and anthocyanins in grapes for processing. MARCON FILHO et al. (2021), evaluating training systems in the 'Sauvignon Blanc' grapevine, observed that the aromatic profile and phenolic composition of wines are influenced by the training systems.

According to WÜRZ et al. (2018), in the high-altitude region of Santa Catarina, there is little data on the composition of wines due to changes in the vegetative canopy. In this context, the objective of this study is to evaluate the effect of two training systems on the chemical and phenolic composition of wines made with the 'Cabernet Sauvignon' grape grown in the high-altitude region of Santa Catarina.

MATERIAL AND METHODS

The present study was conducted during the 2012 to 2015 vintages, in three commercial vineyards, located in the municipalities of Painel (27°59' S, 50°07' O, 1200 m a.s.l.), São Joaquim (28°14' S, 49°58' O, 1300 m a.s.l.) and Urubici (27°56' S, 49°34' O, 1150 m a.s.l.). The climate of the region is humid mesothermic (Cfb) according to the Koppen classification (PEEL et al. 2007), with a Heliothermic Index of 1,714, mean annual rainfall of 1,621mm and relative humidity of 80% (TONIETTO & CARBONNEAU 2004). According to MARCON FILHO et al. (2020), the soil type is Cambisol, which is characterized by high levels of clay and organic matter. The variety Cabernet Sauvignon grafted on the rootstock 'Paulsen 1103' was used, the vineyards were planted in 2004, with a spacing of 3.0 m between rows and 1.5 m between plants.

The experimental design used was randomized blocks with five replications and five plants per plot. In all of experiments, the training systems Y-trellis and vertical shoot position trellis (VSP) were compared. The vines were pruned in bilateral spur cordon with two buds for VSP and two to four buds for Y-trellis, which corresponded to an average of 45 and 74 buds per plant, respectively. Management practices (pruning, leaf removal, topping and phytosanitary treatments) were carried out by the grape grower in accordance with the recommendations of the technicians in charge.

In the municipality of Painel, harvests took place on April 23, 2012, April 7, 2014, and April 13, 2015, in São Joaquim on April 23, 2012, April 8, 2013, and April 8, 2015, and in Urubici on April 23, 2012 and April 8, 2013. Due to the availability of grapes and climatic conditions, winemaking was not carried out in all the vintages at the sites evaluated. In both experiments 60 kg of grapes were manually harvested from each training system for winemaking. The microvinifications were carried out in the experimental winery of Santa Catarina State University (UDESC) and followed the protocol adapted from PSZCZÓŁKOWSKI & LECCO (2011) and MAKHOTKINA et al. (2013).

The wine samples were analyzed for total acidity (meq L^{-1}), pH and total polyphenols content (mg L^{-1} of gallic acid), anthocyanins (mg L^{-1}), color intensity (420 + 520 + 620 nm), and color hue (420 520 nm^{-1}). The color and anthocyanins were determined by the spectrophotometry method, described by RIZZON (2010). Total acidity (meq L^{-1}) and pH, according to the methodology proposed by the Office International de la Vigne et du Vin (OIV 2016). The concentration of total polyphenols in the skin was determined by the spectrophotometry method, described by SINGLETON & ROSSI (1965).

Phenolic compounds were only quantified for wines made with grapes from the municipality of Painel, in the 2014 and 2015 harvests, and from São Joaquim in the 2015 harvest. The wines phenolic compounds were quantified using high performance liquid chromatography (HPLC) according to the methodology described by CADAHÍA et al. (2009), adapted by FERREIRA-LIMA et al. (2013).

