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Agronomic potential of new seedless grapes grafted on rootstocks for Southern Brazil

Abstract – The objective of this work was to evaluate the phenology, productive performance, plant vigor, and fruit physicochemical characteristics of three white seedless grape cultivars, recently introduced into Brazil, when grafted on the main rootstocks used in the Southern region of country, during two crop seasons. The experiment was carried out in a randomized complete block design, in a 2×3×4 factorial arrangement (crop seasons×cultivars×rootstocks). The used cultivars were Neptune, Hope, and Gratitude, and the rootstocks were Paulsen 1103, VR 043-43, IAC 572, and IAC 766. Neptune was the first cultivar to be harvested, on January 27, followed by Hope, on January 31, and by Gratitude, on February 15. Sprouting and harvest occurred earlier (2 to 7 days and 2 to 3 days, respectively) on 'IAC 766' and later (2 to 5 days and 2 to 3 days, respectively) on 'VR 043-43'. In addition, plants grafted on 'IAC 572' were more vigorous. The three evaluated cultivars showed a high total soluble solids/total titratable acidity ratio, varying from 24.96 to 49.22. However, the three cultivars present different responses regarding phenological stages, yield, plant vigor, and fruit physicochemical characteristics in both crop seasons when grafted on the Paulsen 1103, VR 043-43, IAC 572, and IAC 766 rootstocks.

Index terms: *Vitis* spp., adaptation, phenology, table grapes, viticulture.

Potencial agronômico de novas uvas sem sementes enxertadas em porta-enxertos para o Sul do Brasil

Resumo – O objetivo deste trabalho foi avaliar a fenologia, o desempenho produtivo, o vigor das plantas e as características físico-químicas dos frutos de três cultivares de uvas brancas sem sementes, recentemente introduzidas no Brasil, quando enxertadas nos principais porta-enxertos utilizados na região Sul do país, durante duas safras. O experimento foi conduzido em blocos ao acaso, em arranjo fatorial 2×3×4 (safras×cultivares×porta-enxertos). As cultivares utilizadas foram Neptune, Hope e Gratitude, e os porta-enxertos foram Paulsen 1103, VR 043-43, IAC 572 e IAC 766. Neptune foi a cultivar de colheita mais precoce, em 27 de janeiro, seguida por Hope, em 31 de janeiro, e Gratitude, em 15 de fevereiro. A brotação e a colheita foram mais precoces (2 a 7 dias e 2 a 3 dias, respectivamente) em 'IAC 766' e mais tardias (2 a 5 dias e 2 a 3 dias, respectivamente) em 'VR 043-43'. Além disso, as plantas enxertadas em 'IAC 572' foram mais vigorosas. As três cultivares avaliadas apresentaram elevada relação sólidos solúveis totais/acidez total titulável, que variou de 24,96 a 49,22. No entanto, as três cultivares apresentam respostas diferentes quanto a estádios fenológicos, produtividade, vigor das plantas e características físico-químicas dos frutos nas duas safras, quando enxertadas nos porta-enxertos Paulsen 1103, VR 043-43, IAC 572 e IAC 766.

Termos para indexação: *Vitis* spp., adaptação, fenologia, uvas de mesa, viticultura.

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Introduction

The Southern region is the main grape production area in Brazil, covering 55,329 ha (IBGE, 2024). However, the produced grapes are mainly destined for processing into wines, juices, jams, and other by-products (Mello & Machado, 2022), whereas table grape production is concentrated in the Northeastern region, where the Submédio do Vale do São Francisco is the main center for production and export in the country, with 10,325 ha (IBGE, 2024). Aiming to increase the supply of table grapes both for the Brazilian domestic market and for export (Leão, 2020), the used seeded cultivars were quickly replaced over the last decade by modern ones without seeds, a desirable characteristic for the table grape market worldwide (Leão et al., 2021).

Despite the growing consumer preference for seedless grapes (Maia et al., 2018), the production area in the Southern region is still insignificant. Among the faced challenges are the climate, characterized by a high relative humidity and excessive rain from grape budburst to harvest, as well as the lack of adapted cultivars, which hinders the increase in production (Dias et al., 2023). In this context, three white seedless hybrid cultivars were introduced in Brazil in 2016: Neptune, Hope, and Gratitude. Released by the University of Arkansas, these cultivars show a good tolerance to rain, berry cracking, and the main fungal diseases, in addition to a differentiated flavor (Clark & Moore 1999, 2013).

As to the rootstocks used in Brazil, Paulsen 1103 is the main one for new vineyards in the states of Santa Catarina and Rio Grande do Sul in the Southern region, whereas VR043-43 rootstocks is adopted on a smaller scale, especially in areas where the occurrence of ground pearl (*Eurhizococcus brasiliensis*) is higher (Camargo et al., 2011). In the state of Santa Catarina, young vine decline in the early years of planting is one of greatest difficulties encountered by viticulture (Dalbó & Feldberg, 2019). Although plant mortality was previously associated with specific causes such as the susceptibility of rootstocks to fusariosis (*Fusarium oxysporum* f.sp. *herbemontis*) or ground pearl, its etiology is still not well-defined, being related to several factors (Menezes-Netto et al., 2016). Plant weakening is also attributed to the susceptibility to other fungi such as black foot (*Cylindrocarpon destructans*) and descending rot (*Botryosphaeria* spp.), planting in clayey soils with a low macroporosity, vineyards with nutritionally unbalanced plants, and the occurrence of frost and hail (Dambros, 2016). Therefore, one of the most important factors for a successful implementation of new vineyards is the use of resistant rootstocks (Menezes-Netto et al., 2016).

In addition to Paulsen 1103 and VR 043-43, the IAC 572 and IAC 766 rootstocks have also shown to be promising in an area with the occurrence of young vine decline, inducing a good production in the tested scion (Dalbó & Feldberg, 2019). Knowing the influence of these rootstocks on a cultivar's phenological cycle may also be a useful tool for grape growers to scale operations and labor in the vineyard, as well as move harvest to earlier or later periods, in order to obtain more favorable prices.

