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Article

AGRONOMIC PERFORMANCE AND WINE PHENOLIC COMPOSITION OF 'MERLOT' GROWN IN ALTITUDE REGION WITH DIFFERENT ROOTSTOCKS

DESEMPENHO AGRONÔMICO E COMPOSIÇÃO FENÓLICA DO VINHO DE 'MERLOT' CULTIVADA EM REGIÃO DE ALTITUDE COM DIFERENTES PORTA-ENXERTOS

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SUMMARY

Several studies have reported the influence of rootstocks on grape and wine composition, however, there is considerable variability in the results. The objective of this work was to evaluate the effects of three different rootstocks on vegetative-productive balance and the wine composition of 'Merlot'. The present work was conducted in the municipality of Painel, during the 2014/2015, 2015/2016 and 2016/2017 vintages. The vegetative, productive, and enological variables of 'Merlot' grafted onto 'Paulsen 1103', '3309 Couderc' and '101-14 Mgt' rootstocks were evaluated. The ANOVA results showed that'3309C' rootstock promoted an increase in the productive indices, and consequently in more adequate vegetative-productive balance for 'Merlot' variety compared to the rootstocks 'Paulsen 1103' and '101-14 Mgt'. The rootstocks '3309C' and '101-14 Mgt' provided more adequate maturation indices for 'Merlot'. The '101-14 Mgt' rootstock was associated with the highest contents of flavonoid compounds, while the '3309C' rootstock was related to higher contents of non-flavonoid compounds, especially resveratrol.

RESUMO

Vários estudos têm relatado a influência dos porta-enxertos na composição da uva e do vinho, mas existe uma variabilidade considerável nos resultados. O objetivo deste trabalho foi avaliar o efeito de diferentes porta-enxertos sobre o equilíbrio vegeto produtivo e a composição dos vinhos da variedade 'Merlot'. O presente trabalho foi conduzido no município de Painel, durante os ciclos 2014/2015, 2015/2016 e 2016/2017. Foram avaliadas as variáveis vegetativas, produtivas e enológicas da variedade 'Merlot' enxertada sobre 'Paulsen 1103', '3309 Couderc' e '101-14 Mgt'. Os resultados da ANOVA revelaram que o porta-enxerto '3309C' promoveu um incremento dos índices produtivos e, consequentemente, índices de equilíbrio vegeto-produtivos mais adequados para a variedade 'Merlot' em comparação com os porta-enxertos 'Paulsen 1103' e '101-14 Mgt'. Os porta-enxertos '3309C' e '101-14 Mgt' propiciaram uma maturação mais adequada da variedade 'Merlot'. O porta-enxerto '101-14 Mgt' esteve associado a teores mais elevados de compostos flavonóides, enquanto o porta-enxerto '3309C' esteve relacionado com teores superiores de compostos não-flavonóides, com destaque para o resveratrol.

Keywords: *Vitis vinifera* L., phenolic compounds, technological maturation, altitude wines.
Palavras-chave: *Vitis vinifera* L., compostos fenólicos, maturação tecnológica, vinhos de altitude.

INTRODUCTION

The high-altitude region of Santa Catarina State/Brazil is characterized by presenting its vineyards at an altitude ranging from 900 to 1400 m above sea level, where grape phenological cycle is longer than in other Brazilian wine producing regions (Brighenti *et al*., 2013). Wine produced in this region has high-color quality and aroma capable of differentiating it from wine made in other regions (Marcon Filho *et al*., 2015).

The environmental conditions found in high altitude regions are challenging to obtain balanced vineyards. Among them, high water availability (Bem *et al*., 2016) and high organic matter in the soil (Mafra *et al*., 2011) stand out, which associated with the use of vigorous rootstock (Borghezan *et al*., 2011) promote excessive vegetative growth; this shows that it is

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necessary to improve vine balance, which allows grapes to be harvested at appropriate levels of maturity (Wurz *et al*., 2017).

The use of rootstocks in viticulture provides a platform for manipulating a wide range of vine traits that can improve the productive efficiency of the vineyard. Among them, we can report, the ability to absorb and transport nutrients (Stockert *et al*., 2013; Lecourt *et al*., 2015), resistance to water deficit (Pavlousek, 2011) and the transport of plant hormones (Nikolaou *et al*., 2000). Rootstocks can play an important role in controlling excessive vegetative growth and increasing fruit set in low-fertility varieties (Kidman *et al*., 2013). These skills depend on their adaptability to the environment and interaction with the canopy variety (Tandonnet *et al*., 2010).

Several studies have reported the influence of rootstocks on grape and wine composition, however, there is considerable variability in the results. According to Han *et al*. (2022), some research indicated that rootstocks with different characteristics confer different phenotypic traits to the scion. For example, rootstocks with high vigor increase yield and pruning weight, as well as the titratable acid content in the juice. Several studies, however, showed that rootstocks did not affect basic fruit composition parameters. Miele and Rizzon (2017) studied the composition of ‘Cabernet Sauvignon’ must on 15 rootstocks and found higher levels of sugars and pH in rootstocks that had ‘*V. riparia*’ in their genetics, such as ‘101-14 Mgt’ and ‘3309C’. Ollat *et al*. (2003), found higher anthocyanin contents in grapes of plants grafted onto *V. Riparia* compared to ‘101-14 Mgt’ and ‘SO4’. The same study found differences in the concentration of sugars.

Some authors argue that the rootstock has some significant effects on grape and wine composition, but that the determining factors are related to the scion variety and the environment factor (Harbertson and Keller, 2011). But in general, other studies have clearly demonstrated that the rootstock has considerable potential to determine important characteristics of grape and wine quality (Jogaiah *et al*., 2015). The mechanisms involved in this phenomenon may be related to the modification of the relationship between vegetative and reproductive development (Kidman *et al*., 2013; Miele and Rizzon, 2017), or even to the direct influence on fruit composition (Kodur *et al*., 2013; Jogaiah *et al*., 2015).

In the highlands of Santa Catarina State/Brazil, it is observed that 72% of the vines are grafted onto ‘1103 Paulsen’ (Vianna *et al*., 2016), which is described in the literature as a vigorous genotype (Keller, 2015). Regarding the characteristics of '1103 Paulsen' with the edaphoclimatic conditions found in the highlands of Santa Catarina, an environment conducive to the vegetative growth of the canopy varieties exists, which leads to an imbalance in the vineyards (Brighenti *et al*., 2011; Zalamena *et al*., 2013).