Approximately 2 mL of sample was filtered on a 0.45 µmmembrane (PES-Kasvi membrane, São José dos Pinhais, Brazil, 2014) with a syringe and placed in the vial for direct injection into the the high-performance liquid chromatography system. The reagents used in the analysis, such as acetonitrile (≥ 99.9%, LabMaster, Pinhais, Brazil, 2014), acetic acid (≥ 99.7%, Sigma -Aldrich, Darmstadt, Germany, 2016) and methanol (≥ 99.8%, LabMaster, Pinhais, Brazil, 2016) were of chromatographic grade. Tartaric acid L (+) (≥ 99%, Sigma-Aldrich, Darmstadt, Germany, 2015) and ethanol (≥ 99.8%, Sigma-Aldrich, Darmstadt, Germany, 2016) were of analytical grade. The water used for analysis was obtained through the Milli-Q purification system, Simplicity UV System (Millipore, Massachusetts, USA). The standards anhydrous gallic acid (≥ 98%), (+) - catechin (≥ 98%), p-coumaric acid (≥ 98%), vanillic acid (≥ 97%), resveratrol (≥ 95%), quercetin (≥ 95%), rutin (≥ 94%) and kaempferol (≥ 97%) were obtained from Sigma-Aldrich (Darmstadt, Germany, 2016).

Chromatographic analyzes were performed using Shimadzu high performance liquid chromatography equipment (Kyoto, Japan). The column was C18 (5 µm, 250 mm x 4.6 mm, Restek). All solvents used as a mobile phase were previously filtered through a 0.45 µm pore membrane (PES-Kasvi membrane).

The software used to control the gradient system, the detector and for data acquisition was Shimadzu Class-VP. For each sample, a duplicate reading was performed and when a variation > 10% was detected, a third reading was performed. The phenolic compounds were read at 280nm.

The calibration ranges and equations for determining phenolic compounds are described in Table 1. Quantification in mg L^{-1} of all compounds was determined by calibration curves with an external standard.

Table 1. Parameters used to quantify the phenolic compounds in 'Cabernet Sauvignon' wines from grapes produced in two different training systems.

Compound	Calibration Range (mg L^{-1})	Linear equation (y=ax)	R^2	Quantification threshold (mg L^{-1})
Gallic Acid	0.8 – 78.1	y=62155x	0.997	0.006
Catechin	0.4 – 158.8	y=17546x	0.999	0.072
Vanillic Acid	0.4 – 39.8	y=41400x	0.998	0.026
p-coumaric Acid	0.3 – 29.4	y=116481x	0.996	0.009
Rutin	0.3 – 29.9	y=21032x	0.996	0.033
Resveratrol	0.2 – 18.8	y=83839x	0.994	0.013
Quercetin	0.6 – 58.9	y=33919x	0.998	0.031
Kaempferol	0.1 – 13.4	y=40635x	0.997	0.029

R^2= Coefficient of Determination

The experimental design used for winemaking and analysis was randomized blocks, with four replicates for each treatment, with the samples previously frozen at the time of bottling, to take the readings of all the wines at the same time, and with the same calibration of the equipment. The data were submitted to analysis of variance (ANOVA) by F Test ($p < 0.05$).

RESULTS AND DISCUSSION

The determination of total acidity, pH, total polyphenols, anthocyanins, intensity and color hue were analyzed for the 'Cabernet Sauvignon' wines from Painel (1200 m a.s.l.) – 2012, 2014 and 2015 vintages (Table 2); São Joaquim (1300 m a.s.l.) – 2012, 2013 and 2015 vintages (Table 3) and Urubici (1150 m a.s.l.) – 2012 and 2013 vintages (Table 4).

Table 2. Total acidity (meq L^{-1}), hydrogen potential (pH), total polyphenol content (mg L^{-1} of gallic acid), anthocyanins (mg L^{-1}), color intensity and hue of wines from 'Cabernet Sauvignon' on Y-trellis and VSP training systems. Vintages 2012, 2014 and 2015, Painel (1200 m a.s.l.).