The objective of this work was to evaluate the phenology, productive performance, plant vigor, and fruit physicochemical characteristics of three white seedless grape cultivars, recently introduced into Brazil, when grafted on the main rootstocks used in the Southern region of country, during two crop seasons.

Materials and Methods

The experiment was carried out in the 2020/2021 and 2021/2022 crop seasons, in the municipality of Três Barras, in the state of Santa Catarina, in the Southern region of Brazil, specifically in the Planalto Norte Catarinense region (26°11'03"S, 50°16'22"W, at 794 m above sea level). The climate in Três Barras is Cfb, according to Köppen's classification, constantly humid temperate, without a dry season, but with cool summers and frequent frosts (Alvares et al., 2013). The climate data were provided by Centro de Informações de Recursos Ambientais e de Agrometeorologia of Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina, including: maximum, mean, and minimum air temperatures (°C); precipitation (mm); and humidity (%). Monthly meteorological data from August 1, 2020, to February 28, 2022, were obtained at the weather station closest to the vineyard (Figures 1 and 2). Chilling hours (≤7.2°C) were calculated from April 1 to August 31 in each evaluation year, being 355 in 2020 and 444 in 2021.

The soil of the experimental area is classified as a Latossolo Vermelho distrófico (Santos et al., 2018), i.e., an Oxisol. In 2021, soil samples were analyzed by the Soil Testing Laboratory of Empresa de Pesquisa

Agropecuária e Extensão Rural de Santa Catarina, showing the following chemical characteristics at a depth of 0–20 cm: 4.8% organic matter, pH in H_2O 6.5, 0.0 $cmol_c\ dm^{-3}\ Al^{+3}$, 2.3 $cmol_c\ dm^{-3}\ H+Al^{+3}$, 12.3 $cmol_c\ dm^{-3}\ Ca^{+2}$, 5.7 $cmol_c\ dm^{-3}\ Mg^{+2}$, 304 $mg\ dm^{-3}\ K^{+}$, 9.2 $mg\ dm^{-3}$ P, and base saturation of 88.98%.

The experimental design was in randomized complete blocks in a 2×3×4 factorial arrangement (crop seasons × cultivars × rootstocks), with five replicates of three plants per plot. The evaluated cultivars were: the Neptune, Hope, and Gratitude seedless white grapes; and the Paulsen 1103, VR 043-43, IAC 572, and IAC 766 rootstocks. Phenology, productive performance, plant vigor, and the physicochemical characteristics of bunches and berries were determined for the seedless white grapes.

The vineyard was settled on a field in October 2018 with grafted vines, and the used training system was the Y-trellis, with a row spacing of 3.0 and 2.0 m between plants (population density of 1,667 plants per hectare), without irrigation or plastic cover. In 2019, the plants were formed into a bilateral cordon and pruned

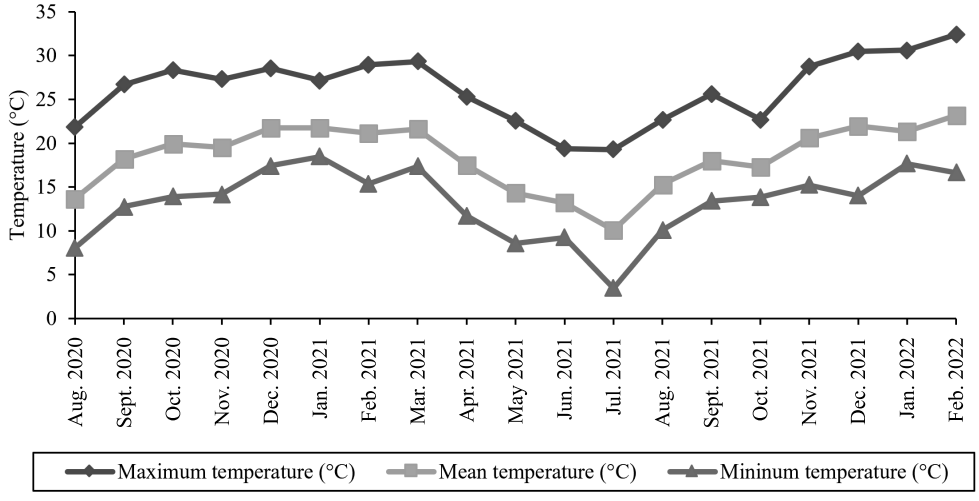

Figure 1. Monthly maximum, mean, and minimum temperatures from August 2020 to February 2022 in the municipality of Três Barras, in the state of Santa Catarina, Brazil.

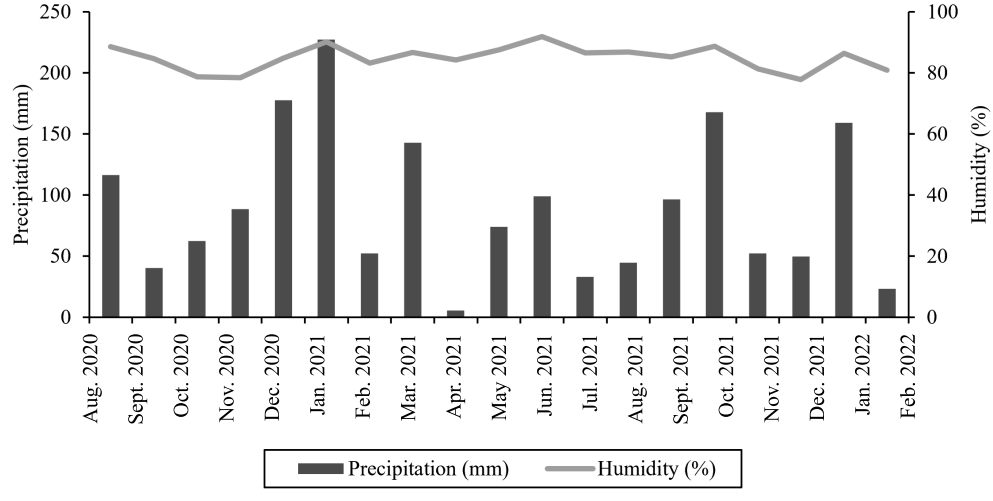

Figure 2. Precipitation and humidity from August 2020 to February 2022 in the municipality of Três Barras, in the state of Santa Catarina, Brazil.

