Orographic Effects on Berry Morphology and Chemical Composition of Carignan and Grenache Noir Grapes

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A variation in the climatic parameters of an orographic vineyard influences the growth and development of vines and grapes. Understanding the effects of this is highly beneficial in determining how viticulture practices can be modified to enhance grape quality. The aim of this study was to assess the effects of in-row grape position, altitude and vigour on berry morphology and grape maturity. The effects of vigour, altitude and in-row grape position on berry weight and diameter, titratable acidity, pH and sugar concentration of Carignan and Grenache noir grapes grown in a vineyard located in Priorat were investigated in the 2021 vintage. The results show that Carignan grapes with a lower vigour demonstrated a higher sugar concentration, berry weight and diameter, as well as lower titratable acidity, while the Grenache noir grapes with a lower vigour achieved only a higher sugar concentration. The grapes at high altitude had a higher sugar concentration in Carignan and higher titratable acidity in Grenache noir. Outer-row grapes of Carignan were characterised by lower titratable acidity and a higher sugar concentration, berry weight and diameter, while the outer-row grapes of Grenache noir displayed lower berry diameter, and a higher pH and sugar concentration. Vigour and in-row grape position have stronger effects on berry morphology and chemical composition than altitude. Sugar concentration is more susceptible than other parameters to be influenced by variability in the vineyard conditions.

INTRODUCTION

In the first stage of grape berry development, organic acids, phenolic precursors, minerals, amino acids and other compounds are synthesised and accumulated in the berries, while in the second stage, the berries are characterised by an increase in berry volume, softening, acidity reduction, pH increase, sugar accumulation, hormonal variation, synthesis of aromatic compounds and flavour, and pigment accumulation in the skin (Conde *et al*., 2007; Serrano *et al*., 2017). The concentration of these compounds determines the flavour and quality of the grapes (Gerós *et al*., 2012). Apart from the role of grapes in human nutrition, grape phenolics possess many biological activities and human health benefits (Xie *et al*., 2006; Xia *et al*., 2010). During wine aging, the phenolic compounds are converted into the derivatives or new pigments that are responsible for maintaining colour intensity, adding violet hues and wine quality (Pérez-Magariño & José, 2004). Due to the economic and health benefits of grapes, many researchers have focused on improving their chemical composition to increase the quality of the grapes and their derivative products. However, it is not an easy task to achieve because the chemical composition is influenced by several factors, including climate, soil, the vine (rootstock and cultivar), and human practices; and all of these interact with each other, in short, comprising the influence of terroir (Seguin, 1986, 1988). For the production of high-quality wine, environmental conditions should induce moderate vine vigour through moderate water deficit stress and low nitrogen supply (Leeuwen & Seguin, 2006). The effects of some terroir parameters are greater than others (Leeuwen *et al*., 2004). Differences in terroir parameters influence grape bunch uniformity, ripening and berry composition (Edo-Roca *et al*., 2013). Terroir-specific effects on grape berry composition allow vineyard to be characterised by the unique profile of specific metabolites (Vaudour, 2002; Anesi *et al*., 2015). Sunlight is essential for photosynthesis in vine and grape berry development and growth, influencing the content of soluble solids and other grape components that contribute to grape yield and quality (Smart, 1985; Bergqvist *et al*., 2001; Spayd *et al*., 2002). UV radiation increases with altitude and varies with latitudes, promoting the activation of

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the plant defence mechanisms responsible for the synthesis of secondary metabolites, especially phenolic and volatile compounds (Xing *et al*., 2014; Du Plessis *et al*., 2017; Gutiérrez-Gamboa *et al*., 2021).