Variables	Vintage	Training System		F Test (ANOVA)
		Y-Trellis	VSP	p<0.05
Total Acidity (meq L^{-1})	2012	72.9 ± 1.6	74.9 ± 0.7	ns
	2014	50.3 ± 3.6	53.5 ± 6.3	ns
	2015	80.7 ± 0.5	87.5 ± 1.6	*
	Average	67.9 ± 15.8	71.9 ± 17.2	*
pH	2012	3.75 ± 0.00	3.74 ± 0.01	ns
	2014	3.60 ± 0.07	3.55 ± 0.13	ns
	2015	3.36 ± 0.01	3.32 ± 0.01	*
	Average	3.57 ± 0.19	3.54 ± 0.21	ns
Total Polyphenols (mg L^{-1} gallic acid)	2012	1622.7 ± 126.3	1475.8 ± 68.8	ns
	2014	918.1 ± 50.0	929.2 ± 114.5	ns
	2015	1895.5 ± 61.2	2240.9 ± 64.3	*
	Average	1478.7 ± 504.4	1548.6 ± 658.9	ns
Anthocyanins (mg L^{-1})	2012	140.6 ± 5.8	160.4 ± 9.8	*
	2014	96.7 ± 11.5	91.8 ± 5.1	ns
	2015	377.7 ± 2.2	541.3 ± 41.2	*
	Average	205.0 ± 151.1	264.5 ± 242.1	*
Color Intensity (420+520+620 nm)	2012	10.61 ± 0.12	11.01 ± 0.27	*
	2014	9.29 ± 0.53	9.50 ± 0.92	ns
	2015	7.81 ± 0.21	9.78 ± 0.34	*
	Average	9.23 ± 1.40	10.10 ± 0.80	*
Color Hue (420 520 nm^{-1})	2012	0.89 ± 0.01	0.92 ± 0.01	*
	2014	0.69 ± 0.02	0.66 ± 0.03	ns
	2015	0.75 ± 0.01	0.69 ± 0.01	*
	Average	0.78 ± 0.11	0.75 ± 0.14	*

* = significant. ns = not significant. Average ± standard deviation.

Regarding São Joaquim (1300 m a.s.l.), total acidity and color intensity levels were higher for wines from plants trained in Y-Trellis. While the 'Cabernet Sauvignon' wines from the VSP presented higher color hue, pH, total polyphenols and anthocyanins (Table 3). This was also observed for wines from Urubici (1150 m a.s.l.), except for the variables total polyphenols and color intensity, where no difference was observed between the training systems (Table 4).

Table 3. Total acidity (meq L^{-1}), hydrogen potential (pH), total polyphenol content (mg L^{-1} of gallic acid), anthocyanins (mg L^{-1}), color intensity and hue of wines from 'Cabernet Sauvignon' on Y-trellis and VSP training systems. Vintages 2012, 2013 and 2015, São Joaquim (1300 m a.s.l.).

Variables	Vintage	Training System		F Test (ANOVA)
		Y-Trellis	VSP	p<0.05
Total Acidity (meq L^{-1})	2012	89.0 ± 1.4	80.3 ± 0.8	*
	2013	86.6 ± 0.8	72.8 ± 0.5	*
	2015	80.6 ± 0.7	69.9 ± 1.5	*
	Average	85.4 ± 4.3	74.3 ± 5.4	*
pH	2012	3.37 ± 0.01	3.78 ± 0.01	*
	2013	3.77 ± 0.07	4.15 ± 0.05	*
	2015	3.14 ± 0.01	3.50 ± 0.01	*
	Average	3.43 ± 0.32	3.81 ± 0.33	*
Total Polyphenols (mg L^{-1} gallic acid)	2012	1920.4 ± 113.6	1784.1 ± 113.2	ns
	2013	1531.8 ± 40.3	1552.3 ± 46.6	ns
	2015	2306.1 ± 9.5	2713.6 ± 25.7	*
	Average	1919.4 ± 387.1	2016.7 ± 614.6	*
Anthocyanins (mg L^{-1})	2012	261.9 ± 9.2	256.1 ± 29.3	ns
	2013	266.0 ± 8.3	318.2 ± 8.7	*
	2015	640.2 ± 84.7	785.7 ± 74.1	ns
	Average	389.4 ± 217.3	453.3 ± 289.5	*
Color Intensity (420+520+620 nm)	2012	16.58 ± 0.24	13.33 ± 1.00	*
	2013	13.54 ± 0.17	8.69 ± 0.31	*
	2015	10.11 ± 0.78	9.39 ± 0.43	ns
	Average	13.41 ± 3.24	10.47 ± 2.50	*
Color Hue (420 520 nm^{-1})	2012	0.76 ± 0.02	0.93 ± 0.02	*
	2013	0.67 ± 0.01	0.84 ± 0.05	*
	2015	0.72 ± 0.02	0.82 ± 0.04	*
	Average	0.71 ± 0.05	0.86 ± 0.06	*

* = significant. ns = not significant. Average ± standard deviation.

