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Physicochemical and aromatic composition of 'Sauvignon Blanc' wines obtained from the Y-trellis and VSP training systems

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Abstract – The objective of this work was to compare the effect of the Y-trellis and vertical shoot position trellis (VSP) training systems on the physicochemical composition and aromatic profile of 'Sauvignon Blanc' (*Vitis vinifera*) wines in a high-altitude region of the state of Santa Catarina, Southern Brazil. The experiment was conducted during the 2015 vintage in a commercial vineyard located in the municipality of São Joaquim. The treatments consisted of the training systems: Y-trellis and VSP pruned in spur cordon. Sixty kilograms of grapes were harvested from each training system to make the wines, which were evaluated as to their chemical and phenolic composition and aromatic profile. There is no effect of the training system on the wine chemical variables pH, total acidity, color, and total polyphenols. The aromatic profile and phenolic composition of the wines are affected by the training systems, being related to the variables ethyl acetate, isoamyl acetate, 3-methyl-1-butanol, propanoic acid, and gallic acid in the Y-trellis, and to 1-hexanol, isovaleric acid, caprylic acid, capric acid, and catechin in VSP. The Y-trellis system can be an alternative for high-altitude regions of Southern Brazil.

Index terms: *Vitis vinifera*, polyphenols, vegetative-productive balance, volatile compounds.

Composição físico-química e aromática de vinho 'Sauvignon Blanc' obtido dos sistemas de sustentação Y e espaldeira

Resumo – O objetivo do trabalho foi avaliar o efeito dos sistemas de sustentação ípsilon e espaldeira na composição físico-química e no perfil aromático de vinhos 'Sauvignon Blanc' (*Vitis vinifera*), em região de elevada altitude no estado de Santa Catarina, no Sul do Brasil. O experimento foi conduzido durante a safra 2015 em vinhedo comercial localizado no município de São Joaquim. Os tratamentos consistiram nos sistemas: sustentação Y e espaldeira podada em cordão esporonado. Foram colhidos 60 kg de uva de cada sistema de sustentação para a elaboração dos vinhos, os quais foram avaliados quanto à sua composição química e fenólica e ao seu perfil aromático. Não há efeito do sistema de sustentação nas variáveis físico-químicas do vinho pH, acidez total, coloração e polifenóis totais. O perfil aromático e a composição fenólica dos vinhos são influenciados pelos sistemas de condução, tendo se relacionado com as variáveis acetato de etila, acetato de isoamila, 3-metil-1-butanol, ácido propanoico e ácido gálico no sistema em Y, e com 1-hexanol, ácido isovalérico, ácido caproico, ácido cáprico e catequina no sistema em espaldeira. O sistema em Y pode ser uma alternativa para regiões de elevada altitude no Sul do Brasil.

Termos para indexação: *Vitis vinifera*, polifenóis, equilíbrio vegeto-produtivo, compostos voláteis.

Introduction

The high-altitude regions of the state of Santa Catarina, Brazil, are characterized by having vineyards between 900 and 1,400 m above sea level, with longer phenological cycles, as well as a greater solar radiation availability and thermal amplitude than the other wine-growing regions of the country (Brighenti et al., 2013). Among grape cultivars, the Sauvignon Blanc white grape (*Vitis vinifera* L.) is well adapted to the edaphoclimatic conditions of high-altitude regions, such as those of Santa Catarina, and its wines present high quality, with specific features such as a high aromatic complexity and quality and also typicality (Brighenti et al., 2013).

In high-altitude regions, grapevine production is based on the vertical shoot position trellis (VSP), and vines are pruned in spur cordon (Vianna et al., 2016). These features, combined with high concentrations of organic matter in the soil (Zalamena et al., 2013) and with the choice of vigorous rootstocks, results in an excessive vegetative growth in the vineyards.

