Effect of vigour and number of clusters on enological parameters of cabernet sauvignon red wines

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Abstract

Vegetative growth and yield are reported to affect grape and wine quality. The objective of this research was to determine the effect of vine vigour and number of clusters per vine on physicochemical composition and phenolic profile of red wines, during two vegetative cycles (2020 and 2021), in Bento Gonçalves-RS, south Brazil. Cabernet Sauvignon, grafted onto Paulsen 1103, was evaluated from three vine vigour (low, medium and high), according to shoot weight. Five treatments of number of clusters were used for each vigour, with 15, 22, 29, 36, and 45 clusters per vine. Grapes were harvested in the same day and wines were elaborated by classical methodology for red wines. Classical analyzes and phenolic compounds were performed. Different responses were obtained from each vintage. In 2020, a dry season from veraison to harvest, grapes and wines obtained presented high sugar content, pH, low acidity, and lower total anthocyanins, unexpectedly, varying between treatments. In 2021, characterized by wet season at harvest, responses were different, wines presented lower alcohol content, pH, and higher total anthocyanins, also high differences between treatments. As conclusions, yield and vine vigour had strong influence on grape and wine quality, promoting different enological potentials of grapes wines.

Introduction

The grape composition at harvest, and consequently wine composition, is the result of biotic and abiotic factors, interacting during vine development and grape maturation in the field, and winemaking in the winery (Van Leeuwen et al., 2017). Many parameters play a very important role in the field, such as climate, soil, cultivar, rootstock, as well as cultural practices (Barros et al., 2018). These one, managed by man, can be applied according to different goals in terms of enological potential for the grapes wanted, and type of wine to be elaborated. The vine can be modulated differently, according to the number of buds per vine, then the number of clusters per vine, influencing on the yield, and consequently, the grape and wine compostion (Song et al., 2014; Van Leeuwen et al., 2017; Barros et al., 2018).
Vine vigour is related and depending on the genetic and environmental conditions, expressing the impact of climatic conditions and soil fertility, and it can be used as an integrative indicator for terroir studies (Van Leeuwen et al., 2010; Gambetta et al., 2012). It is the propensity to assimilate, store, and/or use non-structural carbohydrates for producing large canopies, and it is associated with intense metabolism and fast shoot growth (Hugalde et al., 2020). Understanding grape vigour is necessary to optimize vineyard management and improvement strategies, because the vine needs sufficient canopy and growth to ripen grapes (Hugalde et al, 2020). Some authors reported that the removal of some bunches from the vine can increase the concentration of total soluble solids (TSS), the pH of the grape juice and accelerate ripening (Reynolds et al., 1994; Barros et al., 2018). In this way, the objective of this study was to determine the effect of vine vigour and number of clusters per vine on physicochemical composition and phenolic profile of Cabernet Sauvignon red wines in the southern Brazil.

Material and Methods

Characterization of the vineyard

The experiment was carried out in an experimental vineyard located at the Embrapa Grape & Wine, in Bento Gonçalves, state of Rio Grande do Sul (Brazil), during two consecutive vegetative cycles (2020 and 2021). Cabernet Sauvignon of twelve years old grafted onto Paulsen 1103 rootstock was used, the vines are conducted on vertical shoot positioning (VSP), with 1.0 m spacing between plants and 2.75 m between rows. The experimental design was a randomized block, consisting of different treatments with three levels of vigour (low, medium and high), defined according to the pruning weight of branches in previous seasons, and five treatments of different number of bunches per vigour, with 15 , 22, 29, 36 and 45 bunches per vine. Twenty-five vines (biological replicates) composed each treatment. From each, one hundred berries were collected at harvest time, to determine the pH, total soluble solids, total acidity and soluble solids/total acidity ratio (OIV, 1990).