For Painel (1200 m a.s.l.), except for vintage 2015, no statistical difference was observed for the acidity, pH and total polyphenols between the wines from both training systems. The higher values observed in wines from plants trained in VSP in the vintage 2015 for polyphenol, anthocyanin and color intensity are possibly related to the ripeness degree of the grapes in VSP during this vintage, with a more pronounced discrepancy in soluble solids and total polyphenols contents in relation to the Y-Trellis. In 2015 vintage, the wines derived from VSP system present higher acidity, anthocyanin and color intensity content. While the 'Cabernet Sauvignon' wines from the Y-Trellis presented a greater color hue (Table 2).

The analytical results of acidity were similar to those reported by ZALAMENA et al. (2013) in 'Cabernet Sauvignon' wines from the high-altitude region of Santa Catarina. Furthermore, the values observed for the two training systems are in accordance with the identity and quality standards established by the Brazilian Ministry of Agriculture, Livestock and Food Supply for dry fine red wines (BRASIL 2018).

Table 4. Total acidity (meq L^{-1}), hydrogen potential (pH), total polyphenol content (mg L^{-1} of gallic acid), anthocyanins (mg L^{-1}), color intensity and hue of wines from 'Cabernet Sauvignon' on Y-trellis and VSP training systems. Vintages 2012 and 2013, Urubici (1150 m a.s.l.).

Variables	Vintage	Training System		F Test (ANOVA)
		Y-Trellis	VSP	p<0.05
Total Acidity (meq L^{-1})	2012	76.4 ± 8.0	60.2 ± 0.4	*
	2013	82.5 ± 0.5	82.1 ± 1.2	ns
	Average	79.5 ± 4.3	71.2 ± 15.5	*
pH	2012	3.70 ± 0.08	3.94 ± 0.01	*
	2013	3.94 ± 0.08	3.99 ± 0.08	ns
	Average	3.82 ± 0.16	3.97 ± 0.04	*
Total Polyphenols (mg L^{-1} gallic acid)	2012	1788.6 ± 129.9	1734.1 ± 52.7	ns
	2013	1879.5 ± 8.7	1793.2 ± 44.2	*
	Average	1834.1 ± 64.3	1763.6 ± 41.8	ns
Anthocyanins (mg L^{-1})	2012	113.2 ± 11.5	179.8 ± 35.2	*
	2013	330.9 ± 4.6	332.8 ± 10.1	ns
	Average	222.0 ± 153.9	256.3 ± 108.2	*
Color Intensity (420+520+620 nm)	2012	10.21 ± 0.59	10.61 ± 0.83	ns
	2013	9.52 ± 0.12	9.18 ± 0.37	ns
	Average	9.86 ± 0.49	9.89 ± 1.01	ns
Color Hue (420 520 nm^{-1})	2012	0.86 ± 0.04	0.95 ± 0.07	*
	2013	0.70 ± 0.01	0.73 ± 0.01	*
	Average	0.78 ± 0.11	0.84 ± 0.16	*

* = significant. ns = not significant. Average ± standard deviation.

It was observed that the pH values were high in wines, greater than 3.50. 'Cabernet Sauvignon' wines generally have high pH, due to the accentuated extraction of potassium from the grape skin during its maceration during winemaking (RIZZON & MIELE 2002). To produce wines, a pH between 3.40 and 3.80 is recommended (AMERINE & OUGH 1976). In this context, the three areas evaluated in the Y-Trellis presented adequate values, while for VSP, only the wines from the Painel area (1200 m a.s.l.) presented an ideal value for this variable.