To overcome the problem of excessive vigor, changing canopy shape can be an alternative to achieve a balance between vegetative growth and grape production. This can be done through canopy division, which simultaneously increases production and can improve grape composition (Würz et al., 2019). An alternative for canopy division is the adoption of the Y-trellis, which has been used in many regions of Brazil (Hernandes et al., 2013). This training system, despite having a higher initial implantation cost than VSP, has the advantage of increasing production without loss of grape quality, besides facilitating the installation of protected cultivation, such as plastic cover or anti-hail nets (Pedro Júnior et al., 2015; Marcon Filho et al., 2017).

Grapevine training systems have been widely studied, as they affect plant ecophysiology, vineyard productivity, grape quality (Hernandes et al., 2013; Würz et al., 2019), and wine sensory and phenolic characteristics (Fragasso et al., 2012). In addition, the choice of training system directly influences wine phenolic composition and volatile compounds (Liu et al., 2018).

The phenolic compounds and the aromatic profile of wines are strongly dependent on the grape genetic basis (Guerrero et al., 2019) and can be altered by modifying the vegetative canopy or through winemaking practices based on the genetic plasticity of cultivars (Hernandez-Orte et al., 2015). Therefore, the chemical composition and aromatic quality of wines can be changed by training systems, which involve specific growing conditions, including exposure to light, inter-vine distance, distribution and orientation of foliage within a canopy, and vine density and size (Howell et al., 1991). These factors affect the content of the vine metabolites constituting the grape volatile profile and wine aroma (Zoecklein et al., 1998).

However, there are no known studies on the phenolic compounds and aromatic profile of 'Sauvignon Blanc' wines from grapes produced in vineyards under different training systems in high-altitude regions of the South of Brazil.

The objective of this work was to compare the effect of the Y-trellis and VSP training systems on the physicochemical composition and aromatic profile of 'Sauvignon Blanc' wines in a high-altitude region of the state of Santa Catarina, Southern Brazil.

Materials and Methods

The experiment was conducted during the 2015 harvest in a commercial vineyard located in the municipality of São Joaquim, in state of Santa Catarina, Brazil (28º13'86"S, 49º81'14"W, at an altitude of 1,350 m). The climate of the region is Cfb, constantly humid temperate according to Köppen-Geiger's classification, with a heliothermic index of 1,714, an average annual rainfall of 1,621 mm, and a relative humidity of 80% (Tonietto & Carbonneau, 2004). The soils of the region are classified as Cambissolo Húmico, Neossolo Litólico, and Nitossolo Háplico according to the Brazilian classification system (Santos et al., 2018), i.e., Inceptisol, Entisol, and Ultisol, respectivelly (Soil Survey Staff, 2014), developed from rhyodacite and basalt rock.

The implantation of the vineyard was carried out in the winter of 2009. The Sauvignon Blanc cultivar grafted onto the Paulsen 1103 rootstock was used, with a spacing of 3.0 m between rows and 1.5 m between plants. The used experimental design was randomized complete blocks with five replicates and five plants per plot.

The Y-trellis and VSP training systems were compared. The vines were pruned in bilateral spur cordon with two buds for VSP and two to four buds for the 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 company responsible for the vineyard, following the recommendations of the technicians in charge.

At harvest time, on 2/12/2015, 60 kg of grapes were manually harvested from each training system for winemaking. Microvinification was performed in the experimental winery of Universidade do Estado de Santa Catarina 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, total polyphenol content (mg L^{-1} gallic acid), and color (Abs 420 nm). Total acidity and pH were obtained by the methodology proposed by Organisation International de la Vigne et du Vin (OIV, 2012), whereas color was determined by the spectrophotometry method. The concentration of total polyphenols in grape skin was determined by the spectrophotometry method described by Singleton & Rossi (1965).

The phenolic compounds of the wines were quantified using high-performance liquid chromatography according to the methodology in Ferreira-Lima et al. (2013). Approximately 2.0 mL of a sample were filtered on a PES 0.45 µm membrane (Kasvi, São José dos Pinhais, PR, Brazil) with a syringe and then placed in a vial for direct injection into the high-performance liquid chromatography system.