The grapes exposed to more sunlight gain important effects of higher temperatures (Dokoozlian & Kliewer, 1996). Temperature influences the phenological development of the vines and grapes. Higher temperatures lead to an earlier budburst, flowering and ripening; increasing the accumulation of sugar and phenolic compounds, and the catabolism of malic acid. Under warmer conditions, the grapes produce higher total soluble solids. However, under extreme temperatures, the grapes decrease in berry size and weight, and sugar concentration (Lakso & Kliewer, 1975; Greer & Weston, 2010; Brandt *et al*., 2019). Altitude influences the climatic parameters that have effects on vine physiology and berry biochemistry and hence the chemical composition of the grapes (Teixeira *et al*., 2013; De Oliveira *et al*., 2019; Mansour *et al*., 2022). Several factors of terroir influence vine vigour and have effects on grape yield, bunch morphology, chemical composition (Dry & Loveys, 1998; Bramley *et al*., 2011); procyanidin in the seeds (Edo-Roca *et al*., 2014b); and anthocyanin in the skins (Edo-Roca *et al*., 2014a). Water status has effects on vine vigour, berry growth and development. Water deficit that occurs in the flowering stage increases berry weight, while after véraison there are minor effects (McCarthy, 1997). Wind plays a crucial role in evapotranspiration, which increases with an increase in wind intensity, resulting in a reduction in stomatal conductance. As a consequence, wind-exposed grapes are smaller in size, have a lower berry weight, and higher pH values and potassium concentration (Pienaar, 2005).

Canopy management is needed to increase efficient use of climatic parameters by the vines and grapes in order to produce grapes with the desired yield and quality (Smart *et al*., 1990). However, in orographic viticulture, it is very difficult or impossible to homogenise the climatic parameters for the vines and grapes. Due to the high topography, land is transformed into terraces to accommodate the conditions for vine growth and soil conservation, and this modifies soil properties, particularly depth and water availability (Ramos *et al*., 2007; Bramley *et al*., 2011). Terrace building influences vine row orientation, which causes differentiation in the climatic parameters, particularly air movement and sunlight exposure (Strack & Stoll, 2011; Hunter *et al*., 2020). In Priorat, there are different orographic conditions dedicated to wine grape production. Therefore, it is important to know the influence of variation in the climatic parameters on berry growth and development in the orographic vineyards, and to understand how viticultural practices can be adapted to improve grape quality. This study aimed to assess the influence of in-row grape position, altitude and vigour on the morphology and maturity of Carignan and Grenache noir grapes grown in an orographic vineyard in La Morera del Montsant Priorat municipality, Priorat.

MATERIALS AND METHODS

Description of experimental vineyard

The study was carried out in 2021 in a vineyard located in La Morera del Montsant municipality, in the northern part of DOQ Priorat, with a geographical location of 41º 13’53.5” N, 0º 52’30.4” E. Carignan (Ca) and Grenache noir (Gn) grafted onto 110 Richer were selected for this study. Both vine varieties were 20 years old and planted in the same vineyard divided into two parcels. Ca is classified as a late-maturing variety and was planted in the upper part of the vineyard, while Gn is a variety of medium-late maturity and was planted at the bottom of the vineyard (Fig. 1). The vineyard area is 1.78 ha and belongs to Perinet Winery. The Gn and Ca are currently considered as the most important local varieties for the wine industry in the region. The vines are planted on cut-off drain terraces (trellis) with a plantation frame of 2.4 x 1 m, of which two rows are planted on one terrace and pruned in Royat. The soil is slate, with a negative slope downward to the southwest. The results of the soil composition analysis are shown in Table 1. Two dominant

