Study of mesoclimate and its impact on *Vitis vinifera* L. cv. Tannat in the Atlantic winegrowing region of Uruguay.

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Abstract

Climate is part of the terroir environment, so it is necessary to know and describe it as an element influencing the typicity and quality of the berry and wine. The objective is to evaluate the Atlantic region of Uruguay at the mesoclimatic level and to determine the effect of topography and the ocean on temperature and thus on the response of Tannat grapevine. For this, data from 19 temperature sensors installed in a commercial vineyard in contrasting topographic situations was used for 3 growing seasons. Bioindicators were calculated and relationships between site topography and plant response of 9 Tannat plots were established. Temporal climatic variability was conditioned by rainfall and spatial variability was associated with topography. Altitude and exposure to the Ocean were the main elements that statistically differentiated the plots. The effect was observed on thermal amplitude, Cool Nigh Index and number of days above 30 °C. As for vine response, higher elevations (140 masl) favored malic acid, while lower elevations (70 masl) showed higher amounts of secondary metabolites. The characterization of the region with respect to its climate and its response on the vine will allow agronomic decisions aimed at enhancing the typicity of the terroir.

Introduction

Climate is one of the main components of the viticultural terroir and its interaction with wine production is studied worldwide. The meso-climate analysis contributes to improve knowledge of the regional climate by studying the influence of topography (slope, aspect and altitude) on the various climatic variables in a specific location such a vineyard (the terrain on the incidence of radiation and therefore on temperature, wind exposure). The topographical components also influence soil drainage (Dumas et al., 1997). Meso-climatic conditions also includes the role of the proximity to water bodies such as oceans, rivers or lakes, with the effect of sea-breeze circulation, which is the case in this eastern wine region of Uruguay (Fourment et al., 2017; Manta et al., 2021). The arrival of the sea breeze in the afternoon prevents from too high temperatures reducing heat stress during the vine cycle and berry ripening while the proximity of the Ocean prevents from too low temperature reducing/avoiding frost phenomena.
Among climate factors, temperature turns out to be the component with the greatest impact on plant and grape development (Jackson et al., 1993). Temperature accelerates plant development and the passage from one phenological stage to another, generating high soluble solids, low acidity and low aromatic intensity in warm climates, with the opposite occurring in cool-temperate climate.
The objective of this study is to analyze the spatial and temporal variability of climate at meso-scale in relation to vineyards' topography, and its effect on the development of Tannat grapevines.

Materials and methods

A commercial vineyard was selected in Garzón, Uruguay (34. 57º S; 54. 60º W) in which 19 productive plots were chosen, located in different topographic situations, within a radius of 2 km and an average distance of 18 km from the Atlantic Ocean. In each plot, a Tiny Tag data logger ® temperature sensor (Gemini Data Loggers Ltd., UK) was placed at a height of 2 m above ground level (Figure 1). The sensors recorded air temperature every 15 minutes during the vegetative cycles corresponding to the 2018-2019, 2019-2020 and 2020-21 growing seasons (September 1 - March 1). Based on the thermal data recorded, the bioclimatic indices adapted to grapevine cultivation Growing degree day (GDD), Heliothermal Index (HI), Cool Night Index (CNI), number of days with temperatures above 30°C and 35°C (ND30) (ND35), Average temperature of the cycle (Tavg), Thermal amplitude of maturation period correspond to January 15 to March 15(TA) and Average of maximum summer temperature (TmaxS). The topographic information was processed through the QGiS geographic software (QGIS Development Team) using the virtual altitude layer (DEM) generated by IDEuy (Spatial Data Infrastructure of Uruguay). It has a pixel definition of 3m x 3m and was used to calculate the values of altitude, slope and land surface exposure. The Inumet weather station in Rocha (RO; Uruguayan Institute of Meteorology), located at 34.49361° S and 54.31250° W, 30 km from the vineyard under study, was used to record the climatic variables of precipitation (PP) and ETP.