The quantification of all compounds (mg L^{-1}) was determined by calibration curves using an external standard. Most reagents used in the analysis, such as ≥ 99.9% acetonitrile (LabMaster Comércio de Produtos Científicos Ltda, Pinhais, PR, Brazil), ≥ 99.7% acetic acid (Sigma-Aldrich, Inc., Merck KGaA, Darmstadt, Germany), and ≥ 99.8% methanol (LabMaster Comércio de Produtos Científicos Ltda, Pinhais, PR, Brazil), were of chromatographic grade. However, ≥ 99% L-(+)-tartaric acid and ≥ 99.8% ethanol (Sigma-Aldrich, Inc., Merck KGaA, Darmstadt, Germany) were of analytical grade. The water used for the analyzes was obtained through the Milli-Q purification system and the Simplicity UV Water Purification System (MilliporeSigma, Burlington, MA, USA). Other used standards were: ≥ 98% anhydrous gallic acid, ≥ 98% (+)-catechin, ≥ 98% p-coumaric acid, ≥ 97% vanillic acid, ≥ 95% trans-resveratrol, ≥ 95% quercetin 3-glucoside, ≥ 94% rutin, and ≥ 97% Kaempferol-3-glucoside (Sigma-Aldrich, Inc., Merck KGaA, Darmstadt, Germany).

All solvents used as a mobile phase were previously filtered through a PES 0.45 µm pore membrane (Kasvi, São José dos Pinhais, PR, Brazil). The calibration ranges and equations for determining phenolic compounds are shown in Table 1.

Chromatographic analyzes were performed using a Shimadzu high performance liquid chromatography equipment (Shimadzu Corporation, Kyoto, Japan). The used column was C18, with 5 µm and 250 x 4.6 mm (Restek Corporation, Bellefonte, PA, USA). The software used to control the gradient system and the detector, as well as for data acquisition, was the Class-VP workstation (Shimadzu Corporation, Kyoto, Japan). For each sample, a duplicate reading was performed and, when a variation > 10% was detected,

Table 1. Parameters used to quantify the phenolic compounds in 'Sauvignon Blanc' (*Vitis vinifera*) wines from grapes produced in the Y-trellis and vertical shoot position training systems in a high-altitude region in the municipality of São Joaquim, in the state of Santa Catarina, Brazil, in 2015.

Compound	Calibration range (mg L^{-1})	Linear equation (y=ax)	$R^{2(1)}$	Quantification threshold (mg L^{-1})
Gallic acid	0.8–78.1	y=62,155x	0.997	0.006
Catechin	0.4–158.8	y=17,546x	0.999	0.072
Vanillic acid	0.4–39.8	y=41,400x	0.998	0.026
p-coumaric acid	0.3–29.4	y=116,481x	0.996	0.009
Rutin	0.3–29.9	y=21,032x	0.996	0.033
Trans-resveratrol	0.2–18.8	y=83,839x	0.994	0.013
Quercetin 3-glucoside	0.6–58.9	y=33,919x	0.998	0.031
Kaempferol-3-glucosid	0.1–13.4	y=40,635x	0.997	0.029

(1)R^2, coefficient of determination.

there was a third reading. The phenolic compounds were read at 280 nm.

The volatile compounds of the wines were quantified by the solid phase microextraction method in headspace mode, combined with gas chromatography with a flame ionization detector. A solid phase microextraction fiber composed of 50/30 mm divinylbenzene/carboxen/polydimethylsiloxane (Supelco, Bellefonte, PA, USA) was initially conditioned according to the manufacturer's recommendations. In a 20 mL vial, 5.0 mL of the sample and 1.5 g sodium chloride were added. The procedure for extracting volatile compounds was carried out using the TriPlus RSH autosampler (Thermo Fischer Scientific, Waltham, MA, USA) and the ChromQuest software (Thermo Fischer Scientific, Waltham, MA, USA). The samples were incubated for 5 min at 56°C and, afterwards, the fiber was exposed in the headspace for 55 min. The adsorption in the gas chromatograph injector was performed for 2 min, at 265°C, in splitless mode.

