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Research Article

Agronomic performance of 'Cabernet Sauvignon' grapevine in a high-altitude region on different rootstocks

Desempenho agronômico da videira 'Cabernet Sauvignon' cultivada em região de altitude sobre diferentes porta-enxertos

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ABSTRACT

The objective of this work was to evaluate the effect of different rootstocks on the agronomic performance of the 'Cabernet Sauvignon' grapevine grown in the high-altitude region of Santa Catarina State. The rootstocks 'Paulsen 1103', 'Courdec 3309' and '101-14 Mgt' were tested. The experiments were conducted in the municipalities of Painel (1,200 m) and São Joaquim (1,300 m), during the 2014/2015, 2015/2016 and 2016/2017 cycles. Yield components, vigor characteristics, cluster architecture and berry ripeness were evaluated. The rootstocks modified the yield and vegetative growth parameters. The rootstocks 1103P and 3309C presented the highest average yields per plant when compared to 101-14 Mgt. In the São Joaquim area (1,300 m), the rootstock '3309C' had the highest number of clusters per shoot, the lowest leaf area/fruit ratio (cm² g^{-1}) and the highest Ravaz index. The rootstock 101-14 Mgt reduced the size of Cabernet Sauvignon berries in Painel (1,200 m); and in São Joaquim (1,300 m), '101-14 Mgt' and 3309C reduced the diameter and mass of the berries. The soluble solids and total acidity of Cabernet Sauvignon grapes suffered little influence from the rootstock in the two locations studied, throughout the cycles.

KEYWORDS: *Vitis vinifera* L. Productive components. Technological ripeness. Vegetative-productive balance-productive.

RESUMO

O objetivo deste trabalho foi avaliar o efeito de diferentes porta-enxertos sobre o desempenho agronômico da videira 'Cabernet Sauvignon' cultivada em região de altitude de Santa Catarina. Para tanto, foram testados, os porta-enxertos 'Paulsen 11031', 'Courdec 3309' e '101-14 Mgt'. Os experimentos foram conduzidos nos municípios de Painel (1.200 m) e São Joaquim (1.300 m), durante os ciclos 2014/2015, 2015/2016 e 2016/2017. Foram avaliados componentes de rendimento, características de vigor, arquitetura de cachos e maturação das bagas. Os porta-enxertos modificaram os parâmetros de produção e de crescimento vegetativo. Os porta-enxertos 1103P e 3309C conferiram as maiores médias de produção por planta, quando comparados a 101-14 Mgt. Na área de São Joaquim (1.300 m), o porta-enxerto 3309C apresentou o maior número de cachos por ramo, a menor relação área foliar/fruto (cm² g^{-1}) e o maior índice de Ravaz. O porta-enxerto 101-14 Mgt diminuiu o tamanho das bagas de Cabernet Sauvignon em Painel (1.200 m); e em São Joaquim (1.300 m), 101-14 Mgt e 3309C diminuíram o diâmetro e a massa da baga. O conteúdo de sólidos solúveis e acidez total da Cabernet Sauvignon sofreu pouca influência do porta-enxerto nos dois locais estudados, ao longo de ciclos.

PALAVRAS-CHAVE: *Vitis vinifera* L. Componentes produtivos. Maturação tecnológica. Equilíbrio vegeto-produtivo.

INTRODUCTION

The high-altitude region of Santa Catarina is characterized by having its vineyards between 900 and 1,400 meters above sea level (WURZ *et al.* 2017a), with longer maturation periods, the vineyards produce grapes with greater enological potential (MALINOVSKI *et al.* 2016). The cultivation of the 'Cabernet Sauvignon' vine stands out in this region, with the largest area (37.9% of the total area), with the Paulsen 1103 rootstock predominating, present in 72.1% of the planted area (VIANNA *et al.* 2016).