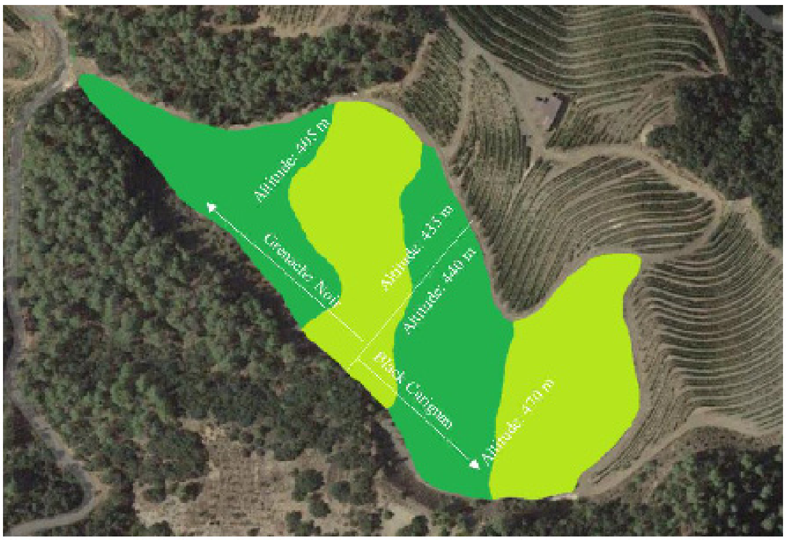

FIGURE 1
Vine vigour (▲ low and ▼ medium), altitudes, and parcels of Carignan and Grenache noir in the vineyard.

TABLE 1
Principal component analysis of the experimental vineyard soil

Analysis	Unit	Results
Humidity	%	1.42
pH H2O	Units pH	6.54
Conductivity at 25ºC		0.06
Nitrogen (NH4)	%	0.04
P	ppm	1.64
K	ppm	11.26
Mg	ppm	232.08
Organic matter	%	1.62
Total carbonates	%	0.00
Active limestone	%	0.00
Slate	%	95

vigour levels (LV = low vigour and MV = medium vigour = normal vigour) were identified in the vineyard and monitored from flowering stage onwards. This was done by aerial imagery of satellite maps using the normalised vegetative index of difference (NVDI) to estimate the quantity, quality and development of vegetation by means of remote sensors installed on a space platform (Fig. 1). The low- and medium-vigour vines had approximately 1.74 m^2 and 3.12 m^2 of leaf area at fruit set, respectively. The vineyard altitude ranged from 405 m to 470 m, in which Gn and Ca were planted in the low and high plots, respectively. As the vineyard had a negative slope downwards to the southwest, the row orientation of the cut-off terraces was northwest. For each vine variety, two land levels were classified, namely lower and upper (Table 2).

Experimental sampling

Samples were collected in the morning from 06:00 to 10:00 on a clear day without recent rain, heavy fog or dew to avoid discharge temperature and preserve attribute quality. Samples were placed in transparent plastic bags of 30 x 15 cm with an airtight closure (Ziploc type). The sample bags were labelled with the corresponding identifier names and transferred in a portable refrigerator with ice from the vineyard to the laboratory for analysis. The sampling was performed at the same shoot level in the vines, three days before harvest. The sampling methodology consisted of three treatments (altitude, vigour and in-row grape position), which were subdivided into two experimental units. Twelve grape bunches (around 4 800 berries) were randomly collected in every homogeneous experimental unit. To balance the samples within the experimental units, for an experimental unit of altitude treatment, the 12 bunches were a combination of six bunches from low-vigour vines, with the others from medium-vigour vines in inner-row and outer-row positions; for an experimental unit of vine vigour treatment, the 12 bunches comprised six bunches from low-terrace vines and other six from medium-terrace vines in the two positions; for an experimental unit of in-row grape position, the 12 bunches were six bunches from low-vigour vines and other six from medium-vigour vines on the low and high terraces. As the vines are cultivated on terraces, the sampling was carried out in a zig-zag movement and from 25 vines on each terrace. Sample collection was done in triplicate, with 36 bunches from each experimental unit, to analyse the berry weight, berry diameter (Ø), sugar concentration, titratable acidity (TA) and pH for maturity control.

Must extraction

A mortar and strainer were used in the must-extraction process to prevent the seeds from breaking, and the berries were trampled. The must was put in 250 mL beakers and then filtered using strainers and funnels to remove solid particles.

Analytical determinations

To determine the date of harvest, the parameters analysed were the level of acidity and the sugar, berry weight, berry diameter and pH. Sugar content and acidity level were determined according to the resolution of the OIV (Aurand, 2017); titratable acidity was measured in g/L of tartaric acid by titration at a final point of pH 7 and at 20ºC; pH was measured with a pH meter; the total soluble sugars (°Brix) were determined with a refractometer.