Chromatographic analyses were carried out on the CP-3800 GC-IT/MS chromatograph (Varian Inc., Walnut Creek, CA, USA), equipped with the Saturn 4000 ion-trap analyzer (Varian Inc., Walnut Creek, CA, USA), using the MS Workstation software (Agilent, Santa Clara, CA, USA). The ion trap detector functioned at 200°C in the transfer line, at 50°C in the manifold, and at 180°C in the trap. All mass spectra were obtained by electron impact, in the scan mode (25–400 m/z). The emission current was 50 μA, with 25,000 s maximum ionization. The positive identification of compounds was performed by comparing: the retention time obtained for the sample with the time observed for the standards of the volatile compounds injected under the same conditions; and the obtained mass spectra with those found in the MS 05 spectral database of National Institute of Standards and Technology (NIST, 2021), considering a similarity above 70%.

Chromatographic analyzes were carried out on the Trace 1310 gas chromatograph (Thermo Fischer Scientific, Waltham, MA, USA), equipped with a flame ionization detector and the ChromQuest software (Thermo Fischer Scientific, Waltham, MA, USA). The chromatographic separation was performed using the ZB-WAXplus column (Phenomenex, Torrance, CA, USA), with 60 m x 0.25 mm x 0.25 μm, and nitrogen gas as a carrier at a flow of 1.0 mL min^{-1}. The initial oven temperature was 40°C for 5 min, which was increased 2°C per minute until reaching 220°C.

Compounds were identified through retention time, compared with that of the standards of the volatile compounds. The evaluated aromatic compounds were: ethyl acetate, ethyl octanoate, ethyl decanoate, ethyl laurate, ethyl cinnamate, isoamyl acetate, ethyl isovalerate, phenylethyl acetate, 3-methyl-1-butanol, 1-propanol, 1-hexanol, propanoic acid, caproic acid (hexanoic), capric acid (decanoic), isovaleric acid (3-methylbutanoic), geraniol, α-terpineol, and γ-nonalactone. The quantification of all compounds (μg L^{-1}) was carried out by calibration curves with an external standard. The analytical standards of the volatile compounds studied were obtained from Sigma-Aldrich, Inc. (Merck KGaA, Darmstadt, Germany), with a purity equal to or greater than 98%. The used ethanol and sodium chloride were purchased from LabSynth (Diadema, SP, Brazil). For the experiment, ultrapure water was obtained through the Milli-Q purification system (MilliporeSigma, Burlington, MA, USA). For each studied compound, a 100 mg L^{-1} stock solution was prepared in 50% ethanol and stored at 4°C. The standard solutions were prepared in synthetic wine (5.0 g L^{-1} tartaric acid, 11% ethanol, and 3.5 pH)

The active odor value (AOV) of the wines was determined to assess the contribution of the chemical compounds to the drink's aroma. The AOV was calculated by the relationship between the concentration of a given compound and the threshold of perception described in the literature (Caliari et al., 2014).

The experimental design used for winemaking and analysis was randomized complete blocks, with four replicates for each treatment. The data were subjected to the analysis of variance by the F-test, at 5% probability. For the variables for which differences were detected by the analysis of variance, data were also subjected to the principal component analysis.

Results and Discussion

Regarding the wine chemical characteristics total acidity, pH, and color, there were no significant differences between the Y-trellis and VSP training systems in the 2015 vintage (Table 2). The acidity values in both systems can be considered high, in comparison with those reported by Würz et al. (2018), also in a high-altitude region of Santa Catarina.

For the content of total polyphenols in the wines, there was no difference between the evaluated training systems, with similar values for polyphenols, p-coumaric acid, and vanillic acid (Table 3). The wines derived from grapes produced in Y-trellis had a higher amount of gallic acid, while those in VSP had a higher catechin content.

Gallic acid is originated from the hydrolysis of esters after a few months and is stable during aging, with an average amount of 10 mg L^{-1} in white wine (Ribéreau-Gayon et al., 2006).