The variety Cabernet Sauvignon, when grown in fertile soils and grafted onto vigorous rootstocks, such as Paulsen 1103, tends to increase its vigor year after year, especially when subjected to spur cordon pruning management (FOGAÇA 2022). In the high altitude region of Santa Catarina, this is the pruning method adopted for 'Cabernet Sauvignon' vineyards. Also, the region is characterized by the occurrence of high-water availability (BEM *et al.* 2016) and high organic matter in the soil (MAFRA *et al.* 2011). In addition, the rootstock Paulsen 1103 has a high nitrogen absorption capacity (STOCKERT *et al.* 2013). Considering the characteristics of 'Paulsen 1103' with the edaphoclimatic conditions found in the high-altitude region of Santa Catarina, there is an environment that favors the vine vegetative growth, which can lead to imbalance in the vineyards (BRIGHENTI *et al.* 2011, ZALAMENA *et al.* 2013). This shows that it is necessary to improve vine balance, which allows grapes to be harvested at appropriate levels of maturity (WURZ *et al.* 2017b).

The literature has clearly demonstrated that rootstocks have considerable potential to determine important grape and wine quality characteristics (JOGAIAH *et al.* 2015). Rootstocks influence water relations, phenology, vigor, yield and quality of grapes and wines (KELLER 2020). 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 & RIZZON 2017), or even by the direct influence on grape composition (KODUR *et al.* 2013, JOGAIAH *et al.* 2015).

For example, the rootstock 101-14 Mgt tends to reduce vigor and might hasten maturation. Additionally, it adapts well to clayey soils that retain a high amount of water (DRY 2007). In a study carried out in the Serra Gaúcha region, in which 15 rootstocks were evaluated for 'Cabernet Sauvignon' maturation, the authors concluded that the 101-14Mgt rootstock provided the best grape maturation rates (MIELE & RIZZON 2017). JOGAIAH *et al.* (2015) found the same results for Cabernet Sauvignon wines, when the plants were grafted onto 101-14Mgt.

In relation to the Courdec 3309 rootstock, it gives the plant low to moderate vigor, like other rootstocks in this group, it induces early fruit ripening, high productivity and is recommended for varieties with low fruit set (FREGONI 2006). A study carried out by ALLEBRANDT *et al.* (2020) found an increase in the concentration of most flavonoid compounds in Cabernet Sauvignon wines, in relation rootstock 1103 P, in the vineyards of the high-altitude region of Santa Catarina.

It should be noted that the rootstock recommendation cannot be generalized, and it is necessary to evaluate the best variety x rootstock combination for each growing region (SERRA *et al.* 2014). Therefore, according to LEÃO & OLIVEIRA (2023), it is necessary to understand the phenotypic corrections, their causes and importance, thus indicating the best combination between canopy variety and rootstock. In this sense, field trials with different rootstocks in high-altitude regions are essential to understand their viticultural potential (NARDELLO *et al.* 2023).

In this context, the objective of this work was to evaluate the effect of different rootstocks on the agronomic performance of the 'Cabernet Sauvignon' vine grown in the high-altitude region of Santa Catarina.

MATERIAL AND METHODS

The present work was conducted in the cities of São Joaquim (28°14'S, 49°58'W and 1,300m of altitude) during the seasons 2015 and 2016, and Painel (28°01'S, 50°08'W and 1,200 m of altitude) during the seasons 2015, 2016 and 2017. The vineyards were established in 2004, with spacings of 3.0 m between rows and 1.5 m between plants. The plants are trained using the Y Trellis system with double spur cordon pruning. The soil was an Humic Cambisol, Litholic Neosol and Haplic Nitisol classes, developed from rhyodacite and basalt rock (SANTOS *et al.* 2018). The region's climate, according to the Koeppen classification system, is humid mesothermal and mild summer (Cfb).

The experimental design was randomized blocks, with four blocks, each replication consisting of 10 uniform plants. The vegetative and productive variables, cluster architecture and technological maturity of the 'Cabernet Sauvignon' variety grafted onto Paulsen 1103, 3309 Couderc and 101-14 Mgt rootstocks were evaluated.