Polyphenols play an important role in the sensory characteristics of wine, such as color, astringency and bitterness (WÜRZ et al. 2020) and play an important role in wine quality (CONDE et al. 2007). The total polyphenol contents found in wines from the studied regions were similar to those found by other authors. BURIN et al. (2011) when evaluating wines from two 'Cabernet Sauvignon' clones found total polyphenol contents for the wines of 2389 and 1884 mg L^{-1}. SIMON (2014) with 'Cabernet Sauvignon' wines from high-altitude regions reported total polyphenol contents of 2259 and 2011 mg L^{-1}.

Of the chemical variables mentioned above, the anthocyanin was an effect of the training system on the wines. According to SEGADE et al. (2009), light causes an increase in the concentration of grape total monomeric anthocyanins. The VSP training system allows for better incidence of light on the cluster, a factor that may be related to the higher anthocyanin content observed in the 'Cabernet Sauvignon' wines from VSP in the three locations. The other variables do not allow us to

conclude that there was an effect on the training systems, given the variation in response between location and year.

Both color intensity and hue are important attributes of a wine, as information about its qualities and possible defects is obtained through its appearance (FREITAS 2006). The color intensity of wines is determined mainly by the anthocyanin content of the grape (ALLEBRANDT et al. 2024).

The wines from Painel (1200 m a.s.l.) from the 2014 and 2015 vintages (Table 5) and from São Joaquim (1300 m a.s.l.) from the 2015 vintage (Table 6) were analyzed for the levels of phenolic compounds. The quantified phenolic compounds belong to the group of Flavan-3-ols (catechin), Flavonols (quercetin, kaempferol and rutin), hydroxybenzoic acids (gallic and vanillic), hydroxycinnamic acids (p-coumaric) and stilbenes (resveratrol) (JACKSON 2014).

Table 5. Phenolic compounds of wines from 'Cabernet Sauvignon' on Y-trellis and VSP training systems. Vintages 2014 and 2015, Painel (1200 m a.s.l.).

Phenolic compounds (mg L^{-1})	Vintage	Training System		F Test (ANOVA)
		Y-Trellis	VSP	p<0.05
Gallic Acid	2014	8.6 ± 1.3	10.2 ± 1.9	ns
	2015	29.3 ± 0.9	26.2 ± 0.7	*
	Average	18.9 ± 1.5	18.2 ± 1.8	ns
Catechin	2014	27.0 ± 5.8	29.0 ± 4.9	ns
	2015	24.3 ± 3.3	56.9 ± 2.8	*
	Average	25.6 ± 4.2	42.5 ± 3.3	*
Vanillic Acid	2014	3.7 ± 0.4	3.9 ± 0.5	ns
	2015	4.8 ± 0.2	4.9 ± 0.2	ns
	Average	4.3 ± 0.4	4.4 ± 0.8	ns
P-Coumaric Acid	2014	1.4 ± 0.1	1.4 ± 0.1	ns
	2015	2.8 ± 1.4	1.3 ± 0.2	ns
	Average	2.1 ± 1.9	1.4 ± 0.2	ns
Rutin	2014	1.9 ± 0.8	1.7 ± 1.1	ns
	2015	NQ	NQ	-
	Average	1.9 ± 0.8	1.7 ± 1.1	ns
Resveratrol	2014	1.2 ± 0.5	0.9 ± 0.3	ns
	2015	3.2 ± 0.6	1.6 ± 0.1	*
	Average	2.3 ± 0.7	1.3 ± 0.3	*
Quercetin	2014	1.1 ± 0.7	2.3 ± 0.2	ns
	2015	4.5 ± 0.6	12.4 ± 0.6	*
	Average	2.9 ± 0.5	14.5 ± 0.9	*
Kaempferol	2014	NQ	NQ	-
	2015	0.3 ± 0.1	2.0 ± 0.1	*
	Average	0.3 ± 0.1	2.0 ± 0.1	*

* = significant. ns = not significant. Average ± standard deviation. NQ = not quantified.

For the wines from Panel (1200 m a.s.l.) from vintage 2014, no statistical difference was detected for any of the phenolic compounds evaluated. However, in 2015, the 'Cabernet Sauvignon' wines from plants trained in VSP presented higher levels of catechin, quercetin and kaempferol. While the wines from plants trained in Y-Trellis had higher values of gallic acid and resveratrol (Table 5).