Winemaking

The wines were elaborated in an experimental scale, where each treatment was composed by 20 kg of grapes. The protocol followed traditional winemaking for reds. After harvest, grapes were destemmed and put in glass tanks (20 l each), with 50 mg L^{-1} of sulfur dioxide and 20 g hL^{-1} of yeast (*Saccharomyces cerevisiae*). The alcoholic fermentation-AF occurred at 25±2 ºC, with one pumping over (manually) per day, for six days, when AF finished. After pressing and separation of wine and solids, malolactic fermentation-MF performed with native bacteria, for 30 days at 18±2 ºC. At the end of MF, wines were placed in a cold room, for stabilization (0±2°C) for 30 days, free sulfur dioxide was corrected for 30 mg L^{-1}. At the end, the wines were bottled and stored at 16± 2 ºC until the analyses, carried out thirty days after bottling.

Wine analyses

The wines were analyzed to determine the classical parameters, as well as using colorimetric parameters to determine total anthocyanins, total phenols, color intensity and tonality (Ribéreau-Gayon, 1970; OIV, 1990). The minerals potassium, sodium, calcium, magnesium, manganese, iron, phosphorus and copper were analyzed in a SpectrAA 240FS atomic absorption spectrophotometer (Varian) (Miele and Rizzon, 2017). The quantification of minerals was based on the standard curve of the compounds using Tritisol (Merck) solutions of each element.

Statistical analysis

The analysis of variance (ANOVA) was performed and differences between treatments were tested by a multiple mean’s comparison test (Tukey Honestly Significant Difference) at a 5% significance level. Both analyzes were performed using Action Stat 3.7 software.

Results and discussion

Grape and wine composition

In 2020, the grapes were characterized by higher concentrations of total soluble solids (22.6 - 25.2 ºBrix), pH (3.98 - 4.25) and lower total acidity (2.4 - 3.3 g L^{-1} of tartaric acid). In 2021, the grapes had lower concentrations of total soluble solids (20.1 - 22.0 ºBrix) and pH (3.34 - 3.48), in addition to higher total acidity (5.7 - 7.2 g L^{-1} of tartaric acid) (data not shown).
The yield presented the same behaviour in both vintages, increasing the weight of grapes according to the number of clusters per vine and vigour of the plants (data not shown). For example, the low vigour and 15 clusters produced 4,632 and 4,511 kg hectare $^{-1}$ in 2020 and 2021, respectively, while the high vigour with 43 clusters per vine produced 17,271 and 17,144 kg hectare $^{-1}$ in 2020 and 2021, respectively.
The results of the treatments on Cabernet Sauvignon wines are shown in the **Table 1** (2020) and **Table 2** (2021). In 2020, the alcohol content of the wines ranged from 13.6 to 15.3 % v/v, while in 2021 from 12.0 to 13.0 % v/v. The highest alcohol content in 2020 is associated to better maturation index of the grapes, in a dry season (above 22 °Brix). It is possible to observe a trend towards higher values of alcohol content in treatments with low vigor. Similar results were obtained by previous study (Song et al., 2014). Regarding the total acidity, the lowest value was 4.9 g L^{-1} and the highest 6.9 g L^{-1} in 2020. The treatments with 36 and 45 clusters, regardless the vigour, had the lowest acidities. These results can be different according to the terroir, but in this case, the

soils present high fertility, explaining the low differences between treatments with low or high vigour. In 2021, the lowest value for acidity was 5.9 g L^{-1} and the highest was 7.7 g L^{-1}, with a tendency towards higher contents in wines from low vigour of the vines. These behavior was expected according to previous study (Barros et al., 2018). The pH ranged from 3.84 to 4.06 in 2020 and between 3.80 to 3.95 in 2021. The high pH of the wines is explained by high amounts of minerals in the soils of the region, which in a driest season (2020), presented the highest values, linked to lowest values of total acidity.

Table 1. Physicochemical analysis of Cabernet Sauvignon wines made with different treatments of number of clusters and pruning weight, harvest 2020.