On the harvest date, yield and leaf area data were recorded, and samples of clusters and berries were collected for subsequent analysis. Yield (kg) and number of clusters were recorded for each plant in each treatment. The cluster mass was estimated by dividing the yield per plant by the number of clusters per plant, and the results were expressed in grams (g). 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 (LA) per plant, 10 shoots per treatment were selected in the middle third of the plant cordon. In these shoots, the central vein length (cm) of all leaves was obtained using 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 central vein length in cm (BORGHEZAN *et al.* 2010). 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, with the results expressed in m². The ratio between leaf area and fruit mass (LA/Fruit) was calculated by dividing the leaf area (m²) by yield (kg), with the results expressed in cm^2g^{-1}.

To determine the vigor of the plants, the mass of the pruned material and the Ravaz index were used. The Ravaz index was determined as a relationship between the weight of the fruits produced and the weight of the pruned material.

Samples of 100 berries per repetition were collected for technological maturity analyzes and determination of berry diameter and mass. In the laboratory, the berries were weighed and individually squeezed to obtain the must. The soluble solids content was analyzed using a digital refractometer with temperature compensation (Atago®, Ribeirão Preto, SP); pH, using a potentiometer (Impac®, Vargem Grande Paulista, SP), and titratable acidity, through titration with 0.1N NaOH, using bromothymol blue indicator until the pH of the medium reaches 8.2, with the results expressed in meq L^{-1} (OIV 2016).

The data were subjected to analysis of variance (ANOVA), when significant effects of rootstocks were detected, the Fisher's LSD means comparison test was carried out, at a level of 5% probability of error.

RESULTS AND DISCUSSIONS

The effects induced by rootstocks on yield components were relatively consistent at both study sites, throughout the three seasons (Table 1). Considering the averages of the 3 seasons, the rootstocks P1103 and 3309C showed the highest average yield per plant when compared to 101-14 Mgt, both in the experimental area of Painel (1,200 m) and São Joaquim (1,300 m). In Painel (1,200 m), the average 'Cabernet Sauvignon' yield at P1103 and 3309C was 15.5% higher compared to plants grafted onto '101-14 Mgt'. In São Joaquim (1,300 m), this same comparison revealed an increase of 46.3% for P1103 and 3309C when compared to plants grafted onto '101-14 Mgt'

Table 1. Yield components of the 'Cabernet Sauvignon' (*Vitis vinifera* L.) on different rootstocks, grown in Painel (1,200 m) and São Joaquim (1,300 m), during the 2015, 2016 and 2017 seasons.

Variables	Season	Rootstock											
		1103P				3309C				101-14 Mgt			
Painel (1,200 m)													
Yield/plant (kg)	2015	4.3	±	0.2	ns	4.5	±	0.2		3.9	±	0.2	
	2016	3.5	±	0.3	ns	2.9	±	0.4		1.8	±	0.3	
	2017	8.0	±	0.6	ns	7.9	±	0.5		7.6	±	0.9	
	Average	5.3	±	0.4	a	5.1	±	0.4	a	4.5	±	0.5	b
Clusters/plant	2015	60.2	±	3.0	ab	70.8	±	4.3	a	56.8	±	3.3	b
	2016	54.7	±	4.6	a	48.1	±	3.7	ab	38.7	±	3.7	b
	2017	74.9	±	5.4	a	82.2	±	6.5	a	86.3	±	3.0	a
	Average	63.3	±	2.9	ab	67	±	3.8	a	60.6	±	4.0	b
Cluster mass (g)	2015	72.5	±	2.8	a	65.1	±	3.4	a	69.7	±	3.8	a
	2016	67.2	±	9.1	a	59.1	±	4.5	a	42.7	±	4.0	b
	2017	106.3	±	2.9	a	97.6	±	4.1	ab	85.8	±	7.7	b
	Average	82.0	±	4.5	a	73.9	±	3.9	a	66.4	±	4.5	b
São Joaquim (1,300 m)													
Yield/plant (kg)	2015	4.2	±	0.4	a	3.7	±	0.4	a	4.1	±	0.5	a
	2016	4.2	±	0.3	a	3.7	±	0.2	a	1.6	±	0.2	b
	Average	4.2	±	0.2	a	3.7	±	0.2	a	2.7	±	0.3	b
Clusters/plant	2015	59.8	±	3.8	a	69.3	±	5.2	a	68.3	±	5.0	a
	2016	57.5	±	3.0	a	56.1	±	2.1	a	34.2	±	2.4	b
	Average	58.7	±	2.3	ab	62.7	±	2.7	a	49.0	±	3.8	b
Cluster mass (g)	2015	70.2	±	3.5	a	53.2	±	3.3	b	59.4	±	3.9	b
	2016	72.2	±	2.2	a	65.9	±	3.9	a	46.8	±	4.3	b
	Average	71.2	±	2.0	a	59.5	±	2.9	b	52.3	±	3.2	b