by alternating spurs with two to three buds and canes with five to six buds, with a maximum of four canes per plant. Winter pruning was carried out by observing the beginning of sprouting of the first buds from the apices of the canes. To standardize bud sprouting, hydrogenated cyanamide was applied at 3.0% and a non-ionic adhesive spreader at 0.1%, considering the lack of prior knowledge of the behavior of the tested cultivars. Weeds and diseases were controlled through frequent mowing and periodic spraying with fungicides, respectively, as recommended for the crop in the South of Brazil (Nachtigal et al., 2010). As the primary interest of the experiment was to characterize grape cultivars and the influence of the used rootstocks, there was no cluster intervention, such as thinning, topping, or gibberellin application.

To define the phenological stages of the vine, the BBCH scale was used (Lorenz et al., 1995). The dates of the following phenological stages were noted: budburst, considered when around 10% of the buds were at the green tip stage (BBCH code 07); beginning of flowering, considered when 5% of the flowers were open (BBCH code 60); end of flowering, when less than 5% of the flowers were open and the rest were already fertilized (BBCH code 69); beginning of ripening, appearance of the first berries, with changes in color or consistency (BBCH code 81); end of ripening, when more than 90% of the berries changed color or softened (BBCH code 85); and harvest, established based on the visual and sensory evaluation of the berries, when the bunches were ready for harvest (BBCH code 89). The average of the dates for the two evaluated harvests was obtained from the dates registered for each phenological stage.

Productive performance was determined through mean number of shoots and bunches per plant, bunch weight (g), estimated yield (Mg ha^{-1}), and estimated bud fertility (number of bunches per number of shoots). Specifically, during the production cycle, the shoots were counted individually after canopy management operations of defoliation and lateral shoot thinning. The bunches were counted and weighed at the beginning of harvest and 7 days later, at full harvest. The average bunch weight was estimated by dividing the total weight of the bunches by the number of bunches harvested in each crop season. Yield was obtained by multiplying bunch weight per plant by the density of plants per hectare (Mg ha^{-1}). In addition, bud fertility was estimated by the relationship between the number of bunches and the number of shoots.

To obtain pruning weight, the branches were weighed immediately after winter pruning. Both bunches and branches were weighed using the AY 220 electronic balance (Shimadzu, Kyoto, Japan), with a precision of three decimal places. Plant vigor was evaluated considering the amount of plant material from winter pruning per plant (kg). For the physical characterization of the fruits (bunches and berries), bunch length and width (cm), berry length and width (mm), and number of berries per bunch were measured at the beginning and end of the harvest of each plot. One bunch with a weight close to the average weight was chosen for the physical characterization. Bunch length and width were measured with a ruler, and all the berries were removed to be counted and be measured in length and width using the IP54 digital caliper (Vonder, Curitiba, SC, Brazil). The berries were also weighed to calculate their average weight (g), based on the ratio between the total weight of the berries and the number of berries per bunch.

The chemical characteristics of the berries were evaluated by analyzing total soluble solids (TSS), total titratable acidity (TTA), and the TSS/TTA ratio. For this, samples of 100 berries were collected randomly from each plot approximately 5 days after the first harvest, identified, and immediately frozen. TSS content (ºBrix) was measured using the REF103 refractometer (General Tools & Instruments, New York, NY, USA), and TTA (grams of tartaric acid per 100 mL of must) was obtained by the 0.1 N NaOH neutralization titration method, until reaching pH 8.1, using the DL-pH digital pH meter (Del Lab, Araraquara, SP, Brazil). From these parameters, the TSS/TTA ratio was calculated.

The data were tested for normal distribution using the Lilliefors test and subjected to individual and joint analysis of variance in a factorial model for crop seasons, cultivars, and rootstocks, and means were grouped by the Scott-Knott test ($p \leq 0.05$). All statistical analyzes were carried out using the Genes statistical software (Cruz, 2013).

Results and Discussion

On average, the earliest dates observed for budburst and harvest were, respectively, September 8 and

January 27 for Neptune, followed by September 15 and January 31 for Hope, with the latest occurrences on September 24 and February 15 for Gratitude (Table 1). The three cultivars grafted on the IAC 766 rootstock showed slightly anticipated phenological stages, mainly for bud sprouting (2 to 7 days), end of ripening (2 to 4 days), and harvest (2 to 3 days).

Cultivars that have a natural late budburst, as Gratitude, are preferable for areas similar to that of the carried out experiment, where frosts are common from late August to the first two weeks of September (Persico et al., 2021), decreasing the risk of loss caused by frost damages on bud sprouting. Dalbó & Feldberg (2019) reported production and yield losses at harvest following frost damage only for plants grafted on IAC 766 rootstock due to a few days of budburst anticipation.

For early spring frost-free regions, the anticipation of bud sprout and cycle may be an advantage that can also be improved by advanced pruning, likely resulting in an earlier harvest and better market prices. In the state São Paulo, Tecchio et al. (2019) observed that the 'IAC 766' rootstock anticipated the phenological cycle, from bud sprouting to harvest, of Venus, an early seedless table grape cultivar.

The phenological stages of the three analyzed cultivars were similar when grafted on the IAC 572 and Paulsen 1103 rootstocks, occurring on intermediate dates, between those on IAC 766 and VR 043-43 rootstock (Table 1), showing no significant differences. Contrastingly, Dalbó & Feldberg (2019) found that the bud sprouting of 'Moscato Embrapa' grafted on 'IAC 572' started a few days after than on 'Paulsen 1103', but occurred later on 'VR 043-43', as observed in the present work.