Statistical analysis

The effect of altitude, vigour and in-row grape position on titratable acidity, °Brix, berry weight, berry diameter and pH for maturity determination was evaluated through one-way analysis of variance (factorial ANOVA); $p < 0.05$, and Tukey's b post-hoc test were used with IBM SPSS software 27. The Pearson correlation matrix for all parameters with a level of significance (α) of 0.05 was also calculated.

RESULTS AND DISCUSSION

Table 3 and Table 4 show the effects of in-row grape position, vigour and altitude in the vineyard on berry weight and diameter, titratable acidity, pH and °Brix of Carignan grapes and Grenache noir grapes, respectively.

Climatic conditions

The monthly climate data for 2021 are shown in Table 5. Precipitation, reference evapotranspiration (ET_O), maximum, minimum and average temperatures were recorded from climatic data obtained from a public weather station of the Torroja del Priorat municipality in the Priorat region, at an altitude of 300 m and close to the experimental vineyard (Agrometeorological Data of Torroja del Priorat [ADTP], 2022). A heavy fall of snow occurred in January 2021. In addition, hurricane Filomena brought a significantly thick snow layer on the top and bottom soil in the Priorat, causing high water availability for the plants and water reserves of the region. It was the heaviest snowfall recorded in three decades in the zone according to the Regulatory Council of the DOQ Priorat (Inicio – Consell Regulador de la DOQ Priorat). Some temperature peaks were recorded early in the spring, while both temperatures and precipitation were as usual for the rest of the spring. The summer was dry, and the good rhythm of the vegetative cycle occurred normally. The

TABLE 2
Details of the experimental vineyard

Variety	Terrace zone	Vigour	Plantation frame (m x m)	Altitude (m)
Carignan	Upper	Low and medium	2.40 x 1.0	470
	Lower	Low and medium	2.40 x 1.0	440
Grenache noir	Upper	Low and medium	2.40 x 1.0	435
	Lower	Low and medium	2.40 x 1.0	405

TABLE 3
Berry weight, berry diameter (Ø), titratable acidity (TA), pH and °Brix in different experimental units (EU) of Carignan (a and b indicate a significant difference, with $p < 0.05$)

Treatment	EU	Berry weight (g)	Ø (cm)	TA (g/L)	pH	°Brix
Vigour	Low	1.83 ± 0.04a	1.45 ± 0.02a	7.80 ± 0.13b	3.24 ± 0.05a	22.14 ± 0.18a
	Medium	1.60 ± 0.04b	1.32 ± 0.02b	8.56 ± 0.13a	3.27 ± 0.05a	17.82 ± 0.18b
Altitude	High	1.59 ± 0.08a	1.39 ± 0.02a	8.31 ± 0.20a	3.27 ± 0.02a	21.06 ± 0.36a
	Low	1.66 ± 0.08a	1.41 ± 0.02a	8.22 ± 0.20a	3.21 ± 0.02a	18.18 ± 0.36b
Row grape position	Outer	1.52 ± 0.04b	1.33 ± 0.02b	8.02 ± 0.13b	3.28 ± 0.01a	20.7 ± 0.18a
	Inner	1.90 ± 0.04a	1.44 ± 0.02a	8.33 ± 0.13a	3.22 ± 0.01a	19.26 ± 0.18b

TABLE 4
Berry weight, berry diameter (Ø), titratable acidity (TA), pH and °Brix in different experimental units (EU) of Grenache noir