Means with different letters in the line differ significantly by Fisher's LSD test ($p<0.05$). Mean ± standard error. ns = not significant in ANOVA ($p<0.05$).

The Cabernet Sauvignon load on the most productive rootstocks was determined by both the increase in the number of clusters per plant and the increase in cluster mass, however, the importance of each of these components varied according to the location. In the Painel area, P1103 and 3309C produced statistically the same number of clusters, but P1103 did not differ significantly from 101-14 Mgt. However, the cluster mass in the two most productive rootstocks was 17.4% higher than that observed in 101-14 Mgt. In São Joaquim the same behavior was observed in relation to the number of clusters per plant, and in this area, the cluster mass in P1103 was 27% greater than those observed in 3309C and 101-14 Mgt.

Bunch weight depends on several factors such as mineral absorption, Ravaz index, number of berries per bunch, leaf area, factors that can be influenced by the rootstock (GUILPART *et al.* 2014, FERREIRA *et al.* 2020).

The rootstocks significantly influenced the vegetative canopy parameters of the Cabernet Sauvignon variety (Table 2). The leaf area was similar between the rootstocks, with an average of 8.5 and 8.0 m² per plant, in the Painel (1,200 m) and São Joaquim (1,300 m) areas, respectively.

Table 2. Vigor characteristics of the 'Cabernet Sauvignon' (*Vitis vinifera* L.) on different rootstocks, grown in Painel (1,200 m) and São Joaquim (1,300 m), during the 2015, 2016 and 2017 seasons.

Variable	Season	Rootstocks					
		1103P		3309C	1103P	101-14 Mgt	
		Painel (1,200 m)					
Leaf Area (m²)	2015	10.1 ± 0.4	ns	10.5 ± 0.6		10.0 ± 0.3	
	2016	5.4 ± 0.2	ns	6.8 ± 0.4		6.2 ± 0.3	
	2017	9.4 ± 0.9	ns	9.2 ± 0.6		9.5 ± 0.4	
	Average	8.3 ± 0.5		8.8 ± 0.4		8.5 ± 0.3	
Pruning mass (kg)	2015	2.1 ± 0.1	ns	1.5 ± 0.1		1.2 ± 0.1	
	2016	3.0 ± 0.1	ns	2.2 ± 0.2		2.1 ± 0.2	
	2017	2.0 ± 0.1	ns	1.8 ± 0.1		1.3 ± 0.2	
	Average	2.4 ± 0.1	a	1.9 ± 0.1	b	1.6 ± 0.1	c
Shoot mass (g)	2015	46.1 ± 3.1	ns	31.5 ± 2.5		25.2 ± 2.3	
	2016	72.7 ± 3.7	ns	60.6 ± 5.4		54.9 ± 4.1	
	2017	43.3 ± 4.6	ns	39.3 ± 4.2		26.0 ± 2.8	
	Average	54.0 ± 3.3	a	43.8 ± 3.3	b	35.7 ± 3.0	c
		São Joaquim (1,300 m)					
Leaf Area (m²)	2015	9.5 ± 0.7	ns	10.0 ± 0.6		8.9 ± 0.6	
	2016	7.7 ± 0.3	ns	6.1 ± 0.3		6.2 ± 0.2	
	Average	8.6 ± 0.4	ns	8.1 ± 0.4		7.4 ± 0.4	
Pruning mass (kg)	2015	1.7 ± 0.1	ns	1.3 ± 0.1		1.7 ± 0.1	
	2016	1.5 ± 0.1	ns	0.8 ± 0.0		1.3 ± 0.0	
	Average	1.6 ± 0.1	a	1.0 ± 0.1	b	1.5 ± 0.1	a
Shoot mass (g)	2015	47.0 ± 3.8	ns	30.9 ± 2.5		48.6 ± 3.8	
	2016	37.9 ± 0.2	ns	21.4 ± 0.9		34.4 ± 0.0	
	Average	42.4 ± 2.1	a	26.2 ± 1.7	b	40.6 ± 2.2	a