In relation to the wines from vintage 2015 of the experimental area of São Joaquim (1300 m a.s.l.), the levels of gallic acid, vanillic acid, quercetin and kaempferol were quantified in higher concentrations in the wines from 'Cabernet Sauvignon' of plants trained in VSP. For the other compounds (catechin, p-coumaric acid, resveratrol), no statistical difference was observed in the concentration between the training systems (Table 6). The phenolic compound rutin was quantified only in the Painel wines from the vintage 2014.

Table 6. Phenolic compounds of wines from 'Cabernet Sauvignon' on Y-trellis and VSP training systems. Vintage 2015, São Joaquim (1300 m a.s.l.).

Phenolic compounds (mg L^{-1})	Training System		F Test (ANOVA)
	Y-Trellis	VSP	p<0.05
Gallic Acid	22.7 ± 2.1	31.0 ± 1.6	*
Catechin	63.1 ± 13.3	59.5 ± 3.5	ns
Vanillic Acid	5.3 ± 0.4	6.9 ± 0.5	*
P-Coumaric Acid	3.4 ± 0.6	5.2 ± 0.4	ns
Resveratrol	2.6 ± 0.6	2.8 ± 0.1	ns
Quercetin	11.3 ± 0.6	18.7 ± 1.4	*
Kaempferol	1.5 ± 0.1	3.9 ± 0.0	*
Rutin	NQ	NQ	-

* = significant. ns = not significant. Average ± standard deviation. NQ = not quantified.

Catechin was the predominant polyphenol in the evaluated 'Cabernet Sauvignon' wines, corroborating the results obtained by BURIN et al. (2011). The catechin concentrations obtained in this study were higher than those reported by GRIS et al. (2011) who observed levels between 13.7 and 20.4 mg L^{-1}; by BURIN et al. (2011) of 49.3 and 14.5 mg L^{-1} and by SIMON (2014) of 25.1 mg L^{-1} evaluating Cabernet Sauvignon wines in a high-altitude region.

Flavan-3-ols, represented mainly by catechin and epicatechin, are important because they confer astringency to wines (DOWNEY et al. 2003). Bitterness and astringency are associated with high levels of flavan-3-ols, which in turn are found in wines originated from plants with low productivity (CHAPMAN et al. 2004). This may explain the greater difference in catechin concentration between VSP and Y-Trellis wines in the vintage 2015, since vines trained in VSP had lower productivity in high-altitude regions of southern Brazil (MARCON FILHO 2017, WÜRZ et al. 2019).

Flavonols are important compounds in wine quality, as they contribute to bitterness and color, stabilizing anthocyanins (PUÉRTOLAS et al. 2010). Of the flavonols evaluated, quercetin was the most abundant in the wines analyzed. The levels of flavonol compounds (quercetin and kaempferol) were statistically higher in samples of 'Cabernet Sauvignon' wines originated from plants trained in VSP. Work carried out by WÜRZ et al. (2020) found that quercetin was the most abundant phenolic compound in Cabernet Sauvignon wines in high altitude region of Santa Catarina.

It is known that the expression of genes involved in the regulation of flavonol synthesis are stimulated by sunlight (DOWNEY et al. 2003, RISTIC et al. 2007), and

that the flavonol content in grapes exposed to the sun is normally increased (RISTIC et al. 2007), in addition, there may be an effect of plant vigor (CORTELL et al. 2005), directly influenced by the training system.

Bitterness and astringency are associated with high levels of flavan-3-ols (CHAPMAN et al. 2004). In this context, low catechin values are desirable in wines (MARCON FILHO et al. 2021). These compounds are extracted from grape skins and seeds during the winemaking process and, during wine aging, undergo structural transformations, oxidation and condensation reactions that influence the astringency and color of wines (MATEUS et al. 2003).