Regarding cycle length, small differences of 1 to 3 days were identified for each cultivar considering the used rootstocks. Bunch ripening was the earliest for plants grafted on 'IAC 766', but harvest was the latest on 'VR 043-43' when compared with 'IAC 572' and 'Paulsen 1103'. Among the evaluated cultivars, the shortest (139 days) and the longest (144 days) cycles were those of Hope and Gratitude, which only differed from each other in 5 days; Neptune's cycle was of 142 days, considering the average of the rootstocks. In the origin site of the cultivars, the cycle from bud sprouting to harvest was of 140 days for Hope, 144 days for Gratitude, and 149 days for Neptune (Clark & Moore, 2013), showing a very similar cycle duration to that observed in the present study, except for Neptune, whose cycle was 7 days shorter under the conditions of the state of Santa Catarina.

There were significant interactions among the three evaluated factors (crop seasons × cultivars × rootstocks)

Table 1. Average dates of the phenological characteristics of the 'Neptune', 'Hope', and 'Gratitude' white seedless grapes, grafted on the 'Paulsen 1103', 'VR043-43', 'IAC 572', and 'IAC 766' rootstocks in the municipality of Três Barras, in the state of Santa Catarina, Brazil, in the 2020/2021 and 2021/2022 crop seasons.

Cultivar/rootstock	Pruning	Budburst	Flowering		Ripening		Harvest		Cycle (days)
			Beginning	End	Beginning	End	Beginning	End	
Neptune/IAC 766	Aug. 30	Sept. 5	Oct. 16	Nov. 6	Dec. 22	Jan. 2	Jan. 24	Jan. 31	141
Neptune/IAC 572	Aug. 30	Sept. 7	Oct. 20	Nov. 11	Dec. 24	Jan. 4	Jan. 28	Feb. 4	143
Neptune/P1103	Aug. 30	Sept. 8	Oct. 21	Nov. 11	Dec. 24	Jan. 4	Jan. 28	Feb. 4	142
Neptune/VR 043-43	Aug. 30	Sept. 12	Oct. 24	Nov. 16	Dec. 26	Jan. 9	Jan. 30	Feb. 6	140
Average	Aug. 30	Sept. 8	Oct. 20	Nov. 11	Dec. 24	Jan. 5	Jan. 27	Feb. 3	142
Hope/IAC 766	Sept. 4	Sept. 8	Oct. 22	Nov. 10	Jan. 2	Jan. 13	Jan. 28	Feb. 4	142
Hope/IAC 572	Sept. 4	Sept. 15	Oct. 25	Nov. 18	Jan. 5	Jan. 18	Feb. 2	Feb. 9	140
Hope/P1103	Sept. 4	Sept. 16	Oct. 26	Nov. 18	Jan. 1	Jan. 16	Jan. 30	Feb. 6	136
Hope/VR 043-43	Sept. 4	Sept. 20	Oct. 28	Nov. 22	Jan. 9	Jan. 22	Feb. 3	Feb. 10	136
Average	Sept. 4	Sept. 15	Oct. 25	Nov. 17	Jan. 4	Jan. 17	Jan. 31	Feb. 7	139
Gratitude/IAC 766	Sept. 11	Sept. 22	Oct. 31	Nov. 19	Jan. 13	Jan. 23	Feb. 12	Feb. 19	143
Gratitude/IAC 572	Sept. 11	Sept. 24	Nov. 4	Nov. 23	Jan. 14	Jan. 25	Feb. 15	Feb. 22	144
Gratitude/P1103	Sept. 11	Sept. 24	Nov. 3	Nov. 23	Jan. 15	Jan. 25	Feb. 15	Feb. 22	144
Gratitude/VR 043-43	Sept. 11	Sept. 26	Nov. 7	Nov. 25	Jan. 17	Jan. 26	Feb. 17	Feb. 24	144
Average	Sept. 11	Sept. 24	Nov. 4	Nov. 22	Jan. 15	Jan. 25	Feb. 15	Feb. 22	144

for all productive performance parameters (Table 2). In the 2021 harvest, the number of bunches was the highest for 'Hope', averaging 36.35 bunches per plant, but did not differ between 'Gratitude' (21.5 bunches per plant) and 'Neptune' (21.8 bunches per plant). In the 2022 harvest, due to the interactions between cultivars and rootstocks, Hope was superior to Gratitude and Neptune on all rootstocks, but showed the lowest number of bunches on 'IAC 766'. For 'Gratitude', there were no differences between rootstocks, but, for 'Neptune', the highest number of bunches per plant was observed both on 'VR 043-43' and 'Paulsen 1103'. For the seedless table grape 'BRS Clara' evaluated on six rootstocks in Vale do São Francisco, in the Northeastern region of Brazil, a greater number of bunches per plant occurred on 'IAC 766' and 'Paulsen 1003' when compared with 'IAC 572'; however, this result was not observed for other cultivars, confirming a strong interaction among cultivars and rootstocks (Leão et al., 2023).

There was an interaction between factors over the two crop seasons for bud fertility (Table 2). In 2021, 'Neptune' showed the highest value for this characteristic, along with 'Hope', grafted on 'VR 043-43' rootstock. In addition, 'Hope' presented a higher bud fertility when grafted both on 'VR 043-43' (1.48

Table 2. Productive performance and plant vigor of the 'Hope', 'Gratitude', and 'Neptune' white seedless grapes, grafted on the 'VR 043-43', 'IAC 572', 'IAC 766', and 'Paulsen 1103' rootstocks in the municipality of Três Barras, in the state of Santa Catarina, Brazil, in the 2020/2021 and 2021/2022 crop seasons[(1)].