Means with different letters in the line differ significantly by Fisher's LSD test ($p<0.05$). Mean ± standard error. ns = not significant in ANOVA ($p<0.05$).

According to the study by MARKOVIĆ (2011), Cabernet Sauvignon shows variability in shoot growth depending on the rootstock on which it is grafted. The 'Paulsen 1103' rootstock confers a medium to high level of canopy vigor (GIOVANNINI 2014).

The pruning mass per plant varied according to the rootstock and experimental area. 3309C and 101-14 Mgt induced the lowest pruning mass, with 1.6 and 1.0 kg per plant, in Painel (1,200 m) and São Joaquim (1,300 m), respectively. The highest average mass of ‘Cabernet Sauvignon’ in Painel (1,200 m) was obtained in rootstock P1103 (54.0 g). In the São Joaquim (1,300 m) area, the shoot mass in 101-14 Mgt was similar to that observed in P1103, and both were higher than 3309C.

As in previous reports, the 1103P tended to increase scion pruning weights (SATISHA *et al.* 2010, KELLER *et al.* 2020. According to HAN *et al.* (2022), 1103P is a hybrid rootstock, with *V. rupestris* and *V. berlandieri* as parents, and absorbs more water and nutrients to supply the vegetative growth of the canopy, resulting in greater canopy pruning weight and greater vegetative growth.

After individual analysis of yield components and vigor parameters, calculations of the relationships between reproductive and vegetative parts revealed that rootstocks, seasons, and locations induced variations in the balance of ‘Cabernet Sauvignon’ vine (Table 3). In the São Joaquim area, rootstock 3309C had the highest number of clusters per shoot, the lowest leaf area/fruit ratio ($cm^2\ g^{-1}$), and the highest Ravaz index.

Table 3. Vegetative:productive balance of 'Cabernet Sauvignon' (*Vitis vinifera* L.) on different rootstocks, grown in Painel (1,200 m) and São Joaquim (1,300 m), during the 2015, 2016 and 2017 seasons.