Treatment	Alcohol Content (% v/v)	Total acidity (g.L^{-1})	Volatile acidity (g.L^{-1})	pH	Total polyphenols (mg.L^{-1})	Total anthocyanins (mg.L^{-1})	Color intensity (ua)	Hue (ua)	Total minerals (mg L^{-1})
15 clusters - low vigor	14.1^{cd} ±0.0	6.3^{bc} ±0.1	0.81^{a} ±0.07	3.96^{ab} ±0.02	3227.6^{cd} ±24.0	249.9^{abc} ±10.9	16.82^{de} ±0.73	0.85^{a} ±0.00	2203^{fg} ±0.00
15 clusters - medium vigor	13.8^{fg} ±0.0	6.3^{bc} ±0.1	0.55^{a} ±0.19	3.84^{b} ±0.06	2924.6^{hi} ±22.9	254.5^{abc} ±8.9	17.77^{bcd} ±0.42	0.84^{a} ±0.02	2144^{i} ±0.00
15 clusters -high vigor	13.6^{g} ±0.0	6.5^{ab} ±0.1	0.62^{a} ±0.17	3.98^{ab} ±0.08	3516.1^{a} ±7.5	210.3^{abc} ±8.5	16.75^{de} ±0.05	0.85^{a} ±0.02	2318^{c} ±4.0
22 clusters -low vigor	14.0^{de} ±0.0	6.9^{a} ±0.2	0.63^{a} ±0.09	3.97^{ab} ±0.07	3263.8^{bc} ±24.0	274.1^{ab} ±2.9	19.59^{b} ±0.19	0.82^{a} ±0.02	2392^{a} ±1.1
22 clusters - medium vigor	13.8^{fg} ±0.0	6.5^{ab} ±0.0	0.77^{a} ±0.00	4.02^{ab} ±0.01	3990.1^{def} ±61.7	272.4^{ab} ±15.5	17.24^{cd} ±0.09	0.82^{a} ±0.00	2200^{g} ±0.1
22 clusters -high vigor	14.0^{de} ±0.0	5.7^{de} ±0.2	0.71^{a} ±0.00	4.02^{ab} ±0.00	3402.0^{ab} ±2.1	234.0^{abc} ±3.5	15.05^{e} ±0.05	0.84^{a} ±0.00	2212^{efg} ±5.8
29 clusters -low vigor	14.2^{bc} ±0.0	6.1^{cd} ±0.1	0.58^{a} ±0.16	4.01^{ab} ±0.07	2976.4^{ghi} ±28.8	263.5^{abc} ±2.7	19.02^{bc} ±0.17	0.84^{a} ±0.02	2335^{b} ±2.2
29 clusters - medium vigor	14.0^{d} ±0.0	5.7^{de} ±0.0	0.86^{a} ±0.02	4.06^{a} ±0.00	3131.0^{cde} ±51.2	293.3^{a} ±47.3	18.04^{bcd} ±0.34	0.83^{a} ±0.00	2216^{ef} ±3.8
29 clusters - high vigor	14.0^{d} ±0.0	5.9^{cd} ±0.1	0.76^{a} ±0.00	3.95^{ab} ±0.01	2912.4^{hi} ±9.6	254.1^{abc} ±17.5	17.30^{cd} ±0.15	0.83^{a} ±0.00	2207^{fg} ±0.4
36 clusters - low vigor	14.3^{b} ±0.0	5.3^{ef} ±0.0	0.74^{a} ±0.00	4.01^{ab} ±0.00	2983.3^{fghi} ±4.8	283.0^{ab} ±14.2	18.45^{bcd} ±0.19	0.83^{a} ±0.00	2270^{d} ±2.1
36 clusters - medium vigor	13.8^{ef} ±0.0	5.2^{ef} ±0.1	0.64^{a} ±0.00	4.02^{ab} ±0.00	2999.3^{fghi} ±9.1	191.1^{bc} ±10.1	18.48^{bcd} ±0.88	0.82^{a} ±0.01	2138^{i} ±1.2
36 clusters - high vigor	14.0^{de} ±0.0	5.0^{f} ±0.0	0.79^{a} ±0.01	4.02^{ab} ±0.00	3197.7^{cd} ±5.9	206.8^{bc} ±1.7	17.90^{bcd} ±0.29	0.81^{a} ±0.00	2174^{h} ±2.0
43 clusters - low vigor	15.3^{a} ±0.0	4.9^{f} ±0.0	0.79^{a} ±0.00	4.08^{a} ±0.00	3122.5^{cdef} ±11.7	178.9^{c} ±5.0	22.63^{a} ±0.04	0.80^{a} ±0.00	2322^{bc} ±4.7
43 clusters - medium vigor	14.1^{d} ±0.0	5.4^{ef} ±0.0	0.82^{a} ±0.00	3.94^{ab} ±0.00	2860.1^{i} ±9.6	209.7^{bc} ±2.7	17.63^{bcd} ±0.19	0.79^{a} ±0.00	2224^{e} ±0.5
43 clusters -high vigor	14.0^{d} ±0.0	5.2^{ef} ±0.0	0.70^{a} ±0.00	3.95^{ab} ±0.01	3023.3^{efgh} ±11.7	203.0^{bc} ±4.9	16.93^{de} ±0.23	0.82^{a} ±0.00	2216^{ef} ±0.3