Rootstock	2020/2021 crop season				2021/2022 crop season			
	'Hope'	'Gratitude'	'Neptune'	Average	'Hope'	'Gratitude'	'Neptune'	Average
				Number of bunches per plant				
'VR 043-43'	38.20	22.40	23.60	28.07a	59.20aA	33.20aC	40.00aB	44.13
'IAC 572'	37.80	22.60	21.40	27.27a	63.40aA	31.00aB	20.00bC	38.13
'IAC 766'	32.00	20.20	20.20	24.13a	53.40bA	32.80aB	24.40bC	36.87
'Paulsen 1103'	37.40	20.80	22.00	26.73a	62.80aA	30.60aB	34.20aB	42.53
Average	36.35A	21.50B	21.80B		59.70	31.90	29.65	
CV (%)		13.94				12.28		
				Bud fertility (number of bunches per number of shoots)				
'VR 043-43'	1.48aA	1.08bB	1.46aA	1.34	1.56aA	1.04aB	1.60aA	1.40
'IAC 572'	1.26bB	0.94bC	1.56aA	1.25	1.40bA	0.78bB	0.78cB	0.99
'IAC 766'	1.18bB	0.98bC	1.54aA	1.23	1.30bA	0.96aB	1.08bB	1.11
'Paulsen 1103'	1.40aB	1.24aB	1.58aA	1.41	1.66aA	1.02aC	1.46aB	1.38
Average	1.33	1.06	1.54		1.48	0.95	1.23	
CV (%)		9.86				9.74		
				Yield (Mg ha^{-1})				
'VR 043-43'	23.60aA	14.80aC	19.16bB	19.19	32.98aA	24.62aB	33.98aA	30.53
'IAC 572'	17.42bA	14.74aA	18.82bA	16.99	31.90aA	21.14aB	10.28bC	21.11
'IAC 766'	12.64cB	13.06aB	16.52bA	14.07	25.98bA	21.24aA	12.02bB	19.75
'Paulsen 1103'	23.30aA	13.68aB	22.44aA	19.81	32.38aA	22.10aB	29.92aA	28.13
Average	19.24	14.07	19.24		30.81	22.28	21.55	
CV (%)		15.42				17.72		
				Plant vigor (kg from pruning per plant)				
'VR 043-43'	3.08bA	3.02bA	2.22aB	2.77	2.62	2.70	1.94	2.42c
'IAC 572'	3.98aA	3.52aA	1.78aB	3.09	3.50	3.40	2.44	3.11a
'IAC 766'	3.64aA	3.26aA	1.74aB	2.88	3.26	2.90	2.28	2.81b
'Paulsen 1103'	3.04bA	2.84bA	1.88aB	2.59	2.40	2.50	1.70	2.20c
Average	3.44	3.16	1.91		2.95A	2.88A	2.09B	
CV (%)		13.20				7.54		

[(1)]Means followed by equal letters, uppercase in the rows and lowercase in the columns, do not differ from each other by the Scott-Knott grouping of means test, at 5% probability.

bunches per branch) and 'Paulsen 1103' (1.40 bunches per branch), when compared with 'IAC 572' (1.26 bunches per branch) and 'IAC 766' (1.18 bunches per branch). Gratitude showed the highest bud fertility of 1.24 bunches per branch on 'Paulsen 1103'. In 2022, 'Hope' had the highest bud fertility on almost all rootstocks (from 1.3 to 1.66 bunches per branch), along with 'Neptune' grafted on 'VR 043-43' (1.6 bunches per branch). The lowest bud fertility was registered for 'Gratitude' on 'IAC 572' (0.78 bunches per branch) and for 'Neptune', both on 'IAC 766' (1.08 bunches per branch) and 'IAC 572' (0.78 bunches per branch).

According to Leão et al. (2017), a key factor to recommend cultivars capable of reaching a high yield potential is a high bud fertility, which is genetically determined, but also strongly affected by environmental factors. Therefore, a low productivity is one of the main reasons why there are currently no white seedless grape cultivars in production in Southern Brazil.

In 2021, the highest average yields were achieved by cultivars Hope and Neptune (Table 2). As for the rootstocks, the highest values for this characteristic were provided by 'Paulsen 1103' for all cultivars and by 'VR-043-43', along with 'Paulsen 1103', for Hope. Regarding the cultivar/rootstock interaction, for Hope, there were no differences between 'VR 043-43' and 'Paulsen 1103', which were superior to the other rootstocks. For 'Neptune', 'Paulsen 1103' provided a higher productivity, while, for 'Gratitude', there were no differences between rootstocks. In 2022, 'Hope' showed the highest average yield, followed by 'Neptune' and 'Gratitude'. As to the rootstocks, 'VR 043-43' and 'Paulsen 1103', once again, induced the highest average yield. Considering the interaction between rootstocks and cultivars, yield was the lowest for Hope on 'IAC 766', the highest for Neptune on 'Paulsen 1103' and 'VR 043-43', and did not differ between rootstocks for Gratitude. In the semiarid region of Brazil, a greater effect of the used rootstock was observed on the production cycle of the BRS Ísis seedless table grape cultivar, and the mean production of the six cycles was the highest on 'IAC 572' (Leão et al., 2020a).

At the origin site of the cultivars, Clark & Moore (2013) obtained crop average yields of 28.3, 23.9, and 16.2 Mg ha^{-1} for Hope, Neptune, and Gratitude, respectively. This means that the average yields in Santa Catarina were higher than those in the United States, showing the high yield potential of the cultivars evaluated in the present work.

In Vale do São Francisco, the main Brazilian producing and exporting region of seedless grapes, the highest yield for 14 cultivars grafted on the 'IAC 766' rootstock, under a pergola trellis system with irrigation, was above 26 Mg ha^{-1} (Leão et al., 2020b). Therefore, the yield values obtained in the present study are promising, except for 'Gratitude' and 'Neptune' grafted on the 'IAC 572' and 'IAC 766' rootstocks. According to those authors, the main difficulties in producing imported seedless grape cultivars is the lack of adaptation and low yields, which is opposite to the observed here.