Variable	Season	Rootstocks			
		1103P	3309C	1103P	101-14 Mgt
Painel (1,200 m)					
Clusters/Shoot	2015	1.29 ± 0.04 ab	1.42 ± 0.07 a		1.15 ± 0.08 b
	2016	1.30 ± 0.08 a	1.30 ± 0.05 a		0.98 ± 0.07 c
	2017	1.51 ± 0.06 b	1.66 ± 0.05 ab		1.73 ± 0.05 a
	Average	1.36 ± 0.04 b	1.47 ± 0.04 a		1.29 ± 0.07 b
Leaf Area/Fruit ($cm^2\ g^{-1}$)	2015	23.3 ± 0.6 a	23.6 ± 1.5 a		26.4 ± 1.6 a
	2016	16.4 ± 1.1 c	26.3 ± 2.8 b		46.2 ± 6.9 a
	2017	11.8 ± 0.5 a	11.8 ± 0.5 a		14.4 ± 1.6 a
	Average	17.2 ± 1.0 b	20.5 ± 1.6 b		28.7 ± 3.3 a
Ravaz Index ($kg\ kg^{-1}$)	2015	2.1 ± 0.1 b	3.0 ± 0.1 a		3.3 ± 0.2 a
	2016	1.2 ± 0.1 ab	1.4 ± 0.2 a		0.9 ± 0.2 b
	2017	4.2 ± 0.6 b	4.5 ± 0.5 b		6.1 ± 0.4 a
	Average	2.5 ± 0.3 b	3.0 ± 0.3 a		3.5 ± 0.4 a
São Joaquim (1,300 m)					
Clusters/Shoot	2015	1.64 ± 0.09 b	1.69 ± 0.07 b		1.93 ± 0.07 a
	2016	1.41 ± 0.06 a	1.45 ± 0.07 a		0.92 ± 0.06 b
	Average	1.52 ± 0.06 ns	1.57 ± 0.06		1.36 ± 0.11
Leaf Area/Fruit ($cm^2\ g^{-1}$)	2015	23.2 ± 1.5 a	28.7 ± 2.3 a		22.8 ± 1.4 a
	2016	19.0 ± 1.3 b	17.5 ± 1.7 b		44.1 ± 3.7 a
	Average	21.1 ± 1.1 b	23.1 ± 1.9 b		34.8 ± 3.1 a
Ravaz Index ($kg\ kg^{-1}$)	2015	2.5 ± 0.2 a	3.0 ± 0.2 a		2.5 ± 0.2 a
	2016	2.7 ± 0.1 b	4.5 ± 0.4 a		1.2 ± 0.2 c
	Average	2.6 ± 0.1 b	3.8 ± 0.3 a		1.8 ± 0.2 c

Means with different letters in the line differ significantly by Fisher's LSD test ($p<0.05$). Mean ± standard error. ns = not significant in ANOVA ($p<0.05$).

The P1103 rootstock was equivalent to the 3309C in terms of the leaf area/fruit yield, but it induced, proportionally, a greater accumulation of reserve substances in the shoots than in the clusters, which is represented by the yield/pruning ratio (Ravaz Index). The number of clusters per shoot in 101-14 Mgt suffered considerable variation according to the season. The Ravaz Index suffered considerable variation according to the location: it was similar to that observed in 3309C in the Painel area but presented the lowest value in São Joaquim.

Due to the increase in yield components, the 3309C rootstock improved the vegetative-productive balance variables Ravaz index. In the scientific literature on vine productive balance, ideal Ravaz Index values are between 5 and 10 (SMART & ROBINSON 1991). In the two areas evaluated, it was observed that rootstock 3309C had more appropriate values for the Ravaz Index. However, it should be noted that no rootstock reached ideal rates (5 to 10), indicating a vegetative-productive imbalance. Although the values found at 3309C are below the ideal minimum, they are still well above rates described in the high-altitude regions of Santa Catarina. In São Joaquim, for example, for the Cabernet Sauvignon and Merlot varieties, values between 1.5 and 2.3 have already been described (BRIGHENTI *et al.* 2011, ZALAMENA *et al.* 2013).

The rootstock 101-14 Mgt decreased the size of Cabernet Sauvignon berries in Painel (1,200 m), and in São Joaquim (1,300 m) (Table 4). The rootstocks 101-14 Mgt and 3309C decreased berry diameter and mass. SATISHA *et al.* (2010), observed the effect of rootstock on berry size. Low vigor rootstocks can reduce the size of the berries, increasing the skin/pulp ratio, which results in an increase in the concentration of phenolic compounds and the color of the wines (GIL *et al.* 2015).

Table 4. Diameter and berry mass of 'Cabernet Sauvignon' grapes (*Vitis vinifera* L.) produced on plants on different rootstocks, grown in Painel (1,200 m) and São Joaquim (1,300 m), during the 2015, 2016 and 2017 seasons.