Among the climatic factors associated with flavonoid biosynthesis, studies report that irradiation by UVB light should be associated with an increase in the concentration of the enzyme responsible for flavonoid biosynthesis, which protects the genetic material of plants against damage caused by ultraviolet rays (KOLOUCHOVÁ-HANZLÍKOVÁ et al. 2004). During the ripening phase of grapes, clusters more exposed to the sun can contain up to ten times more flavonols than shaded clusters, which is due to the increased concentration of quercetin 3-glucoside, kaempferol and myricetin (SPAYD et al. 2002). According to the results obtained in this study, it is possible to state that the VSP training system, by allowing greater exposure of clusters to sunlight, can promote the accumulation of flavonols in grapes and consequently in wines.

The main hydroxybenzoic acid present in red wine is gallic acid, formed mainly by the hydrolysis of flavonoid gallates (CARTONI et al. 1991). Gallic acid is described as one of the most important phenolic compounds because it is a precursor of all hydrolyzable tannins (WÜRZ et al. 2020).

There was a tendency for wines originated from plants trained in VSP to present higher levels of hydroxybenzoic acid (gallic and vanillic). The values obtained were similar to those reported by BURIN et al. (2011) of 23.3 and 13.2 mg L^{-1} and SIMON (2014) of 24.5 mg L^{-1} for gallic acid in ‘Cabernet Sauvignon’ wines from São Joaquim. Work carried out by MARCON FILHO et al. (2021), with the Sauvignon Blanc, observed that grapes grown on Y-Trellis results in wines with higher levels of gallic acid, while the VSP results in higher catechin levels.

Regarding the content of hydroxycinnamic acids (p-coumaric), no difference was observed between the two training systems. This group of compounds is important in wine composition, mainly due to their ability to react with anthocyanins and consequently stabilize the color of wines (GRIS et al. 2007). Hydroxycinnamic acids and their derivatives participate as pigmentation cofactors (GIL et al. 2015). In this work, the values of p-coumaric acid obtained are higher than those reported by BURIN et al. (2011) of 1.69 and 0.47 mg L^{-1}.

The stilbenes monomers, *cis* and *trans*-resveratrol, are phytoalexins, components synthesized by the grapevine in response to a stress situation (WÜRZ et al. 2020). *Trans*-resveratrol (*trans*-3,5,4-trihydroxystilbene) is the most studied due to its potential benefits for human health (GRIS et al. 2010).

In the vintage 2015, higher resveratrol levels were observed in wines from grapes grown in Y-Trellis in the Painel area (1200 m a.s.l.), with a concentration twice

as high as in wines from VSP. This behavior can be explained by the better vegetative-productive balance and solar exposure resulting from the training system, since according to ALLEBRANDT et al. (2024), a better vegetative-productive balance can favor the increase of solar radiation in the vegetative canopy and in the clusters, contributing to the increase in resveratrol.

CONCLUSION

The anthocyanin content was effect of training system on the wines. The other variables (pH, total polyphenols, total acidity, color intensity and color hue) do not allow us to conclude an effect of training systems, given the variation in response between location and vintage.

Cabernet Sauvignon wines made with grapes from Y-Trellis have higher resveratrol levels, while the VSP has higher values for flavonols quercetin and kaempferol.

The results of this study show that the Y-Trellis is an alternative for use in the high-altitude regions of Santa Catarina, as it does not compromise the wine quality, due to its potential for greater yield.

NOTES

AUTHOR CONTRIBUTIONS

Conceptualization, methodology, and formal analysis**, José Luiz Marcon Filho e Leo Rufato**; software and validation**, Alberto Fontanella Brighenti;** investigation**, Douglas André Wurz, Alberto Fontanella Brighenti e José Luiz Marcon Filho**; resources and data curation**, Leo Rufato**; writing-original draft preparation**, Douglas André Wurz, Alberto Fontanella Brighenti e José Luiz Marcon Filho**; writing-review and editing**, Douglas André Wurz, Alberto Fontanella Brighenti e José Luiz Marcon Filho**; visualization**, Douglas André Wurz, Alberto Fontanella Brighenti e José Luiz Marcon Filho**; supervision, **Leo Rufato**; project administration, **Leo Rufato**; funding acquisition, **Leo Rufato**. All authors have read and agreed to the published version of the manuscript.

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Not applicable because this study did not involve humans.

DATA AVAILABILITY STATEMENT

The data can be made available under request.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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