In this context, the objective of this work was to evaluate the effects of different rootstocks on the vegetative-productive balance and the wine composition of 'Merlot'. For this purpose, in addition to ‘1103P’, the rootstocks ‘3309C’ and ‘101-14 Mgt’, which are known to confer moderate to low vigor (Keller, 2015), were tested.

MATERIALS AND METHODS

The present work was carried out in the municipality of Painel (28°01'S, 50°08'W and 1,200 m above sea level) during the 2014/2015, 2015/2016 and 2016/2017 cycles. The vineyards were planted in 2004, spacing 3.0 m between rows and 1.5 m between plants. The plants are trained in Y trellis system with double spur cordon pruning. Soils in the region are considered Humic Cambisol, Litholic Neosol and Haplic Nitosol classes, developed from rhyodacite and basalt rocks (Santos *et al*., 2018). The climate of the region, according to the Koeppen climate classification system, is classified as humid mesothermal and mild summer (Cfb).

The experimental design was randomized blocks, with four blocks, each repetition consisting of 10 uniform plants in vigor. The vegetative, productive, and enological variables of the Merlot variety grafted onto ‘Paulsen 1103’, ‘3309 Couderc’ and ‘101-14 Mgt’ rootstocks were evaluated.

Harvesting took place on the same day for all three rootstocks, according to the winery's criteria. On the date of harvest, data on production and leaf area were recorded, and samples of clusters and berries were collected for further analysis and microvinification in the laboratory.

Yield, number of clusters and number of shoots were recorded for each plant of each treatment. Cluster mass was estimated by dividing production per plant by the number of clusters per plant. The number of clusters per shoot was obtained by dividing the number of clusters per plant by the number of shoots per plant.

To estimate the leaf area per plant, 10 shoots per plot were selected in the middle third of the cordon. In these shoots, the midvein length (cm) of all leaves was obtained with a ruler. For each leaf, the leaf area was calculated using the formula: $y = 1.1265x^{2.0445}$, where y corresponds to the leaf area in cm² and x corresponds to the midvein length in cm (Borghezan *et al*., 2010). By adding the leaf area of the leaves for each shoot, the leaf area per shoot was obtained. From there, the average leaf area per shoot was calculated for each treatment, and by multiplying this value by the number of shoots per plant, an estimate of the leaf area per plant was obtained. The ratio between leaf area and fruit mass (LA/Fruit) was calculated by dividing the leaf area (m²) by the yield (kg), and the results were expressed in cm²/g. The Ravaz index was obtained from the ratio of fruit mass to mass of branches (Cus, 2004).

Samples of 100 berries per plot were collected for technological maturation analyzes and determination of berry diameter and mass. In the laboratory, the berries were weighed and individually crushed to obtain the must. The content of soluble solids was analyzed using a digital refractometer with temperature compensation (ATAGO®, PAL-1); the pH was analyzed with a potentiometer (Impac®); and the total acidity, through titration with 0.1N NaOH, using bromothymol blue indicator until the pH of the medium reached 8.2, with the results expressed in mEq/L (OIV, 2015).

For microvinification, 40 kg samples were collected per treatment, which were kept in a cold storage for 24 hours at 5 ºC. The microvinifications were carried out at the Enology Laboratory of Santa Catarina State University, in the city of Lages/SC and followed the protocol adapted from Pszczolkowski; Lecco (2011), Makhotkina *et al*. (2013), as described by Wurz *et al*. (2018).

The analysis of total polyphenol content was carried out in a UV-VIS spectrophotometer (Biospectro - SP220), according to the methodology described by Singleton and Rossi (1965), and the results were expressed in mg gallic acid/L. The anthocyanin content was determined by spectrophotometry, using the method described by Rizzon (2010). Wine color was measured in a spectrophotometer, through absorbance measurements at 420 nm, 520 nm and 620 nm. The color intensity and hue were calculated as follows: Intensity = 420 nm + 520 nm + 620 nm; Hue = 420 nm/520 nm.

The wines phenolic compounds were quantified by high performance liquid chromatography (HPLC) according to the methodology described by Cadahía *et al*. (2009) and adapted by Ferreira-Lima *et al*. (2013), according to the quantitative methodology described by Marcon Filho *et al*. (2022). A solution containing a mixture of all standards was prepared in a synthetic wine medium (5 g/L tartaric acid, 12% v/v ethanol and pH 3.2). Synthetic wine was used to avoid interference in chromatographic separation and detection response. The calibration solutions were also prepared in synthetic wine by diluting the stock solution containing the mixture of the standards. All the solutions used were previously filtered through a 0.45 µm membrane (PES-Kasvi membrane).

Approximately 2 mL of sample (wine or calibration solution) was filtered on a 0.45 µm membrane (PES-Kasvi membrane) with a syringe and placed in the vial for direct injection into the HPLC system.

The reagents used in the analyzsis, such as acetonitrile (≥ 99.9%, Fluka), acetic acid (≥ 99.7%, Sigma -Aldrich) and methanol (≥ 99.8%, Biotec), were of chromatographic grade. Tartaric acid L (+) (≥ 99%, Vetec) and ethanol (≥ 99.8%, Vetec) were of analytical grade. The water used in analyzes 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 purchased from Sigma-Aldrich.

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). The software used to control the gradient system, the detector and for data acquisition was Shimadzu Class-VP. For each sample was analyzed in duplicate; when a variation of more than 10% was detected, a third analysis was performed. The phenolic compounds were detected at 280 nm.

The data were submitted to analysis of variance (ANOVA); when significant effects of the rootstocks were detected, the Fisher's least significant difference (LSD) test was performed ($p<0.005$).

RESULTS AND DISCUSSION

The yield of 'Merlot' was significantly affected by the rootstock, as shown in Table I. The highest yield was observed with '3309 C' (5.5 kg/plant), which had the highest number of clusters (81.6 clusters/plant) and the heaviest clusters (64.5 g/cluster). The rootstocks '1103 P' and '101-14 Mgt' were associated with the lowest yields (3.7 and 4.5 kg/plant, respectively), the lowest number of clusters (64.7 and 73.0 clusters/plant, respectively), and the lowest average cluster mass (55.5 and 57.8 g/cluster, respectively).