Regarding pruning weight, factor interactions were only verified in 2021 (Table 2). Both 'Hope' and 'Gratitude' had a higher pruning weight than 'Neptune' on all rootstocks. For 'Hope' and 'Gratitude', the least vigorous rootstocks were 'Paulsen 1103' (3.04 and 2.84 kg per plant, respectively) and 'VR 043-43' (3.08 and 3.02 kg per plant, respectively). In 2022, the least vigorous cultivar was Neptune (2.09 kg per plant). Considering the used rootstocks, the highest pruning weight was induced by 'IAC 572', being 3.11 kg per plant for all cultivars.

Although the best strategy to overcome young vine decline in Santa Catarina has been grafting on tropical rootstocks, such 'IAC 572' and 'IAC 766', or on small hybrids of *Muscadinia rotundifolia* Michx., due to a higher scion vigor (Dalbó & Feldberg, 2016, 2019; Menezes-Netto et al., 2016), vigorous rootstocks can induce lower yields in seedless grapes (Feldberg et al., 2007; Leão et al., 2017). Until the 2022 harvest, no plants with young vine decline symptoms were observed in the present experiment.

In 2021, the heaviest bunches were those produced by 'Neptune' on all rootstocks (Table 3). In 2022, the highest values for this characteristic were obtained by 'Neptune' on 'Paulsen 1103' (524.8 g) and 'VR 043-43' (512.8 g) and by 'Gratitude' on 'IAC 572' (413.4 g) and 'IAC 766' (391.2 g). Even though the heaviest bunches can lead to higher yields, they can also result in bunch compactness and berry size reduction (Al-Saif et al., 2023). Bunches from 'Hope' weighed the lowest in both the 2021 and 2022 harvests. Regarding rootstocks, 'IAC 572' and 'IAC 766' induced the production of lighter weight bunches when combined with 'Hope' and 'Neptune' in 2021 and with 'Neptune' in 2022.

Rootstocks that induce a lighter weight bunch can be recommended for cultivars that require thinning, resulting in a quicker, easier, and less costly operation.

In 2021, the longest bunches were produced by 'Neptune' grafted on 'Paulsen 1103' (21.92 cm) and 'IAC 572' (21.48 cm), by 'Gratitude' on 'VR 043-43' (18.68 cm), and by 'Hope' on the 'VR 043-43' (17.76 cm) and 'Paulsen 1103' (17.84 cm) rootstocks (Table 3). In the 2022 harvest, no differences among cultivars and rootstocks were identified.

Regarding bunch width, in 2021, the greatest values were obtained for 'Neptune' grafted on 'IAC 572' (14.56 cm) and 'Paulsen 1103' (13.64 cm), for 'Gratitude' on 'IAC 766' (11.80 cm), and for 'Hope' on 'VR 043-43' (11.66 cm) and 'Paulsen 1103' (11.06 cm). In 2022, no differences were observed for 'Hope' and 'Gratitude', but 'Neptune' produced wider bunches on 'Paulsen 1103' (14 cm) and 'VR 043-43' (12.78 cm).

Larger and wider bunches result directly in higher yields, as the larger the bunches, the greater their weight. However, these features do not always translate into a higher bunch quality for the fresh table grape market. This means that, after reviewing the characteristics of each cultivar, management operations should be carried out to promote an adequate ripening, increase berry size associated with the application of growth

Table 3. Physical characteristics of the bunches of the 'Hope', 'Gratitude', and 'Neptune' white seedless grapes, grafted on the 'VR 043-43', 'IAC 572', 'IAC 766', and 'Paulsen 1103' rootstocks in the municipality of Três Barras, in the state of Santa Catarina, Brazil, in the 2020/2021 and 2021/2022 crop seasons[(1)].

Rootstock	2020/2021 crop season				2021/2022 crop season			
	'Hope'	'Gratitude'	'Neptune'	Average	'Hope'	'Gratitude'	'Neptune'	Average
				Bunch weight (g)				
'VR 043-43'	369.6aB	405.0aB	490.4bA	421.7	335.4aC	439.8aB	512.8aA	429.3
'IAC 572'	275.8bC	407.6aB	531.8bA	405.1	303.2aB	413.4aA	305.6bB	340.7
'IAC 766'	237.4bC	394.2aB	488.2bA	373.3	293.2aB	391.2aA	293.8bB	326.1
'Paulsen 1103'	376.2aB	397.0aB	616.6aA	463.3	309.4aC	430.8aB	524.8aA	421.7
Average	314.8	400.9	531.8		310.3	418.8	409.3	
CV (%)		12.85				9.09		
				Bunch length (cm)				
'VR 043-43'	17.76aA	18.68aA	19.64bA	18.69	16.94	16.84	19.46	17.75
'IAC 572'	16.40bB	16.80bB	21.48aA	18.23	17.42	18.02	17.14	17.53
'IAC 766'	14.34cC	16.60bB	20.20bA	17.05	16.20	16.48	17.16	16.61
'Paulsen 1103'	17.84aB	16.94bB	21.92aA	18.90	17.54	17.48	19.30	18.11
Average	16.59	17.26	20.81		17.03	17.21	18.27	
CV (%)		5.92				6.94		
				Bunch width (cm)				
'VR 043-43'	11.66aA	10.80bA	11.72bA	11.39	12.26aA	13.52aA	12.78aA	12.85
'IAC 572'	10.30bB	10.68bB	14.56aA	11.85	11.58aA	12.72aA	11.54bA	11.95
'IAC 766'	10.20bB	11.80aA	12.42bA	11.47	10.74aA	12.32aA	11.44bA	11.50
'Paulsen 1103'	11.06aB	10.10bB	13.64aA	11.60	12.02aB	11.92aB	14.00aA	12.65
Average	10.81	10.85	13.09		11.65	12.62	12.44	
CV (%)		7.60				8.80		
				Number of berries per bunch				
'VR 043-43'	152.8aA	102.6aB	111.8cB	122.4	160.6aA	126.8aB	159.2aA	148.9
'IAC 572'	93.6cB	90.2aB	151.8bA	111.9	155.8aA	107.4aB	104.4bB	122.5
'IAC 766'	65.2 dC	88.8aB	132.4cA	95.5	122.6bA	116.4aA	102.8bA	113.9
'Paulsen 1103'	128.0bB	86.0aC	179.0aA	131.0	175.0aA	123.2aB	155.4aA	151.2
Average	109.9	91.9	143.8		153.5	118.5	130.5	
CV (%)		14.53				15.76		