Variable	Season	Rootstocks		
		1103P	3309C	101-14 Mgt
Painel (1,200 m)				
Berry diameter (mm)	2015	13.9 ± 0.0 a	13.8 ± 0.0 a	13.6 ± 0.1 a
	2016	12.9 ± 0.1 b	13.4 ± 0.1 a	12.4 ± 0.0 c
	2017	13.9 ± 0.0 a	13.3 ± 0.0 b	13.1 ± 0.0 b
	Average	13.6 ± 1.0 a	13.5 ± 0.1 a	13.0 ± 0.1 b
Berry mass (g)	2015	1.51 ± 4.00 a	1.37 ± 0.02 b	1.35 ± 0.04 b
	2016	1.32 ± 0.02 a	1.37 ± 0.03 a	1.30 ± 0.05 a
	2017	1.28 ± 0.02 a	1.35 ± 0.03 a	1.37 ± 0.02 a
	Average	1.37 ± 0.02 ns	1.36 ± 0.02 -	1.35 ± 0.02
São Joaquim (1,300 m)				
Berry diameter (mm)	2015	13.2 ± 0.1 ns	12.5 ± 0.0	12.9 ± 0.1
	2016	13.2 ± 0.0 ns	12.6 ± 0.1	12.6 ± 0.1
	Average	13.2 ± 0.1 a	12.6 ± 0.1 b	12.8 ± 0.0 b
Berry mass (g)	2015	1.17 ± 0.06 a	1.10 ± 0.04 b	1.13 ± 0.03 ab
	2016	1.38 ± 0.07 a	1.20 ± 0.04 b	1.27 ± 0.04 b
	Average	1.27 ± 0.05 a	1.14 ± 0.03 b	1.19 ± 0.03 b

Means with different letters in the line differ significantly by Fisher's LSD test (p<0.05). Mean ± standard error. ns = not significant in ANOVA (p<0.05).

Technological maturity variables of ‘Cabernet Sauvignon’ grapes suffered little influence from the rootstock (Table 5). The average soluble solids content ranged from 19.7 to 20.2 °Brix in grapes from the Painel (1,200 m) experimental area. In São Joaquim (1,300 m), although the difference in values, in practical terms, was relatively small, it was observed that 101-14 Mgt induced a significantly greater SS accumulation than 3309C, which in turn was greater than P1103 (21.9, 21.6 and 21.2°Brix, respectively).

Only in Painel (1,200 m), total acidity was higher in P1103 (130.2 meq L^{-1}) in relation to the other two rootstocks. In São Joaquim (1,300 m), the average acidity content varied between 109.4 and 115.3 meq L^{-1}. The average pH of the berries was similar in both experimental areas, varying between 3.13 and 3.19.

Table 5. Maturation of 'Cabernet Sauvignon' (*Vitis vinifera* L.) produced on plants on different rootstocks, grown in Painel (1,200 m) and São Joaquim (1,300 m), during the 2015, 2016 and 2017 seasons.