Treatment	EU	Berry weight (g)	Ø (cm)	TA (g/L)	pH	°Brix
Vigour	Low	1.79 ± 0.03a	1.43 ± 0.01a	5.55 ± 0.12a	3.30 ± 0.04 a	25.02 ± 0.36a
	Medium	1.74 ± 0.03a	1.40 ± 0.01a	5.44 ± 0.12a	3.34 ± 0.04 a	20.16 ± 0.36b
Altitude	High	1.75 ± 0.03a	1.40 ± 0.02a	6.00 ± 0.15a	3.29 ± 0.05 a	22.86 ± 0.36a
	Low	1.78 ± 0.03a	1.42 ± 0.02a	5.39 ± 0.15b	3.21 ± 0.05a	22.68 ± 0.36a
In-row grape position	Outer	1.73 ± 0.03a	1.38 ± 0.01b	5.46 ± 0.12a	3.40 ± 0.04a	23.04 ± 0.36a
	Inner	1.81 ± 0.03a	1.45 ± 0.01a	5.53 ± 0.12a	3.23 ± 0.04b	22.03 ± 0.36b

TABLE 5
Monthly climate data for 2021

Month	Temperature (ºC)			Rainfall (mm)	Reference evapotranspiration (mm)
	Average	Maximum	Minimum		
Jan	6.2	21.4	-6.6	51.2	-5.47
Feb	10.6	20.1	2.9	18.4	35.65
Mar	10.9	23.0	-2.3	3.2	74.16
Apr	12.4	25.4	1.6	46.4	78.31
May	17.5	33.4	6.4	22.6	130.64
Jun	22.1	37.7	11.9	63.4	133.76
Jul	24.4	37.7	12.9	18.3	162.02
Aug	24.6	40.8	13.2	18.4	135.63
Sep	21.3	33.2	10.6	66.7	84.69
Oct	16.2	27.9	6.9	20.1	67.57
Nov	9.4	20.3	0.5	63.4	32.9
Dec	8.3	21.3	-0.3	9.7	23.59

average annual temperature in 2021 was 15.14ºC, and the annual temperature peak was recorded at 39.9ºC on 2021-08-14. The annual rainfall was 401.8 mm, a value lower than the average annual rainfall in the area over the preceding five years. The annual rainfall was well distributed throughout the year, with the exception of the dry summer period.

Vigour

The vigour effects showed that there were significant differences in berry weight and diameter, titratable acidity and °Brix between the low- and medium-vigour grapes of Carignan, while the pH values did not differ significantly. °Brix, berry weight and diameter were higher in the low-vigour grapes, while TA was higher in the medium-vigour grapes. However, in Grenache noir, °Brix was the only parameter that demonstrated a significant difference. In general, the sugar concentration was higher in the low-vigour grapes than in the grapes with higher vigour. Vine vigour can be influenced by several factors, including rootstock, soil properties, water and nutritional status (Dry & Loveys, 1998). Due to the orographic topography of the vineyard, natural land had to be transformed into terraces to create favourable conditions for vine growth. The land transformation developed heterogeneity in soil depth, water availability and saturated hydraulic conductivity, which gave rise to differences in water and nutrient status for the vines, and consequently also caused variations in vine vigour (Ramos *et al*., 2007; Ubalde *et al*., 2011).

In the study vineyard, the land transformation and soil management seemed to develop two predominant soil conditions that produced low- and medium-vigour vines. As a result of spatial variation, the lower vigour grapes received less shade and were more exposed to light. Berry temperature increases linearly with sunlight exposure. In this study, the greater berry weight in the low-vigour Carignan grapes was not in accordance with reports in previous studies (Edo-Roca *et al*., 2013; Gatti *et al.*, 2022). Extreme temperatures in the berries occurred during the first stage of berry development and decreased the berry weight and size due to a reduction in stomatal conductance (Greer & Weston, 2010). The greater size and weight should be found in the higher vigour berries with the greater canopy shade and corresponding lower temperatures. However, the results did not seem to be influenced by temperature. Looking at the higher °Brix and lower TA in the low-vigour grapes, the differences in berry weight and size may have been due to maturity level (Conde *et al*., 2007). The berry weight and size of the low- and medium-vigour grapes would be similar if the grapes reached maximum maturity (Bramly *et al*., 2011).