Flavan-3-ols, represented mainly by catechin and epicatechin are important, because they give astringency to wines (Downey et al., 2003). A study by Salacha et al. (2008) showed the positive correlation between browning of white wines and the presence of catechins. Bitterness and astringency are associated with high levels of flavan-3-ols, which are found in wines originated from plants with low yields (Chapman et al., 2004). This may explain the greater difference in catechin concentration between the wines derived from grapes from the VSP and Y-trellis systems, since the vines trained on VSP had lower yields in high-altitude regions of Southern Brazil (Marcon Filho et al., 2017; Würz et al., 2019).

Under the conditions of the chromatographic analysis, polyphenols, rutin, trans-resveratrol, quercetin, and Kaempferol-3-glucosid were not quantified in the 'Sauvignon Blanc' wines.

The aromatic attributes allowed to adequately differentiate the wines resulting from the grapes harvested from the vines trained in Y-trellis and VSP in the 2015 harvest. In the two training systems, 18 aromatic compounds were quantified in the 'Sauvignon Blanc' wines, belonging to the following chemical groups: esters, alcohols, fatty acids, terpenes, and lactones (Table 4).

The aromatic compounds ethyl acetate, isoamyl acetate, 3-methyl-1-butanol, and propanoic acid were quantified at a higher concentration in the wines

Table 2. Total acidity, pH, and color of 'Sauvignon Blanc' (*Vitis vinifera*) wines from grapes produced in the Y-trellis and vertical shoot position (VSP) training systems in a high-altitude region in the municipality of São Joaquim, in the state of Santa Catarina, Brazil, in 2015.

Parameter	Training system[1]		F-test (ANOVA)[2] p<0.05
	Y-trellis	VSP	
Total acidity (meq L^{-1})	159.80±3.90	173.10±11.85	ns
pH	2.85±0.01	2.82+0.03	ns
Color (Abs 420 nm)	0.03±0.00	0.04±0.01	ns

[1]Average ± standard deviation. [2]ANOVA, analysis of variance. [ns]Nonsignificant.

Table 3. Total polyphenols and phenolic compounds of 'Sauvignon Blanc' (*Vitis vinifera*) wines from grapes produced in the Y-trellis and vertical shoot position (VSP) training systems in a high-altitude region in the municipality of São Joaquim, in the state of Santa Catarina, Brazil, in 2015.

Phenolic compound	Concentration of total polyphenols and phenolic compounds (mg L^{-1})[1]		F-test (ANOVA)[2]
	Y-trellis	VSP	p<0.05
Total polyphenols (mg L^{-1} of gallic acid)	172.50±4.85	175.90±6.63	ns
Gallic acid	6.68±0.36	5.77±0.37	*
Catechin	9.84±0.54	10.80±0.40	*
Vanillic acid	0.29±0.01	0.28±0.01	ns
P-coumaric acid	0.05±0.01	0.05±0.01	ns
Rutin	NQ[3]	NQ	-
Trans-resveratrol	NQ	NQ	-
Quercetin 3-glucoside	NQ	NQ	-
Kaempferol-3-glucosid	NQ	NQ	-

[1]Average ± standard deviation. [2]ANOVA, analysis of variance. [3]NQ, nonquantifiable.*Significant. [ns]Nonsignificant.

derived from the vines trained in the Y-trellis. However, 1-hexanol, caproic acid, capric acid, and isovaleric acid were superior in the wines obtained from the vines in VSP. Regarding their concentration in the wines, the other compounds (ethyl octanoate, ethyl decanoate, ethyl laurate, ethyl cinnamate, ethyl isovalerate, phenylethyl acetate, 1-propanol, geraniol, α-terpineol, and γ-nonalactone) did not differ significantly between both training systems.

In relation to the compounds with AOV > 1 (Table 4), isoamyl acetate contributed 2.5 times more to the aroma of the wines from the vines in the Y-trellis than in the VSP training system. Isoamyl acetate is an ester derived from the reaction of acetyl-CoA with higher alcohols formed by the degradation of amino acids or carbohydrates (Perestrelo et al., 2006), being one of the most significant esters in aromatic quality due to its pleasant aroma (Quincozes et al., 2020), which resembles that of a fruit, such as banana and pear (Escudero et al., 2007).