These observations are in line with the literature, especially with the work of Kidman *et al*. (2013), who report an increase in 'Merlot' bud fertility and fruit set when grafted onto rootstocks that have '*V. riparia*' in their genetics. In another study, the authors also found the highest yields when 'Merlot' was grafted onto '3309 C', compared with other rootstocks during three years of studies (Keller *et al*., 2011).

The higher leaf area averages per plant were observed with '1103 P' (15.8 m^2) and '3309 C' (15.2 m^2), and the lowest was observed with '101-14 Mgt' (12.2 m^2), as shown in Table II. 'Merlot' grafted onto '1103 P' and '101-14 Mgt' presented values of 1.8 and 1.6 kg of pruning material per plant, respectively.

Table I

Production components of 'Merlot' (*Vitis vinifera* L.) grafted onto different rootstocks, grown in altitude region, during the 2014/15, 2015/16 and 2016/17 cycles

Variables	Cycle	Rootstocks		
		'1103 P'	**'3309 C'**	**'101-14 Mgt'**
Yield (kg)	2015	3.8 ± 0.2	6.8 ± 0.2	4.3 ± 0.2
	2016	1.6 ± 0.1	2.9 ± 0.3	1.9 ± 0.1
	2017	5.2 ± 0.7	6.8 ± 0.8	6.8 ± 0.8
	Average	3.7 ± 0.4 b	5.5 ± 0.5 a	4.5 ± 0.5 b
Clusters per plant	2015	59.9 ± 2.8	89.1 ± 4.3	72.0 ± 2.6
	2016	54.3 ± 3.3	68.8 ± 3.9	56.3 ± 3.2
	2017	75.7 ± 9.6	87.3 ± 6.5	87.1 ± 7.9
	Average	64.7 ± 4.4 b	81.6 ± 3.5 a	73.0 ± 4.1 ab
Cluster mass (g)	2015	64.1 ± 1.5 b	76.8 ± 2.0 a	59.4 ± 1.7 b
	2016	29.0 ± 2.1 b	41.5 ± 2.3 a	33.0 ± 1.2 b
	2017	68.5 ± 3.1 b	75.5 ± 3.3 ab	76.5 ± 4.7 a
	Average	55.5 ± 3.7 b	64.5 ± 3.4 a	57.8 ± 4.0 b

Means within the same row followed by different letters differ significantly by Fisher's LSD test ($p<0.05$). Mean ± standard error.

This difference is directly related to the variable shoot mass (g), since the rootstock '3309 C' had an average value of 28.1 g per shoot, while the rootstocks '1103 P' and '101-14 Mgt' had average values of 39.7 and 35.9 g per shoot, respectively.

Similar to previous reports, '1103 P' tended to increase scion pruning weights (Keller *et al*., 2012). According to Han *et al*. (2022), '1103 P' is a hybrid rootstock, with '*V. rupestris*' and '*V. berlandieri*' as parents, and absorb more water and nutrients to supply the vegetative growth of the canopy, resulting in a higher pruning weight, and greater vegetative growth.

Data related to vegetative-productive balance are described in Table III. It was observed that the '3309 C' and '101-14 Mgt' rootstocks resulted in a greater number of clusters per shoot (1.6 and 1.5 clusters per shoot, respectively), while the '1103 P' rootstock had 1.4 clusters per shoot. A similar behavior was observed for the leaf area/fruit ratio, with values of 33.4 and 34.7 cm^2/g, for rootstocks '3309 C' and '101-14 Mgt', respectively, while rootstock '1103 P' showed a value of 52.4 cm^2/g for the leaf area/fruit ratio. In high-altitude vineyards, ideal leaf area/yield ratios were established as 23 cm^2/g for 'Merlot' (Borghezan e*t al*., 2011).

Regarding the Ravaz Index, more adequate values were found for the rootstocks '3309 C' and '101-14 Mgt', with 4.1 and 3.2 kg/kg, respectively, while the '1103 P' rootstock presented a ratio of 2.2 kg/kg for this index.

Due to the increase of the production components, the rootstock '3309 C' improved the vegetative:productive balance variables. Kliewer; Dokoozlian (2005) reported that the Ravaz Index generally ranged from 5 to 10 between cultivars. Although the values found in '3309 C' are below the ideal minimum, they are still above the rates described in the high-altitude regions of Santa Catarina. In São Joaquim, for example, for 'Cabernet Sauvignon' and 'Merlot' varieties, values between 1.5 and 2.3 have already been described (Brighenti *et al*., 2011; Zalamena *et al*., 2013). Wooldridge *et al*. (2010) showed that the wine quality of 'Chardonnay' and 'Pinot Noir' onto different rootstocks was inversely proportional to pruning mass but positively correlated with the Ravaz Index.

This shows the importance of control the vegetative canopy for sutiable ratio between source and sink (Panceri *et al*., 2018). This behavior affected the estimated yield, since plants with a more adequate vegetative-productive balance resulted in better productive indices. Furthermore, according to Callili *et al*. (2023), excessive vegetative vigor leads to humid conditions and low radiation, increasing shading in the cluster zone and impairing the accumulation of soluble solids in the berries.

Table II

Vigor traits of 'Merlot' (Vitis vinifera L.) grafted onto different rootstocks, grown in altitude region, during the 2014/15, 2015/16 and 2016/17 cycles

Variables	Cycle	Rootstocks		
		'1103 P'	**'3309 C'**	**'101-14 Mgt'**
Leaf area (m^2)	2015	18.8 ± 0.7	16.3 ± 1.0	13.4 ± 0.3
	2016	12.1 ± 1.0	14.4 ± 0.7	9.9 ± 0.5
	2017	16.3 ± 1.0	15.2 ± 1.0	13.0 ± 0.6
	Average	15.8 ± 0.7 a	15.2 ± 0.5 a	12.2 ± 0.4 b
Pruning mass (kg)	2015	1.8 ± 0.1 a	1.4 ± 0.1 b	1.0 ± 0.1 c
	2016	1.9 ± 0.2 a	1.5 ± 0.1 b	2.1 ± 0.1 a
	2017	1.8 ± 0.1 a	1.3 ± 0.1 b	1.8 ± 0.1 a
	Average	1.8 ± 0.1 a	1.4 ± 0.1 b	1.6 ± 0.1 a
Shoot mass (g)	2015	36.0 ± 2.2 a	26.6 ± 2.8 ab	19.1 ± 1.4 b
	2016	47.2 ± 6.9 a	29.9 ± 2.2 b	52.2 ± 2.6 a
	2017	36.8 ± 3.0 a	27.5 ± 2.6 b	36.2 ± 2.7 a
	Average	39.7 ± 2.6 a	28.1 ± 1.5 b	35.9 ± 2.9 a

Means within the same row followed by different letters differ significantly by Fisher's LSD test ($p<0.05$). Mean ± standard error.