Tartaric and malic acids generally account for the majority of all organic acids in grape berries and leaves (Kliewer, 1966). With maturation, the metabolic origin of tartaric acid lies outside the oxidative metabolism of sugars (Loewus & Stafford, 1958), while malic acid decreases during maturation, being transformed into energy and sugar in the berries. Catabolism increases with temperature, and then sugar accumulation increases with a decrease in acidity (Conde *et al*., 2007). Based on the relationship between sugar concentration and acidity, the differences in sugar concentration and acidity were influenced by temperature during maturation, with the higher temperature in low-vigour grapes leading to earlier ripening (Greer & Weston, 2010). This earlier ripening may have been caused by the effects of water deficit, particularly after véraison (McCarthy, 1997; Castellarin *et al*., 2007).

In Grenache noir, only °Brix showed a significant difference. The higher sugar concentration in the low-vigour grapes was due to higher photosynthetic activities, which were the result of higher sunlight exposure because of less shade. This result has been explained by several authors, who claim that sunlight-exposed berries contain higher levels of soluble solids and other berry components (Smart, 1985; Dokoozlian & Kliewer, 1996; Bergqvist *et al*., 2001; Spayd *et al*., 2002). However, the pH values of the grapes were similar among the vigour levels of the studied vines, meaning that vine vigour did not influence pH. This result is in agreement with a study by Filippetti *et al*. (2013).

Altitude

Regarding altitude effects, significant differences in °Brix between Carignan grapes from the low and higher terraces were shown, while there was a significant difference in TA in Grenache noir. Variation in climatic parameters between the studied altitudes had positive effects on sugar concentration and titratable acidity in the grapes of Carignan and Grenache noir, respectively. Some reports have mentioned that high-altitude cultivation strongly alters solar radiation, temperature and other environmental factors around vines (Mateus *et al*., 2002). A higher altitude generally corresponds to stronger sunlight, lower temperature and humidity, greater temperature difference between day and night, and more extreme environmental conditions, all of which affect the chemical composition of the grapes (Gutiérrez-Gamboa *et al*., 2021; Mansour *et al*., 2022).

Both varieties produced different results compared to a study in which the authors found that grapes grown at lower altitudes had a larger berry size and weight. The observed difference is believed to be due to variations in temperature and humidity levels between the altitudes studied (Mateus *et al*., 2001). According to the altitudes of the experimental vineyards, the altitude difference (30 m) in this study was not sufficient to have variation in climatic parameters that could significantly influence berry weight and size compared to the altitude difference (150 m) in the Mateus *et al*. (2001) study.

At a high altitude, the Carignan grapes demonstrated higher sugar concentration and similar acidity, while the Grenache noir grapes were characterised by a similar sugar concentration and higher acidity. The findings are not in agreement with some studies (see Regina *et al*., 2010; Rienth *et al.*, 2016; De Oliveira *et al*., 2019; Rienth *et al*., 2020). The authors of these studies claimed that higher temperatures at a lower altitude were responsible for the decrease in acidity due to malic acid catabolism and an increase in sugar concentration. The grapes at high altitude would then produce lower titratable acidity and have a higher sugar concentration. The results therefore did not seem to be influenced by temperature. Wind may have been responsible for temperature regulation between the altitudes. The higher sugar concentration in Carignan grapes and higher acidity in Grenache noir grapes at high altitude could be explained by the effects of higher solar radiation, which caused an increase in higher photosynthetic activities. The acidity difference between low- and high-terrace grapes seems to have been influenced by temperature. As a result of the organic acid catabolism of low-terrace grapes, the sugar concentration could be higher in the low-altitude grapes. However, the sugar concentrations of the low- and high-altitude grapes were similar, so the temperature effects would not be significant. On other hand, the pH values in the results show that variations in the climatic parameter between the altitudes was not enough to influence the pH. These results are similar and contrary to the results previously reported by De Oliveira *et al*. (2019) and Regina *et al*. (2010), respectively.