[(1)]Means followed by equal letters, uppercase in the rows and lowercase in the columns, do not differ from each other by the Scott-Knott grouping of means test, at 5% probability.

regulators, and reduce the natural size of bunches to meet the requirements of some markets (Guzmán et al., 2021). Cutting cluster wings, topping, and berry thinning are recommended approaches to satisfy the conditions of more demanding table grape markets (Silvestre et al., 2017).

Regarding the number of berries (Table 3), no differences were observed among rootstocks for 'Gratitude' during the two harvests. For 'Hope', the number of berries was the highest (152.8) on 'VR 043-43' in the 2021 harvest and the lowest (122.6) on 'IAC 766' in 2022. For 'Neptune', the highest number of berries occurred on 'Paulsen 1103' (179) in 2021 and on 'VR 043-43' (159.2) and 'Paulsen 1103' (155.4) in 2022. In their study, Zilio et al. (2019) recommended leaving only 50 to 70 berries per bunch for 'BRS Ísis' and 'BRS Vitória' in the Serra Gaúcha region, in the state of Rio Grande do Sul, to achieve an ideal bunch flavor and color, in addition to a larger berry size.

There were no significant interactions among factors related to berry weight (Table 4). In the 2021 harvest, 'Gratitude' produced berries with the greatest weight (4.25 g), whereas, in the following harvest, both 'Gratitude' (3.47 g) and 'Neptune' (3.15 g) differed from 'Hope' (2.04 g), showing higher values for this characteristic. Rootstock influence on berry weight was not identified for the three tested cultivars. In a research during three harvests in the United States, Clark & Moore (2013) reported an average berry weight from 3.5 to 3.7 g for 'Gratitude', from 2.5 to 3.1 g for 'Hope', and from 3.3 to 3.9 g for 'Neptune', which are similar values to those obtained in the present study.

Regarding berry length and width, in the 2021 harvest, cultivars Gratitude and Neptune produced berries with a greater length (23.05 and 22.15 mm, respectively). In 2022, there were interactions among the studied factors (Table 4). 'Gratitude' and 'Neptune' reached the longest berry length when grafted on 'Paulsen 1103' and 'VR 043-43'. As for berry width, 'Gratitude' was

Table 4. Physical characteristics of the berries of the 'Hope', 'Gratitude', and 'Neptune' white seedless grapes, grafted on the 'VR 043-43', 'IAC 572', 'IAC 766', and 'Paulsen 1103' rootstocks in the municipality of Três Barras, in the state of Santa Catarina Brazil, in the 2020/2021 and 2021/2022 crop seasons[(1)].

Rootstock	2020/2021 crop season				2021/2022 crop season			
	'Hope'	'Gratitude'	'Neptune'	Average	'Hope'	'Gratitude'	'Neptune'	Average
				Berry weight (g)				
'VR 043-43'	2.64	3.92	3.54	3.37a	2.08	3.42	3.22	2.91a
'IAC 572'	3.04	4.28	3.70	3.67a	1.96	3.70	2.94	2.87a
'IAC 766'	3.56	4.58	3.56	3.90a	2.34	3.30	3.14	2.93a
'Paulsen 1103'	3.04	4.20	3.38	3.54a	1.78	3.46	3.28	2.84a
Average	3.07B	4.25A	3.55B		2.04B	3.47A	3.15A	
CV (%)		10.17				12.50		
				Berry length (mm)				
'VR 043-43'	19.56	22.42	21.94	21.31a	18.30aB	21.34aA	20.34aA	19.99
'IAC 572'	20.46	23.32	22.78	22.19a	17.78aC	22.82aA	20.08aB	20.23
'IAC 766'	21.98	23.36	22.32	22.55a	19.36aB	21.46aA	20.40aB	20.41
'Paulsen 1103'	20.42	23.10	21.56	21.69a	16.34bB	21.56aA	20.96aA	19.62
Average	20.61B	23.05A	22.15A		17.95	21.80	20.45	
CV (%)		4.12				5.78		
				Berry width (mm)				
'VR 043-43'	14.54bC	16.56aA	15.52aB	15.54	12.90	15.54	15.10	14.51a
'IAC 572'	14.94bB	17.10aA	15.38aB	15.81	12.64	15.82	15.02	14.49a
'IAC 766'	16.14aB	17.44aA	15.32aC	16.30	12.90	15.12	15.22	14.41a
'Paulsen 1103'	14.90bB	17.10aA	15.26aB	15.75	11.62	15.32	15.20	14.05a
Average	15.13	17.05	15.37		12.52B	15.45A	15.14A	
CV (%)		3.23				4.87		

[(1)]Means followed by equal letters, uppercase in the rows and lowercase in the columns, do not differ from each other by the Scott-Knott grouping of means test, at 5% probability.

superior to 'Hope' and 'Neptune' on all rootstocks. At harvest, cultivars Gratitude (15.45 mm) and Neptune (15.14 mm) differed from Hope (12.52 mm), producing wider berries. Cultivars with natural longer and wider berries are not only preferred by consumers, but also require a lower gibberellin application to reach market demands (Guzmán et al., 2021). In the municipality of Petrolina, in the state of Pernambuco, Brazil, for example, Thompson Seedless, the main white seedless grape cultivar in the world market and one of the most important ones in Brazil, reached a natural berry length and width of 17.99±0.91 and 15.04±0.68 mm, respectively (Leão et al., 2020b).