The different rootstocks influenced the maturation of 'Merlot', as shown in Table IV. Soluble solids were not influenced by the three rootstocks evaluated, however, regarding the pH, the higher values were found for the rootstocks '3309 C' (3.14) and '101-14 Mgt' (3.16) while the '1103 P' rootstock presented a value of 3.06.

Regarding total acidity, the highest value was observed for the rootstock '1103 P' (104.5 mEq/L), while the rootstocks '3309 C' and '101-14 Mgt' resulted in lower values, with averages of 96.7 and 96.9 mEq/L, respectively. Low vigor may also explain the lowest acid content for this combination, probably due to an increased berry exposure to sunlight, favoring acid degradation by rising in temperature (Zufferey *et al*., 2017).

Regarding the maturation of 'Merlot', similar data were observed by Han *et al*. (2022), which also reported the impact of rootstocks on total acidity and pH of the juice, without influencing soluble solids content. Nascimento *et al*. (2022), evaluated the effects of different rootstocks on 'Magna' variety and they observed similar behavior for these variables. Thought Azuma *et al.* (2019) suggested that under conditions of sufficient solar radiation, rootstocks may have less influence on fruit ripening.

These results agree with the work of Pouget (1986), who clearly demonstrated that vines with large canopies, induced by the rootstock, tend to prolong fruit maturation, in comparison with vines grafted onto low vigor genotypes, which in turn tend to accelerate the maturation process. This trend has also been reported in other studies (Brighenti *et al*., 2011; Keller *et al.,* 2011; Neal *et al*., 2014; Jogaiah *et al.,* 2015; Han *et al*., 2022).

The pH of 'Merlot' grapes was significantly higher in plants grafted onto '3309 C' and '101-14 Mgt'. These results are consistent with those found in other studies (Kodur e*t al*., 2013; Neal *et al.,* 2014; *Jogaiah et al.*, 2015). In the case of grapes originated from plants grafted onto '1103 P', the low pH may be related to the lower capacity to absorb potassium in rootstocks with progeny of '*Vitis berlandieri*' (Wolpert *et al*., 2005). The rootstock influenced the anthocyanin content, total polyphenols, and color intensity; only the color hue was not influenced by the rootstock, as shown in Table V.

Table III

Vegetative-productive balance of 'Merlot' (*Vitis vinifera* L.) grafted onto different rootstocks, grown in altitude region, during the 2014/15, 2015/16 and 2016/17 cycles

Variables	Cycle	Rootstocks		
		'1103 P'	**'3309 C'**	**'101-14 Mgt'**
Cluster per shoot	2015	1.2 ± 0.0	1.7 ± 0.1	1.4 ± 0.0
	2016	1.3 ± 0.1	1.4 ± 0.1	1.4 ± 0.1
	2017	1.5 ± 0.1	1.7 ± 0.1	1.7 ± 0.1
	Average	1.4 ± 0.1 b	1.6 ± 0.1 a	1.5 ± 0.0 a
Leaf area/Fruit (cm^2/g)	2015	49.7 ± 2.8 a	24.2 ± 1.5 b	31.8 ± 1.6 b
	2016	79.9 ± 6.5 a	52.0 ± 3.2 b	53.8 ± 1.8 b
	2017	34.3 ± 2.6 a	24.0 ± 1.6 b	21.6 ± 2.7 b
	Average	52.4 ± 4.3 a	33.4 ± 2.8 b	34.7 ± 3.0 b
Ravaz Index (kg/kg)	2015	2.2 ± 0.1	5.0 ± 0.4	4.4 ± 0.3
	2016	1.0 ± 0.2	2.1 ± 0.2	0.9 ± 0.1
	2017	3.1 ± 0.4	5.3 ± 0.7	4.0 ± 0.7
	Average	2.2 ± 0.3 c	4.1 ± 0.4 a	3.2 ± 0.4 b

Means within the same row followed by different letters differ significantly by Fisher's LSD test ($p<0.05$). Mean ± standard error.

Table IV

Maturation of 'Merlot' (*Vitis vinifera* L.) grafted onto different rootstocks, grown in altitude region, during the 2014/15, 2015/16 and 2016/17 cycles

Variables	Cycle	Rootstocks		
		'1103 P'	**'3309C'**	**'101-14 Mgt'**
Soluble solids (°Brix)	2015	20.0 ± 0.1	19.9 ± 0.0	20.2 ± 0.1
	2016	18.5 ± 0.1	18.8 ± 0.1	18.6 ± 0.3
	2017	18.7 ± 0.1	18.4 ± 0.1	18.8 ± 0.2
	Average	19.1 ± 0.2	19.0 ± 0.2	19.2 ± 0.2
pH	2015	3.04 ± 0.02	3.09 ± 0.01	3.11 ± 0.03
	2016	3.10 ± 0.00	3.17 ± 0.00	3.19 ± 0.00
	2017	3.05 ± 0.02	3.17 ± 0.01	3.17 ± 0.01
	Average	3.06 ± 0.01 b	3.14 ± 0.01 a	3.16 ± 0.01 a
Total acidity (mEq/L)	2015	113.5 ± 3.8	103.5 ± 1.9	106.7 ± 3.1
	2016	101.1 ± 0.6	97.6 ± 0.7	95.6 ± 1.9
	2017	98.8 ± 4.2	89.0 ± 0.9	88.4 ± 2.1
	Average	104.5 ± 2.6 a	96.7 ± 1.9 b	96.9 ± 2.6 b

Means within the same row followed by different letters differ significantly by Fisher's LSD test ($p<0.05$). Mean ± standard error.

Regarding the total anthocyanin content, the higher value was observed for the '101-14 Mgt' rootstock (259.7 mg/L), while the '1103 P' and '3309 C' rootstocks showed values of 203.7 and 202.8 mg/L, respectively. Regarding the total polyphenol content, '1103 P' and '101-14 Mgt' showed the highest values, 1279 and 1229 mg/L, respectively, while the rootstock '3309 C' showed the lowest value (1088 mg/L).