*Means followed by the same letter in the column do not differ from each other by the Tukey test at the 5% level.

In 2020, total anthocyanins were higher in wines from low vigour treatment, than high vigour (**Table 1**). In 2021, it was the opposite, with higher anthocyanins in wines from high vigour (**Table 2**). Comparing the two vintages, the concentrations of total polyphenols and total anthocyanins were curiously higher in 2021, ranging from 4360 to 5336 mg L^{-1} of epicatechin, and from 589.9 to 810.0 mg L^{-1} of malvidin, respectively (**Tables 1 and 2**). Lower concentrations of these compounds were unexpectedly observed in 2020 harvest, because 2020 presented the driest conditions close to harvest, as compared to 2021. The likely explanation is a decreasing of the phenolics caused by low accumulation or even degradation, because 2020 vintage was very dry with high temperatures. Grapes from 2020 presented a slight shriveling. In 2020, the highest amounts of total polyphenols were observed in the treatments with 15 and 22 clusters, both n high vigour (**Table 1**). In 2021, the highest amounts of total polyphenols were observed only in low and medium vigour for almost all treatments, except for 15 clusters. The same can be observed for total anthocyanins (**Table 2**).

Table 2. Physicochemical analysis of Cabernet Sauvignon wines made with different treatments of number of clusters and pruning weight, harvest 2021.