Variable	Season	Rootstocks		
		1103P	3309C	101-14 Mgt
Painel (1,200 m)				
Soluble solids (°Brix)	2015	20.7 ± 0.3 ns	20.9 ± 0.2	21.2 ± 0.4
	2016	18.8 ± 0.3 ns	19.2 ± 0.1	19.6 ± 0.2
	2017	19.7 ± 0.0 ns	19.7 ± 0.1	19.7 ± 0.3
	Average	19.7 ± 0.3 ns	19.9 ± 0.3	20.2 ± 0.3
Total acidity (meq L^{-1})	2015	136.7 ± 2.3 ns	131.2 ± 1.8	125.7 ± 2.2
	2016	132.3 ± 6.3 ns	118.1 ± 4.4	117.7 ± 2.4
	2017	121.4 ± 1.9 ns	115.9 ± 2.2	114.4 ± 2.4
	Average	130.2 ± 2.8 a	121.7 ± 2.7 b	119.2 ± 2.0 b
pH	2015	3.16 ± 0.02 ns	3.13 ± 0.01	3.15 ± 0.01
	2016	3.23 ± 0.06 ns	3.21 ± 0.07	3.26 ± 0.02
	2017	3.05 ± 0.01 ns	3.07 ± 0.02	3.10 ± 0.02
	Average	3.15 ± 0.03 ns	3.13 ± 0.03	3.17 ± 0.02
São Joaquim (1,300 m)				
Soluble solids (°Brix)	2015	20.6 ± 0.5 ns	21.5 ± 0.6	21.7 ± 0.7
	2016	21.8 ± 0.6 ns	21.8 ± 0.8	22.3 ± 0.7
	Average	21.2 ± 0.1 c	21.6 ± 0.1 b	21.9 ± 0.1 a
Total acidity (meq L^{-1})	2015	114.1 ± 7.8 ns	114.5 ± 5.1	116.2 ± 9.4
	2016	116.6 ± 9.6 ns	106.4 ± 5.3	102.7 ± 7.8
	Average	115.3 ± 6.0 ns	110.4 ± 4.7	109.4 ± 6.9
pH	2015	3.19 ± 0.01 ns	3.18 ± 0.02	3.15 ± 0.06
	2016	3.21 ± 0.07 ns	3.13 ± 0.02	3.16 ± 0.01
	Average	3.19 ± 0.02 ns	3.13 ± 0.02	3.15 ± 0.03

Means with different letters in the line differ significantly by Fisher's LSD test (p<0.05). Mean ± standard error. ns = not significant in ANOVA (p<0.05).

Total acidity represents the concentration of organic acids found in both grapes and wines, and it is influenced by a variety of factors, including the physiological aspects of maturation, soil composition, climatic conditions, and agronomic practices (NARDELLO *et al.* 2023). Specifically, cooler temperatures and heightened freshness during the harvest tend to increase total acidity in the wine produced (CHAVARRIA *et al.* 2011).

After verifying the change in vine balance parameters, little influence of rootstocks on the maturation of the ‘Cabernet Sauvignon’ grapes was verified. However, some observations are relevant, as they are consistent with results found in other scientific works. For example, in the Painel (1,200 m) area, the significantly higher levels of total acidity in ’Cabernet Sauvignon/P1103’ berries may indicate a delay in the fruit ripening process.

These results agree with the work of POUGET (1986), who clearly demonstrated that vines with large canopies, induced by rootstocks, tend to prolong the maturation of fruits, compared to vines grafted onto low vigor genotypes, which in turn tend to accelerate the maturation process. This characteristic has also been reported in other studies (BRIGHENTI *et al.* 2010, BRIGHENTI *et al.* 2011, NEAL *et al.* 2014, JOGAIAH *et al.* 2015).

CONCLUSION

Rootstocks modified yield parameters, vegetative growth, and vegetative-productive balance.

The rootstock 1103P increased the yield and vigor of Cabernet Sauvignon.

The rootstock 3309C improved the vegetative-productive balance indices of Cabernet Sauvignon. In addition, it reduced the size of the berries.

The rootstock 3309C is most recommended for ‘Cabernet Sauvignon’ grapevines in high-altitude regions.

NOTES

AUTHOR CONTRIBUTIONS

Conceptualization, methodology, and formal analysis**, Ricardo Allbrandt, Leo Rufato, Alberto Brighenti and Douglas Wurz**; software and validation**, Ricardo Allbrandt, Leo Rufato and Alberto Brighenti;** investigation**, Ricardo Allbrandt, Leo Rufato, Alberto Brighenti and Douglas Wurz**; resources and data curation **Ricardo Allbrandt, Leo Rufato, Alberto Brighenti**; writing-original draft preparation**, Ricardo Allbrandt, Alberto Brighenti and Douglas Wurz**; writing-review and editing**, Ricardo Allbrandt, Leo Rufato, Alberto Brighenti and Douglas Wurz**; visualization**, Ricardo Allbrandt, Leo Rufato, Alberto Brighenti and Douglas Wurz**; supervision, **Leo Rufato**; project administration, **Ricardo Allebrandt** and **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.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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