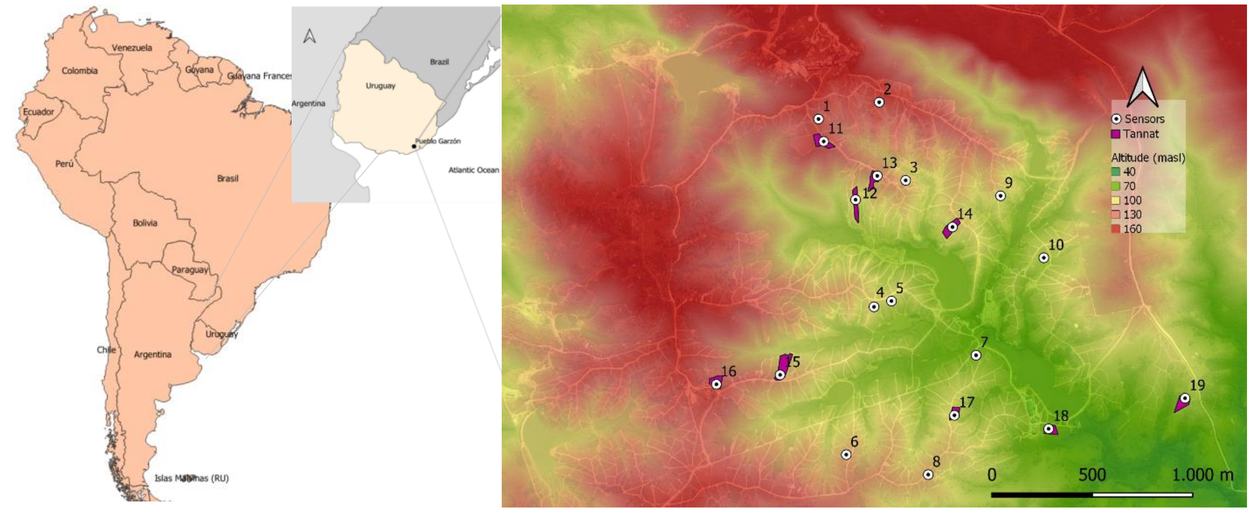

Figure 1. Topographical location of temperature sensors within Tannat´s plots.

For the analysis of vine response, 9 of the 19 selected plot corresponded to Tannat and were classified into 3 groups according to their altitude: Low (72-95 masl), Middle (96-117 masl) and High (118-140 masl). 21 plants 12 years old per plot (one meter apart) from 2-meter spaced rows were selected. The plots' training system was high trellis and 100% drip irrigated. Grape chemical composition measurements were performed for the 2018-19, 2019-20 and 2020-21 growing seasons. To determine primary metabolites, the OIV protocol (OIV, 2009) was performed. We determined Total Soluble Solids (TSS g/l) by refractometry (Hanna® HI 96801 refractometer), Titratable Acidity (g H_2SO_4/l) by titration and pH measurement by potentiometry (pH meter Oakton® 11 series). From the soluble solids value, the level of total sugars per berry (g berry-1) = TSS (g-L-1) x berry weight (g)/ (0.0046 x °brix + 0.9927) /1000 was calculated. To quantify the berries organic acids, was used high performance liquid chromatography (HPLC) determined by OIV (2009) protocol. To determine secondary metabolites in Tannat grapes, the Glories et al. (1992) extraction method modified by Gonzalez-Neves et al. (2003) was applied. Phenolic potential, such as total potential in anthocyanins (A pH1), the potential in extractable anthocyanins (A pH 3.2) and phenolic richness of grapes (IPT) were determined. All the measurements related to phenolic potentials were carried out by duplication with a Unico S-2150 (Dayton, United States) spectrophotometer. Percent anthocyanin extractability (%EA) was calculated from A pH 1 and A pH 3.2 as ((ApH1 - ApH3.2) / ApH1) * 100.
A statistical variance analysis (ANOVA) using a p-value <0.05 was performed in order to assess the temporal and spatial thermal variability and grape berries composition values. Correlations were established by means of simple linear regressions of first and second order using p-value < 0.05.