Treatment	Alcohol Content (% v/v)	Total acidity (g.L^{-1})	Volatile acidity (g.L^{-1})	pH	Total polyphenols (mg.L^{-1})	Total anthocyanins (mg.L^{-1})	Color intensity (ua)	Hue (ua)	Total minerals (mg L^{-1})
15 clusters - low vigor	12.1^{f} ±0.0	7.7^{a} ±0.1	0.81^{a} ±0.07	3.82^{abc} ±0.02	4989.1^{ab} ±38.7	651.7^{def} ±88.1	9.07^{b} ±1.85	0.84^{a} ±0.11	2788^{m} ±0.6
15 clusters - medium vigor	12.4^{d} ±0.0	7.6^{a} ±0.1	0.55^{a} ±0.03	3.80^{c} ±0.02	4486.2^{b} ±48.3	589.9^{fg} ±2.6	9.29^{b} ±0.15	0.78^{a} ±0.00	2922^{h} ±0.3
15 clusters -high vigor	12.3^{e} ±0.0	7.1^{b} ±0.0	0.62^{a} ±0.04	3.90^{ab} ±0.00	4905.0^{ab} ±77.1	675.4^{cde} ±26.5	9.72^{b} ±0.54	0.79^{a} ±0.02	3016^{d} ±0.8
22 clusters -low vigor	12.2^{e} ±0.0	6.3^{de} ±0.1	0.63^{a} ±0.01	3.88^{abc} ±0.04	4786.2^{ab} ±45.8	758.8^{abc} ±0.5	11.54^{ab} ±0.34	0.74^{a} ±0.01	3122^{a} ±0.11
22 clusters - medium vigor	12.0^{h} ±0.0	6.4^{cd} ±0.1	0.77^{a} ±0.27	3.89^{ab} ±0.01	4474.5^{b} ±14.2	712.2^{bcd} ±4.5	8.94^{b} ±0.09	0.81^{a} ±0.01	3088^{b} ±0.11
22 clusters -high vigor	12.4^{d} ±0.0	6.9^{b} ±0.0	0.71^{a} ±0.01	3.84^{ab} ±0.01	4657.9^{b} ±56.7	739.3^{abcd} ±21.0	10.92^{ab} ±0.23	0.74^{a} ±0.01	2896^{j} ±0.4
29 clusters -low vigor	13.0^{a} ±0.0	6.3^{d} ±0.1	0.58^{a} ±0.16	3.89^{ab} ±0.02	5336.2^{a} ±105.8	810.9^{a} ±21.9	11.18^{ab} ±0.38	0.82^{a} ±0.01	3061^{c} ±1.5
29 clusters - medium vigor	12.0^{gh} ±0.0	6.1^{de} ±0.0	0.86^{a} ±0.01	3.90^{ab} ±0.01	4797.5^{ab} ±44.6	651.1^{ef} ±42.1	9.47^{b} ±0.26	0.79^{a} ±0.01	2952^{g} ±0.1
29 clusters - high vigor	12.4^{d} ±0.0	6.1^{de} ±0.0	0.76^{a} ±0.05	3.95^{a} ±0.02	4633.3^{b} ±85.4	610.8^{fg} ±19.6	9.10^{b} ±0.42	0.80^{a} ±0.02	2956^{f} ±0.2
36 clusters - low vigor	12.6^{c} ±0.0	6.8^{bc} ±0.0	0.74^{a} ±0.09	3.88^{ab} ±0.01	4605.4^{b} ±15.0	544.1^{g} ±13.2	12.11^{ab} ±0.09	0.72^{a} ±0.00	2950^{g} ±0.2
36 clusters - medium vigor	12.1^{fg} ±0.0	6.3^{de} ±0.0	0.64^{a} ±0.06	3.89^{ab} ±0.01	4537.5^{b} ±92.1	733.4^{abcde} ±51.0	10.01^{ab} ±0.64	0.75^{a} ±0.03	2821^{l} ±0.0
36 clusters - high vigor	12.1^{fg} ±0.0	6.1^{de} ±0.1	0.79^{a} ±0.01	3.82^{bc} ±0.00	4360.0^{b} ±13.8	745.8^{abcd} ±70.9	9.23^{b} ±0.11	0.76^{a} ±0.01	2887^{k} ±0.0
45 clusters - low vigor	12.8^{b} ±0.0	6.1^{de} ±0.0	0.79^{a} ±0.01	3.90^{abc} ±0.00	5341.6^{a} ±42.1	713.2^{bcde} ±89.6	13.48^{a} ±0.65	0.71^{a} ±0.02	2999^{e} ±0.3
45 clusters - medium vigor	12.1^{fg} ±0.0	6.1^{de} ±0.0	0.82^{a} ±0.13	3.88^{ab} ±0.00	4559.5^{b} ±46.7	773.1^{ab} ±92.1	8.68^{b} ±0.95	0.84^{a} ±0.05	2884^{k} ±0.1
45 clusters -high vigor	12.2^{e} ±0.0	5.9^{e} ±0.0	0.70^{a} ±0.01	3.89^{ab} ±0.01	4582.5^{b} ±69.6	739.1^{abcde} ±78.5	9.98^{ab} ±0.38	0.74^{a} ±0.02	2909^{i} ±0.5

*Means followed by the same letter in the column do not differ from each other by the Tukey test at the 5% level.

The concentrations of total minerals ranged from 2,138.0 to 2,392.0 mgL^{-1} in 2020, and between 2,787.8 to 3,121.7 mg L^{-1} in 2021. There was a trend towards greater potassium absorption in wines made from low vigor grapes in both vintages (data not shown). High concentrations of minerals in 2021 are related to higher availability of water in the soils, in the wettest season, increasing vine absorption.