The color intensity presented a similar behavior to the total anthocyanin content, with the highest value observed for the rootstock '101-14 Mgt' (10.9) and the lowest ones observed for the rootstocks '1103 P' and '3309 C' (9.2 and 9.0, respectively). The color intensity of wines is mainly determined by grape anthocyanin content. One of the factors that contribute to increase color in red wines is linked to the decrease in grapes average size (Gil *et al*., 2015). Relatively less vigorous plants reduce cluster shading, and incident solar radiation induces an increase in anthocyanin synthesis (Downey *et al*., 2006).

Table V

Anthocyanins, total polyphenols and chromatic characteristics of 'Merlot' wines, originated from grapevines grafted onto different rootstocks, grown in altitude region, during the 2015/16 and 2016/17 cycles

Variable	Cycle	Rootstocks		
		1103 P	**3309 C**	**101-14 Mgt**
	2016	174.6 ± 17.6 a	207.8 ± 28.3 a	222.6 ± 31.6 a
Total anthocyanins (mg/L)	2017	232.8 ± 35.2 b	197.9 ± 15.2 c	296.8 ± 26.1 a
	Average	203.7 ± 26.4 b	202.8 ± 21.8 b	259.7 ± 28.9 a
	2016	1175.1 ± 19.6 a	1031.1 ± 26.4 b	1053.6 ± 32.7 b
Total polyphenols (mg/L)	2017	1382.5 ± 13.4 a	1145.7 ± 80.4 b	1404.8 ± 80.4 a
	Average	1279 ± 16.5 a	1088 ± 53.4 b	1229 ± 56.6 a
	2016	7.6 ± 0.1 b	7.8 ± 0.3 b	9.2 ± 0.1 a
Color intensity	2017	10.7 ± 0.3 b	10.2 ± 0.1 b	12.5 ± 0.2 a
	Average	9.2 ± 0,2 b	9.0 ± 0.2 b	10.9 ± 0.15 a
	2016	0.75 ± 0.05	0.76 ± 0.01	0.72 ± 0.03
Color hue	2017	0.73 ± 0.01	0.73 ± 0.00	0.72 ± 0.01
	Average	0.74 ± 0.03	0.75 ± 0.01	0.72 ± 0.02

Means within the same row followed by different letters differ significantly by Fisher's LSD test ($p<0.05$). Mean ± standard error.

In this study, the phenolic compounds analyzed are categorized into flavonoids and non-flavonoids. Flavonoids are the compounds mainly responsible for wines color and astringency, in addition to their great importance for human health (Santos-Buelga and Scalbert, 2000). As indicated in Table VI, rootstocks do not influence the catechin content in wines. However, for quercetin, rutin and kaempferol, a higher value was found for the rootstock '101-14 Mgt' (12.3, 6.0 and 1.03 mg/L, respectively).

In a study on the effect of vigor on the composition of flavonoids in 'Pinot Noir' grapes and wines, the authors concluded that vine vigor exerts a greater influence on the accumulation of flavonoids in the skins and less or no influence of these compounds on the seeds (Cortell *et al*., 2005). The concentration of some flavan-3-ols and flavonols in grape skin increased significantly with the decrease of vine vigor (Cortell *et al*., 2005). Flavonoid compounds concentrations in grapes are mediated by rootstocks, and these differences are most likely due to an imbalance in vegetative and reproductive growth between rootstock combinations (Rasool *et al*., 2020).

Table VI

Flavonoid phenolic compounds of 'Merlot' wines, originated from grapevines grafted onto different rootstocks, grown in altitude region, during the 2015/16 and 2016/17 cycles

Variables	Cycle	Rootstocks		
		'1103 P'	'3309C'	'101-14 Mgt'
Catechin (mg/L)	2016	15.1 ± 0.7	15.1 ± 1.0	16.6 ± 0.0
	2017	51.6 ± 0.1	49.0 ± 2.6	48.1 ± 1.9
	Average	33.3 ± 8,2	32.0 ± 7.7	32.4 ± 7.1
Quercetin (mg/L)	2016	1.5 ± 0.1 a	1.3 ± 0.1 a	1.4 ± 0.1 a
	2017	22.1 ± 0.3 b	21.6 ± 0.2 b	23.2 ± 0.4 a
	Average	11.8 ± 4.6 b	11.5 ± 4.5 b	12.3 ± 4.9 a
Rutin (mg/L)	2016	1.3 ± 0.7 a	1.0 ± 0.1 a	1.5 ± 0.1 a
	2017	7.8 ± 0.2 b	8.1 ± 0.1 b	10.5 ± 0.2 a
	Average	4.6 ± 1.5 b	4.6 ± 1.6 b	6.0 ± 2.0 a
Kaempferol (mg/L)	2016	0.14 ± 0.02 a	0.03 ± 0.00 a	0.10 ± 0.06 a
	2017	1.66 ± 0.04 c	1.80 ± 0.01 b	1.96 ± 0.06 a
	Average	0.90 ± 0.34 b	0.91 ± 0.39 b	1.03 ± 0.42 a

Means within the same row followed by different letters differ significantly by Fisher's LSD test ($p<0.05$). Mean ± standard error.

Shading has been shown to cause significant reductions in the concentration of flavonols in grapes (Downey *et al.*, 2006). Despite their low concentration, flavonols are important because they participate in co-pigmentation processes with anthocyanins, changing the color of wines and stabilizing pigments (Cheynier and Rigaud, 1986). Flavanols, mainly represented by catechin and epicatechin, are important because they provide astringency to wines (Downey *et al.*, 2003). Bitterness and astringency are associated with high levels of flavan-3-ols (Chapman *et al.*, 2004).

The non-flavonoid compounds analyzed in this work are classified as: hydroxybenzoic acids (gallic and vanillic acids), hydroxycinnamic acids (p-coumaric) and stilbenes (resveratrol). For such compounds, a consistent rootstock effect was not observed.

The vanillic acid was not influenced by the different rootstocks. However, gallic acid was higher for rootstock '1103 P' (22.3 mg/L), followed by '3309 C' (21.0 mg/L), and '101-14 Mgt' (19.7 mg/L). For *p*-coumaric acid, the highest value was observed for rootstock '3309 C' (5.0 mg/L), followed by the rootstocks '101-14 Mgt' (4.3 mg/L) and '1103 P' (4.1 mg/L). Gallic acid is described as one of the most important phenolic compounds because it is a precursor of all hydrolysable tannins. This group of compounds is important in the wine composition, mainly due to their ability to react with anthocyanins, consequently stabilizing the wine color (Gris *et al.*, 2007).