In-row grape position

The effects of in-row grape position in the experimental vineyard on berry morphology and maturity were also studied. In Carignan, significant differences between outer-row and inner-row grapes were found for berry weight and diameter, TA and °Brix. The values of berry weight and diameter and TA were higher in inner-row grapes than in outer-row grapes, while °Brix was higher in outer-row grapes. However, the pH values did not differ significantly between outer-row and inner-row grapes. In Grenache noir, significant differences were found between inner-row and outer-row grapes for berry diameter, °Brix and pH. pH and sugar concentration were higher in outer-row grapes, while berry size was higher in inner-row grapes. The main environmental parameters that varied between the inner-row and outer-row grape berries within the canopy were sunlight, wind and humidity (Smart, 1985). According to grape position within the canopy, the outer-row grapes would receive higher levels of sunlight exposure. As a result, the berry temperature would be higher (Smart & Sinclair, 1976). Daytime temperatures of sunlight-exposed berries depend on the time of day and solar conditions (Kliewer & Lider, 1968; Reynolds *et al*., 1986). The optimum temperature for grape berry growth ranges between 25°C and 30°C (Hale & Buttrose, 1974). Some studies have reported that sunlight-exposed berries are smaller than berries grown in the shade (Kliewer & Lider, 1968; Crippen & Morrison, 1986; Reynolds *et al*., 1986), while others found that the berry temperatures were similar among sunlight-exposed and non-exposed bunches, and that the higher berry weight and diameter of sunlight-exposed berries were due to light-mediated effects on cell division and/or cell enlargement, particularly during the initial stage of growth (Dokoozlian & Kliewer, 1996). Regarding the position of the grapes, spatial variation between outer-row and inner-row grapes caused wind circulation differences around the grapes. The outer-row grapes with less sheltering would experience higher transpiration. An increase in transpiration stimulates dehydration, resulting in stomatal conductance in the berries, particularly in the early first stage of development when the berry cells are susceptible. This would have had an essential impact on berry composition and morphology. The effects may have stimulated the accumulation of potassium cations in the grape berries for membrane stabilisation, giving rise to an increased pH (Pienaar, 2005; Mpelasoka *et al*., 2008; Rogiers *et al*., 2017). In this study, the significant differences in berry weight and diameter of Carignan grapes may have been caused by a combination of the effects of temperature and wind. In the same way, the lower acidity and higher sugar concentration in the outer-row grapes were clearly influenced by temperature, as has been explained by several authors (Conde *et al*., 2007; Regina *et al*., 2010; Rienth *et al*., 2016; De Oliveira *et al*., 2019; Rienth *et al*., 2020). Similar acidity and a higher sugar concentration in the outer-row grapes of Grenache noir did not seem to be influenced by temperature (Conde *et al*., 2007). For this variety, the highest temperature found in the vineyard may have been in the range of the optimum temperature for grape berry growth and development. So, the difference in sugar concentration could be explained by differences in sunlight exposure (Dokoozlian & Kliewer, 1996). As a result of the higher soluble solid concentration, the outer-row grapes had similar berry weight with lower berry size in comparison with the inner-row grapes. However, the differences in the berry size and pH between the outer-row and inner-row grapes of the canopy of Grenache noir grapes may have been in response to wind effects, as reported by Pienaar (2005).

CONCLUSION

The analyses conducted of both Carignan and Grenache noir grapes in this study revealed that sugar concentration is more susceptible than other parameters to the influence of variability in vineyard conditions and reaches the highest difference under the effects of vigour. These findings may help viticulturists to adapt the harvest dates of the grapes for optimal maturity.

Due to slight differences in only the sugar concentration of Carignan grapes and the titratable acidity of Grenache noir grapes, the altitude variation of 30 m does not seem to give rise to a significant difference in temperature such as to influence berry morphology and chemical composition.

Sunlight and temperature seem to be more responsible for the differences in the morphology and chemical composition parameters of the grapes, combined with the effects of orographic wind circulation on the in-row grape position.

Concerning the comparison of berry morphology and chemical composition parameters affected by climatic variability, Grenache noir is more stable and resistant than Carignan in challenging climate change in the region. These significant results can help viticulturists adapt their strategies for environmental and vineyard management practices and select the right variety for an improvement in grape quality.

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