Concerning the fruit chemical analysis (Table 5), in 2021, the highest TSS values were observed for 'Neptune' and 'Gratitude' when grafted on 'VR 043-43' and for 'Hope' on 'IAC 766' and 'IAC 572'. However, the grapes produced by 'Hope' on 'IAC 766' and by 'Gratitude' on 'VR 043-43' showed the highest TSS values of 16.08 and 16.72 ºBrix, respectively. In the Vale do Submédio do São Francisco region, cultivar BRS Magna produced higher sugar contents on 'Paulsen 1103' and 'IAC 572' (Santos et al., 2022). In the 2022 harvest, there were no interactions among factors or differences induced by rootstocks; however, Neptune (17.05ºBrix) and Gratitude (16.13°Brix) had sweeter grapes.

As to ATT, 'Neptune' showed the lowest values on all rootstocks in the 2021 harvest, whereas 'Hope' stood out as having the highest acidity on every rootstock in 2022. 'IAC 766' was the rootstock that induced the lowest acidity in all cultivars in 2021 and in Hope and Neptune in 2022. Zang et al. (2023) explained that rootstocks influence the activity of key enzymes involved in acid metabolism and the expression of related genes, such as the NAD-MDH enzyme, which positively correlate with malic acid content.

Regarding the TSS/ATT ratio (Table 5), in the 2021 harvest, 'Neptune' and 'Gratitude' showed the highest values when grafted on 'VR 043-43'. However, in 2022,

Table 5. Chemical characteristics of the berries of the 'Hope', 'Gratitude', and 'Neptune' white seedless grapes, grafted on 'VR 043-43', 'IAC 572', 'IAC 766', and 'Paulsen 1103' rootstocks in the municipality of Três Barras, in the state of Santa Catarina, Brazil, in the 2020/2021 and 2021/2022 crop seasons.

Rootstock	2020/2021 crop season				2021/2022 crop season			
	'Hope'	'Gratitude'	'Neptune'	Average	'Hope'	'Gratitude'	'Neptune'	Average
	Total soluble solids (ºBrix)							
'VR 043-43'	14.76bB	16.72aA	15.84aA	15.77	15.04	17.48	17.04	16.52a
'IAC 572'	15.24bA	13.68bB	16.16aA	15.03	14.20	15.36	16.72	15.43a
'IAC 766'	16.08aA	14.60bB	16.44aA	15.71	13.64	15.92	17.00	15.52a
'Paulsen 1103'	14.84bB	14.08bB	15.90aA	14.94	14.48	15.74	17.44	15.89a
Average	15.23	14.77	16.09		14.34B	16.13A	17.05A	
CV (%)		4.90				5.40		
	Total titratable acidity (g tartaric acid 100 mL^{-1})							
'VR 043-43'	0.73aA	0.62aB	0.54aC	0.63	0.55aA	0.35bC	0.44aB	0.45
'IAC 572'	0.61bA	0.60aA	0.54aB	0.59	0.54bA	0.28cC	0.45aB	0.42
'IAC 766'	0.51cA	0.53bA	0.44bB	0.49	0.51bA	0.32bC	0.39bB	0.41
'Paulsen 1103'	0.65bA	0.63aA	0.58aB	0.62	0.59aA	0.41aB	0.45aB	0.48
Average	0.62	0.60	0.53		0.55	0.34	0.43	
CV (%)		5.54				8.81		
	Total soluble solids/total titratable acidity ratio							
'VR 043-43'	20.24cB	26.82aA	29.54bA	25.53	27.52aC	51.02aA	38.78aB	39.11
'IAC 572'	25.04bB	22.86bB	29.62bA	25.84	26.92aC	55.38aA	37.36aB	39.89
'IAC 766'	31.92aB	27.60aC	37.48aA	32.33	27.28aC	51.40aA	43.78aB	40.82
'Paulsen 1103'	23.00bB	22.56bB	27.70bA	24.42	24.66aB	39.08bA	39.16aA	34.30
Average	25.05	24.96	31.09		26.60	49.22	39.77	
CV (%)		7.94				11.32		

(1)Means followed by equal letters, uppercase in the rows and lowercase in the columns, do not differ from each other by the Scott-Knott grouping of means test, at 5% probability.

both cultivars reached the highest values on 'Paulsen 1103'. According to International Organisation of Vine and Wine (OIV, 2024), white table grape cultivars must present a minimum TSS/ATT ratio of 20 to be considered as ripe, which is important since this variable determines flavor perception. For all cultivar/rootstock combinations tested in the present work, the TSS/TTA ratios were above this minimum standard, varying from 20.24 for Hope on 'VR 043-43' to 55.38 for Gratitude on 'IAC 572'.

The results obtained in the present study, such as high yields, a high bud fertility, and grape bunches ripeness, are promising for the Southern region of Brazil, where no adapted white seedless grape cultivar is available to be recommended for growers.

Conclusions

1. The Neptune, Hope, and Gratitude white seedless grape (*Vitis* spp.) cultivars show different responses regarding phenological stages, yield, plant vigor, and fruit physicochemical characteristics in the 2020/2021 and 2021/2022 crop seasons when grafted on the Paulsen 1103, VR 043-43, IAC 572, and IAC 766 rootstocks.

2. 'Neptune' and 'Hope' grafted on 'VR 043-43' or 'Paulsen 1103' show a high yield and bud fertility, independently of the crop season.

3. 'Neptune', 'Hope', and 'Gratitude' present an earlier budburst, flowering, and harvest when grafted on the 'IAC 766' rootstock, but a later budburst, flowering, ripening, and harvest on 'VR 043-43'.

4. 'Hope' and 'Gratitude' grafted on 'IAC 572' or 'IAC 766' present a higher plant vigor than 'Neptune' on all tested rootstocks.

5. All cultivar/rootstock combinations tested present a high total soluble solids/total titratable acidity ratio.

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