The resveratrol content showed higher values for the rootstocks '3309 C' and '101-14 Mgt', with values of 9.4 and 8.7 mg/L, respectively, while the '1103 P' rootstock showed a lower value of resveratrol, with 7.0 mg/L.

Hydroxycinnamic acids and their derivatives participate as pigmenting cofactors, therefore, a higher proportion of these compounds in wines made with smaller size grape berries could partially explain the intense color of these wines, because of intermolecular copigmentation (Gil e*t al.*, 2015). In the present work, the decrease in berry size, mediated by the rootstocks '3309 C' and '101-14 Mgt', seems to have been sufficient to increase the concentration of *p*-coumaric acid (in 'Merlot'/'3309 C') and resveratrol in 'Merlot'/'3309 C' and 'Merlot'/'101-14 Mgt'.

Table VII

Non-flavonoid phenolic compounds of 'Merlot' wines, originated from grapevines grafted onto different rootstocks, grown in altitude region, during the 2015/16 and 2016/17 cycles

Variables	Cycle	Rootstocks		
		'1103 P'	**'3309 C'**	**'101-14 Mgt'**
Gallic Acid (mg/L)	2016	21.9 ± 0.1 a	20.2 ± 0.0 b	17.2 ± 0.1 c
	2017	22.5 ± 0.1 a	21.7 ± 0.0 c	22.1 ± 0.1 b
	Average	22.3 ± 0.2 a	21.0 ± 0.3 b	19.7 ± 1.1 c
Vanillic Acid (mg/L)	2016	4.6 ± 0.4	5.1 ± 0.1	4.7 ± 0.1
	2017	5.8 ± 2.9	10.5 ± 0.4	9.1 ± 0.4
	Average	5.2 ± 1.3	7.8 ± 1.2	6.9 ± 1.0
***p*-Coumaric acid** (mg/L)	2016	4.6 ± 0.0 c	5.3 ± 0.0 a	4.9 ± 0.1 b
	2017	3.7 ± 0.1 b	4.8 ± 0.1 a	3.7 ± 0.0 b
	Average	4.1 ± 0.2 c	5.0 ± 0.1 a	4.3 ± 0.2 b
Resveratrol (mg/L)	2016	3.4 ± 0.1	6.0 ± 0.1	6.0 ± 0.1
	2017	10.6 ± 0.8	12.8 ± 0.0	11.5 ± 0.2
	Average	7.0 ± 1.7 b	9.4 ± 1.5 a	8.7 ± 1.2 a

Means within the same row followed by different letters differ significantly by Fisher's LSD test ($p<0.05$). Mean ± standard error.

The stilbenes monomers, *cis*- and *trans*-resveratrol, are phytoalexins, what are components synthesized by the vine in response to a stress situation (Mattivi *et al*., 1993), and the ultraviolet (UV) light exposure and climatic conditions are examples of abiotic stress. The effects of sunshine duration and UV light exposure on the resveratrol concentrations of red wines were analyzed separately and were found to increase resveratrol concentrations to a considerable extent (Threlfall *et al*., 1999), with *trans*-resveratrol (*trans*-3,5,4-trihydroxystilbene) being the most studied due to its potential benefit to human health (Gris, 2010). The highest concentrations of these compounds were observed for the '101-14 Mgt' rootstock, which provided a better vegetative-productive balance, which may have favored an increase in solar radiation in vegetative canopy and in the clusters, contributing to the increase of these constituents.

The present work demonstrated that the vegetative growth, yield, wine chemical and phenolic composition of 'Merlot' variety grown in altitude region of Santa Catarina is directly related to the rootstocks used.

CONCLUSIONS

The rootstocks '3309 Courdec' and '1014-14 Mgt' are recommended for the 'Merlot' grapevine in the soil and climate conditions of the Santa Catarina highlands.

The rootstock '3309 C' promoted an increase in the productive indices (yield, cluster per plant and cluster mass), and provided lower vegetative vigor, and consequently resulted in more adequate vegetative-productive balance for 'Merlot' plants. The rootstocks '3309 C' and '101-14 Mgt' provide more adequate maturation of 'Merlot' grapes.

The use of rootstock '101-14 Mgt' resulted in higher contents of total polyphenols, color intensity and anthocyanins, and showed the highest contents of flavonoid compounds.

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REFERENCES

Azuma A., Yakushiji H., Sato A., 2019. Postharvest light irradiation and appropriate temperature treatment increase anthocyanin accumulation in grape berry skin. *Postharvest Biol. Technol.*, **147**, 89–99.

Bem B.P., Bogo A., Everhart S., Casa R.T., Gonçalves M.J., Marcon Filho J.L., Rufato L., Silva F.N., Allebrandt R., Cunha, I., 2016. Effect of four training systems on the temporal dynamics of downy mildew in two grapevine cultivars in southern Brazil. *Trop.Plant Pathol.*, **41**, 370-379.

Borghezan M., Gavioli O., Pit F.A., Silva A.L., 2010. Modelos matemáticos para a estimativa da área foliar de variedades de videira à campo (*Vitis vinifera* L.). *Ciência Téc. Vitiv*., **25**, 1-7.

Borghezan M., Gavioli O., Pit F.A., Silva A.L., 2011. Comportamento vegetativo e produtivo da videira e composição da uva em São Joaquim, Santa Catarina. *Pesq. Agrop. Bras.***46**, 398-405.

Brighenti A.F., Rufato L., Kretzschmar A.A., Schlemper C., 2011. Desempenho vitivinícolas da Cabernet Sauvignon sobre diferentes porta-enxertos em região de altitude de Santa Catarina. *Rev. Bras. Frutic.*, **33**, 96-102.

Brighenti A.F., Brighenti E., Bonin V., Rufato L., 2013. Caracterização fenológica e exigência térmica de variedades de uvas viníferas em São Joaquim, Santa Catarina – Brasil. *Ciênc. Rural*, **43**, 1162-1167.

Cadahía E., Simón B., Sanz M., Poveda P., Colio J., 2009. Chemical and chromatic characteristics of Tempranillo, Cabernet Sauvignon and Merlot wines from DO Navarra aged in Spanish and French oak barrels. *Food Chem.*, **115**, 639-649.

Callili D., Sanchez A.C.P., Campos O.P., Carneiro D. C. S., Scudeletti A.C.B., Tecchio M.A., 2023. Phenology, thermal demand, and maturation development of the 'BRS Vitória' grape cultivated on different rootstocks in subtropical conditions. *Rev. Bras. Frutic.*, **45**, e-999.