In this study, grapes and wines were analyzed from vines with different vigour and clusters per vine. The vintage had different behavior, because climate conditions had different characteristics. In general, we can observe that, in 2020, a dry season from veraison to harvest, grapes and wines obtained from low vigour treatment and 45 clusters per vine was the highest in sugar and alcohol content respectively, while grapes and wines from high vigour and 15 clusters presented the lowest sugar and alcohol content. Total anthocyanins were higher in treatment with low vigour and 15 clusters, while the lowest amounts were found in low vigour with 45 clusters, as well as medium and high vigour with 36 clusters per vine. Total tannins were higher in high vigour with 22 clusters and medium vigour with 29 clusters, while were lower in low vigour with 36 clusters (data not shown). In 2021, a wet season at harvest, responses were different, and great variations were observed between treatments. As conclusions, yield and vine vigour had strong influence on grape and wine quality, promoting different enological potentials on which can be indicated/used for aging strategies of red and even rosé wines.

Conclusion

The season was the main factor influencing the grape and wine composition. The vigour of the vines and number of clusters per vine influenced the concentration of the grapes and wines, mainly the sugar content, the alcohol content, total acidity, polyphenols and minerals. High concentration of anthocyanins were observed in 2020 in low vigour, while the opposite was observed in 2021. As conclusions, yield and vine vigour had strong influence on grape and wine quality, promoting different enological potentials on which can be indicated/used for aging strategies of red and even rosé wines. The choice between increase and/or decrease the yield in a vineyard is dependent of the kind of wine to be produced.

References

Barros, MILF; Frölech D.B.; Mello L.L.; Manica-Berto R.; Malgarim M.B.; Costa V.B.; Mello-Farias P. (2018). Impact of Cluster Thinning on Malbec Grape Quality in Encruzilhada do Sul-RS. J. Plant Sci. 9, 495-506. https://doi.org/10.4236/ajps.2018.93037.

Gambetta, G. A.; Manuck, C. M.; Drucker, S. T.; Shaghasi, T.; Fort, K.; Matthews, M. A.; Walker, M. A.; McElrone, A. J. (2012). J. Exp. Bot, 63, 6445-6455. https://doi.org/10.1093/jxb/ers312.

Hugalde, I.P.; Agüero, C.B.; Barrios-Masias, F.H. et al. (2020). Modeling vegetative vigor in the vine: unraveling the underlying mechanisms. Heliyon 6 (12): e05708. https://doi.org/10.1016/j.heliyon.2020.e05708.

MIELE, A.; RIZZON, L. A. (2017). Rootstock-scion interaction: Effect on the yield components of the Cabernet Sauvignon grapevine. Revista Brasileira de Fruticultura, v.39, n.1: (e-820), p.1-9. https://ainfo.cnptia.embrapa.br/digital/bitstream/item/164185/1/Miele-08.pdf.

Organisation Internationale de la Vigne et du Vin (OIV). Recueil des méthodes internationales d'analyse des vins et des moûts. Paris. 1990. 368 p. www.oiv.int.

Reynolds, A.; Price, S.; Wardle, D.; Watson, B. (1994) Fruit environment and harvest level effects in Pinot noir. I. Vine performance and fruit composition in British Columbia. Am. J. Enol. Vitic., 45, 452-459. doi: https://www.ajevonline.org/content/45/4/452.

Ribéreau-Gayon, P. (1970) Le dosage des composés phénoliques totaux dans les vins rouges. Chim. Anal., 52: 6.

Van Leeuwen, C.; Roby, J.-P.; de Resseguier, L. (2017). Practical Winery and Vineyard, **52 (**2018. 3S Web of Conferences 50:01015. https://doi.org/10.1051/e3sconf/20185001015.

Van Leeuwen, C. Terroir: The effect of the physical environment on vine growth, grape ripening, and wine sensory attributes. *In: Managing wine quality, volume 1: Viticulture and wine quality*, Woodhead Publishing Series in Food Science, Technology and Nutrition. (2022). Pages 341-393. https://doi.org/10.1016/B978-0-08-102067-8.00005-1

Song, J.; Smart, R. E.; Dambergs, R. G.; Sparrow, A. M.; Wells, R. B.; Wang, H.; Qian, M. C. (2014). Food Chemistry 153, 52-59. https://doi.org/10.1016/j.foodchem.2013.12.037.