The fatty acids isovaleric acid, capric acid, and caproic acid had a greater impact on the wines from grapes produced in VSP. Medium-chain fatty acids are biosynthesized during fermentation by yeasts and can have different origins, whereas long-chain fatty acids are probably used as a catabolic source by yeasts at the beginning of alcoholic fermentation and for the formation of capric and caproic acids during their catabolism (Ribéreau-Gayon et al., 2006). The latter fatty acids have a rancid and cheese-like aroma, so, increasing their concentration decreases the sensory quality of wines (Bordiga et al., 2013).

The aromatic compounds that impacted differently the wines of 'Sauvignon Blanc' in Y-trellis and VSP are secondary aromas formed by the metabolism of yeasts in fermentation. Therefore, the influence of the

Table 4. Concentration and active odor value (AOV) of aromatic compounds of 'Sauvignon Blanc' (*Vitis vinifera*) wines derived from grapes produced in the Y-trellis and vertical shoot position (VSP) training systems in a high-altitude region in the municipality of São Joaquim, in the state of Santa Catarina, Brazil, in 2015.

Aromatic compound	Concentration (μg L^{-1})[1]		F-test (ANOVA)[2] $p<0.05$	Active odor value (AOV)	
	Y-trellis	VSP		Y-trellis	VSP
Esters					
Ethyl acetate	1,778±148	961±118	*	0.2	0.1
Ethyl octanoate	499±87	598±57	ns	99.7	119.6
Ethyl decanoate	5±0.5	3±0.6	ns	0.02	0.01
Ethyl laurate	NQ[3]	NQ	-	-	-
Ethyl cinnamate	15±3	14±1	ns	13.2	12.6
Isoamyl acetate	294±6	114±18	*	9.8	3.8
Ethyl isovalerate	740±136	604±61	ns	246.6	201.3
Phenylethyl acetate	659±87	742±311	ns	2.6	2.5
Alcohols					
3-methyl-1-butanol	48±25	7±14	*	0.0	0.0
1-propanol	18,643±1,762	18,110±1,687	ns	0.6	0.6
1-hexanol	548±79	679±56	*	0.1	0.1
Fatty acids					
Propanoic acid	90±14	57±8	*	0.01	0.01
Caproic acid (hexanoic)	1,085±293	1,951±365	*	2.6	4.67
Capric acid (decanoic)	2,218±198	2,844±417	*	147.9	189.6
Isovaleric acid (3-methyl-butanoic)	2,043±231	3,281±368	*	61.9	99.4
Terpenes					
Geraniol	NQ	NQ	-	-	-
α-terpineol	120±4	128±13	ns	0.5	0.5
Lactones					
γ-nonalactone	52±7	49±8	ns	1.7	1.6

[1]Average + standard deviation. [2]ANOVA, analysis of variance. [3]NQ, nonquantifiable. *Significant. [ns]Nonsignificant.

training systems on these compounds may be related to the difference in the concentration of flavor precursors, considering that each training system involves specific plant growth conditions that affect grape metabolite content (Fragasso et al., 2012). Monoterpenes, for example, are affected by the exposure of clusters to sunlight (Zhang et al., 2017). The advanced maturity of grapes may have contributed to higher levels of flavor compounds, compared with those of other training systems (Reynolds & Wardle, 1994).

Conclusions

1. The vine training system does not influence the variables pH, total acidity, color, and total polyphenols of 'Sauvignon Blanc' (*Vitis vinifera*) wines.

2. Wines derived from vines trained on vertical shoot position (VSP) have a higher catechin content, while those from vines in the Y-trellis system have a higher amount of gallic acid.

3. The aromatic profile and phenolic composition of the wines differ when the vines are trained in the Y-trellis and VSP systems, being related to ethyl acetate, isoamyl acetate, 3-methyl-1-butanol, propanoic acid, and gallic acid in Y-trellis, and to 1-hexanol, isovaleric acid, caproic acid, capric acid, and catechin in VSP.

4. Y-trellis can be an alternative training system for high-altitude regions of Southern Brazil, positively impacting the aromatic quality and phenolic composition of 'Sauvignon Blanc' wines.

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