Chapman D.M., Matthews M.A., Guinard J.X., 2004. Sensory attributes of Cabernet Sauvignon wines made from vines with different crop yields. *Am. J. Enol. Vitic.*, **55**, 325-334.

Cheynier V., Rigaud J., 1986. HPLC separation and characterization of flavonols in the skins of *Vitis vinifera* var. Cinsault. *Am. J. Enol. Vitic.*, **37**, 248-252.

Cortell J.M., Kennedy A.J., 2006. Effect of shading on accumulation of flavonoid compounds in (*Vitis vinifera* L.) Pinot noir fruit and extraction in a model system. *J. Agric. Food Chem.*, **54**, 8510-8520.

Cus F., 2004. The effect of different scion/rootstock combinations on yield properties of cv. 'Cabernet Sauvignon'. *Acta Agric. Slov.,* **83**, 63-71, 2004.

Downey M.O., Harvey J.S., Robinson, S.P., 2004. The effect of bunch shading on berry development and flavonoid accumulation in Shiraz grapes. *Aust. J. Grape Wine Res.*, **10**, 55-73.

Downey M., Harvey J.S., Robinson S.P., 2008. Analysis of tannins in seeds of skins of Shiraz grapes throughout berry development. *Aust. J. Grape Wine Res.*, **9**, 15-27.

Ferreira-Lima N.E., Burin V., Bordignon-Luiz M., 2013. Characterization of Goethe white wines: influence of different storage conditions on the wine evolution during bottle aging. *Eur. Food Res. Technol.*, **237**, 509-520.

Gil M., Pascual O., Gomez-Alonso S., Garcia-Romero E., Hermosin-Gutierez I., Zamora F., Canals J.M., 2015: Influence of berry size on red wine colour and composition. *Aust. J. Grape Wine Res.,* **21**, 200-212.

Gris E.F., Ferreira E.A., Falcão L.D., Bordignon-Luiz M.T., 2007. Caffeic acid co-pigmentation of anthocyanins from Cabernet Sauvignon grape extracts in model systems. *Food Chem.*, **100**, 1289-1296.

Gris E.F., Burin V., Brighenti E., Vieira H., 2010. Phenology and ripening of *Vitis vinifera* L. grape varieties in São Joaquim, southern Brazil: a new South American wine growing region. *Ciencia Inv. Agr.*, **37**, 61-75.

Han X., Wang Y., Lu H.C., Yang H.Y., Li G.Q., Gao X.T., Pei X.X., He F., Duan C.Q., Wang J., 2022. The combined influence of rootstock and vintage climate on the grape and wine flavonoids of Vitis vinifera L. cv. Cabernet Sauvignon in eastern China. *Front. Plant Sci.*, **13**, e-978497.

Harbertson J.F., Keller M., 2011. Rootstock Effects on Deficit-Irrigated Winegrapes in a Dry Climate: Grape and Wine Composition. *Am. J. Enol. Vitic.*, **63**, 40-48.

Jogaiah S., Kitture A.R., Sharma J., Upadhyay A.K., Somkuwar, R.G., 2015. Regulation of fruit and wine quality parameters of Cabernet Sauvignon grapevines (*Vitis vinifera* L.) by rootstocks in semiarid regions of India. *Vitis*, **54**, 65-72.

Keller M., Mills L.J., Harbertson J.F., 2011. Rootstock Effects on Deficit-Irrigated Winegrapes in a Dry Climate: Vigor, Yield Formation, and Fruit Ripening. *Am. J. Enol. Vitic.*, **63**, 29-39.

Keller M., 2015. *The science of grapevines*: anatomy and physiology. Academic Press, 522 p.

Kidman C.M., Dry P.R., McCarthy M.G., Collins C., 2013. Reproductive performance of Cabernet Sauvignon and Merlot (*Vitis vinifera* L.) is affected when grafted to rootstocks. *Aust. J. Grape Wine Res.*, **19**, 409-421.

Kliewer W.M., Dokoozlian N.K., 2005. Leaf area/crop weight ratios of grapevines: influence on fruit composition and wine quality. *Am. J. Enol. Vitic.*, **56**, 170-181.

Kodur S., Tisdall J.M., Clingeleffer P.R., Walker, R.R., 2013. Regulation of berry quality parameters in 'Shiraz' grapevines through rootstocks (*Vitis*). *Vit*is, **52**, 125-128.

Lecourt J., Lauvergeat V., Ollat N., Cookson, S.J., 2015. Shoot and root ionome responses to nitrate supply in grafted grapevines are rootstock genotype dependent. *Aust. J. Grape Wine Res.,* **21**, 311-318.

Makhotkina O., Johnstone M., Logan G., Toit W., Kilmartin P.A., 2013. Influence of sulfur dioxide additions at harvest on polyphenols, C6-compounds and varietal thiols in Sauvignon blanc. *Am. J. Enol. Vitic.*, **64**, 203-2013.

Mafra S.H.M., Cassol P.C., Miquelutti D.J., Ernani P.R., Gatiboni L.C., Ferreira E.Z., Barros M., Zalamena J., Grohskopf M., 2011. Atributos químicos do solo e estado nutricional de videira Cabernet Sauvignon (*Vitis vinífera* L.) na Serra Catarinense. *Rev. Ciên. Agrovet.*, **10**, 44-53.

Marcon Filho J.L., Hipólito J.S., Macedo T.A., Kretzschmar A.A., Rufato L., 2015. Raleio de cachos sobre o potencial enológico da uva 'Cabernet Franc' em duas safras. *Ciência Rural*, **45**, 2150-2156.

Marcon Filho J.L., Wurz D.A., Brighenti A.F., Rufato L., Kretzschmar A.A, 2022. Chemical and Phenolic profile of 'Sauvignon Blanc' wines mande in altitude region of Santa Catarina State – Brazil. *Sci. Agr. Paran*, **21**, 21-29.

Mattivi F., 1993. Solid phase extraction of trans-resveratrol from wines for HPLC analysis. Z. Lebensm. Unters. *Forsch*, **196**, 522–525.

Miele A., Rizzon L.A., 2017. Rootstock-scion interaction: 1. Effect on the yield components of cabernet sauvignon grapevine. *Rev. Bras. Frutic.*, **39**, e-820.

Nascimento P.L., Morais P.L.D., Melo M.F., Neta T.R., Morais M.A.S., Silva C.S.A., 2022. Maturation and quality of 'Isabel Precoce' grape grown on different rootstocks under semiarid conditions. *Int. J. Agric. Nat. Resour.*, **49**, 73-84.

Neal S., Friend A.P., Trought M.C.T., McLachlan A.R.G., 2014. The performance of 'Sauvignon Blanc' on five grapevine rootstocks in a Marlborough vineyard. *Acta Horticulturae*, **1115**, 147-155.

Nikolaou N., Koukourikou M., Karagiannidis N., 2000. Effects of various rootstocks on xylem exudates cytokinin content, nutrient uptake and growth patterns of grapevine *Vitis vinifera* L. cv. Thompson seedless. *Agronomie*, **20**, 363-373.

Oiv., 2015. *International Organisation of Vine and* Wine. Compendium of international methods of wine and must analysis. Paris: OIV, 2v.

Ollat N., Tandonnet J.P., Lafontaine M., Schultz H.R., 2003. Short and long term effects of three rootstocks on Cabernet Sauvignon vine behaviour and wine quality. *Acta Horticulturae.*, **617**, 95–100.

Panceri C.P., Fagherazzi M.M., Canossa A.T., Machado B.D., Bringheti A.F., Brighenti E., 2018. Cordão esporonado X Guyot: influência da intensidade de poda sobre os aspectos produtivos e qualitativos da uva Chardonnay em região de altitude de Santa Catarina. *Revista da Jornada de Pós-graduação e Pesquisa*, **15**, 985-997.

Pavlousek P., 2011. Evaluation of drought tolerance of new grapevine rootstock hybrids. *J. Environ. Biol.*, **32,** 543-549.

Pszczolkowski P., Lecco C.C., 2011. *Manual de vinificación*: Guía práctica para la elaboración de vinos. Universidade Catolica do Chile: Santiago.

Rizzon L.A., 2010. *Metodologia para análise de* vinho. Brasília: Embrapa Informação Tecnológica, 120 p.

Santos-Buelga C., Scalbert A., 2000. Proanthocyanidins and tannin-like compounds–nature, occurrence, dietary intake and effects on nutrition and health. *J. Sci. Food Agric.*, **80**, 1094-1117.

Santos H.G., Jacomine P.K., Anjos L.H., Oliveira V.A., Lumbreras J.F., Coelho M.R., Almeida J.A., Araujo Filho, J.C., Oliveira, J.B., Cunha, T.J., 2018. *Sistema Brasileira de Classificação do Solo*, 5 ed., rev. e ampl. – Brasília: DF Embrapa, 356p.

Pouget R., 1986. Usefulness of rootstocks for controlling vine vigour and improving wine quality. Symposium on Grapevine Canopy and Vigor Management. *Acta Horticulturae*, **206**, 109-118.

Rasool A., Mansoor S., Bhat K.M., Hassan G.I., Baba T.R., Alyemeni M.N., 2020. Mechanisms underlying graft union formation and rootstock scion interaction in horticultural plants. *Front. Plant Sci.*, **11**, 590847.

Singleton V.L., Rossi J.A., 1965. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acids reagents. *Am. J. Enol. Vitic.*, **16**, 144-158.

Spiora M., Gutierrez M., 1998. Effect of pre-veraison irrigation cut off and skin contact time on composition color, and phenolic content of young Cabernet-Sauvignon wines in Spain. *Am. J. Enol. Vitic.*, **49**, 153-161.

Stockert C.M., Bisson L.F., Adams D.O., Smart D.R., 2013. Nitrogen status and fermentation dynamics for Merlot on two rootstocks. *Am. J. Enol. Vitic.*, **64**, 195-202.

Tandonnet J., Soyer J.P., Gaudillere J.P., Decroocq S., Bordenave L., Ollat N., 2008. Long term effects of nitrogen and water supply on confered vigour and yield by SO4 and Riparia Gloire de Montpellier rootstocks. *J. Int. Sci. Vigne Vin*, **42**, 89-98.

Threlfall R.T., Morris J.R., Mauromoustakos, A., 1999. Effect of variety, ultraviolet light exposure, and enological methods on the trans-resveratrol level of wine. *Am. J. Enol. Vitic.,* **50**, 57-64.

Vianna L.F., Massignan A.M., Pandolfo C., Dotzbach D., Vieira V.F., 2016. Caracterização agronômica e edafoclimática dos vinhedos de elevada altitude. *Rev. Ciênc. Agrovet.*, **15**, 215-226.

Wolpert, J.A., Smart D.R., Anderson M., 2005. Lower petiole potassium concentration at bloom in rootstocks with Vitis berlandieri genetic backgrounds. *Am. J. Enol. Vitic.* **56**, 163-169.

Wurz D.A., Brighenti A.F., Marcon Filho J.L., Allebrandt R., Bem B.P., Rufato L., Kretzschmar A.A., 2017. Agronomic performance of 'Cabernet Sauvignon' with leaf removal management in high-altitude region of Southern Brazil. *Pesq. Agropec. Bras.*, **52**, 69-876.

Wurz D.A., Allebrandt R., Marcon Filho J.L., Bem B.P., Brighenti A.F., Rufato L., Kretzschmar A.A., 2018. Época de desfolha e sua influência no desempenho vitícola da uva 'Sauvignon Blanc' em região de elevada altitude. *Rev. Ciênc. Agrovet.*, **17**, 91-99.

Wurz D.A., Rufato L., Bogo A., Allebrandt R., Bem B.P., Marcon Filho J.L., Brighenti A.F., Bonin B.F., 2020. Effects of leaf removal on grape cluster architecture and control of Botrytis bunch rot in Sauvignon Blanc grapevines in Southern Brazil. *Crop Protection.*, **131**, 1-6.

Zalamena J., Cassol P.C., Brunetto G., Grohskpf M.A., Mafra M.S., 2013. Estado nutricional, vigor e produção em videiras cultivadas com plantas de cobertura. *Rev. Bras. Frutic.*, **35,** 1190-1200.

Zufferey V., Spring J.L., Verdenal T., Dienes A., Belcher S., Lorenzini F., Koestel C., Rösti J., Gindro K., Spangenberg J., Viret O., 2017. Influence of water stress on plant hydraulics, gas exchange, berry composition and quality of Pinot Noir wines in Switzerland. *Oeno One*, **51**. 37-57.