Results and discussion

Climate

The 2019-20 vintage had significantly higher HI (+ 176), GDD (+ 102), ND30 (+ 29), TmaxS (+ 1.8 °C) and TA (+ 2.2 °C) than the 2018-19 vintage and T avg (+ 0.6 °C) and ND35 (+4) than the 2020-21 vintage (Table 1). The differences between years could be due to the occurrence of precipitation. The 2019-20 growing season experienced drier conditions than the 2018-19 and 2020-21 growing seasons, i.e., lower rainfall and higher daily ETP during the berry ripening period (- 159 mm; + 0.8 mm and -133 mm; +0.8 mm/day respectively). Therefore, summer rainfall interannual variability is the main factor conditioning the vintage climate in this region.
Regarding maximum temperatures, ND30 varied from 29 to 58 with 2019-20 scoring on average 29 days more with these temperatures than the previous cycles, while ND35, did not differ between years. This is due to the findings of Manta et al. (2021), where the sea breeze on the Uruguayan coast avoids thermal situations above 33°C. This aspect is favorable in a context of climate change and increased ambient temperature, since vineyards will be able to find cool places that allow them to obtain aromas and acidity in the grapes (Gutiérrez-Gamboa et al., 2021), extreme thermal conditions, above 35°C, reducing photosynthesis, growth and accumulation of sugars in the vine plant (Jackson et al., 1993).

Table 1. Average value and standard deviation for the thermal variables calculated from the 19 temperature sensors for the three-growing season under study and two contrasted elevation plots (pooled vintages).

	Growing season			Topographic conditions	
Climate variables	2018-19	2019-20	2020-21	Plot 2 (70 masl)	Plot 7 (140 mals)
T avg (°C)	19.1 ± 0.1 b	19.5 ± 0.2 a	18.9 ± 0.2 c	19.3	19.1
GDD	1651 ± 13 b	1748 ± 33 a	1646 ± 39 b	1686	1651
HI	2106 ± 21 c	2282 ± 32 a	2182 ± 31 b	2127	2187
TA (°C)	11.7 ± 0.7 b	13.6 ± 0.7 a	11.7 ± 0.7 b	11.7	13.7
CNI (°C)	16.2 ± 0.4 a	16.1 ± 0.4 a	16.8 ± 0.4 b	16.7	15.4
ND30	29 ± 4 c	58 ± 4 a	38 ± 0.5 b	37	45
ND35	5 ± 2 a	5 ± 2 a	1 ± 1 b	4	3
TmaxS (°C)	28.1 ± 0.4 c	29.7 ± 0.4 a	28.5 ± 0.3 b	28.3	29.1
$PP_{\text{grape maturity}}$ (mm)*	296	137	249		
$ETP_{\text{grape maturity}}$ (mm/day) *	4.2	5.0	4.2		

* Data from on weather station

The temperature recorded by the sensors in the field showed significant correlations with topography. It was observed that the higher the altitude, the lower the thermal amplitude was, described by a second order polynomial regression (r^2 adj.= 0.55; p-value < 0.05) (Figure 2 A). In addition, it can be seen a negative correlation between altitude and ND30 (r^2 adj.= 0.19; p - value < 0.05; Figure 2 C) and TmaxS (r^2 adj.= 0.15; p - value < 0.05; Figure 2 B) and positive correlation with CNI. The positive second order polynomial relationship between altitude and CNI (r^2 adj.= 0.69; p - value < 0.05; Figure 2 B) has an inflection point at 120 masl from which it tends to decrease.
The correlation between topography and thermal indicators can be seen in the result of two contrasting plots, where plot 2 located at 140 masl differs by having a lower TA (-2°C), higher CNI (+ 1.3 °C), lower TmaxS (-0.8 °C) and lower ND30 (- 8 days) than plot 7 located at 70 masl in a concave topographic condition (Table 1) and is due to: 1) the general decrease of temperature with altitude combining with a greater exposure to sea breeze circulation during the day. 2) Cool air at night of greater density accumulating at the bottom slopes resulting in lower minimum temperature and therefore in increased thermal amplitude. This phenomenon is in agreement with that described by Bonnefoy et al. (2013) in the Coteaux du Layon in France and by Bonnardot et al. (2012) in South African coastal conditions. Both effects condition the grapevine in different ways, since cooler daytime conditions such as those obtained in higher altitudes are beneficial to the conservation of malic acid in the grape, while warmer night times conditions can be counterproductive due to increased nocturnal respiration (Gaiotti et al., 2018). At the same time, cooler conditions at night at lower altitudes (bottom slopes) are positive in reducing nocturnal respiration and thus enhance synthesis for anthocyanin accumulation (Mori et al., 2005). However, higher temperatures during the day may degrade malic acid and aromas as stated in Sweetman et al.(2014) and González-Barreiro et al. (2015).

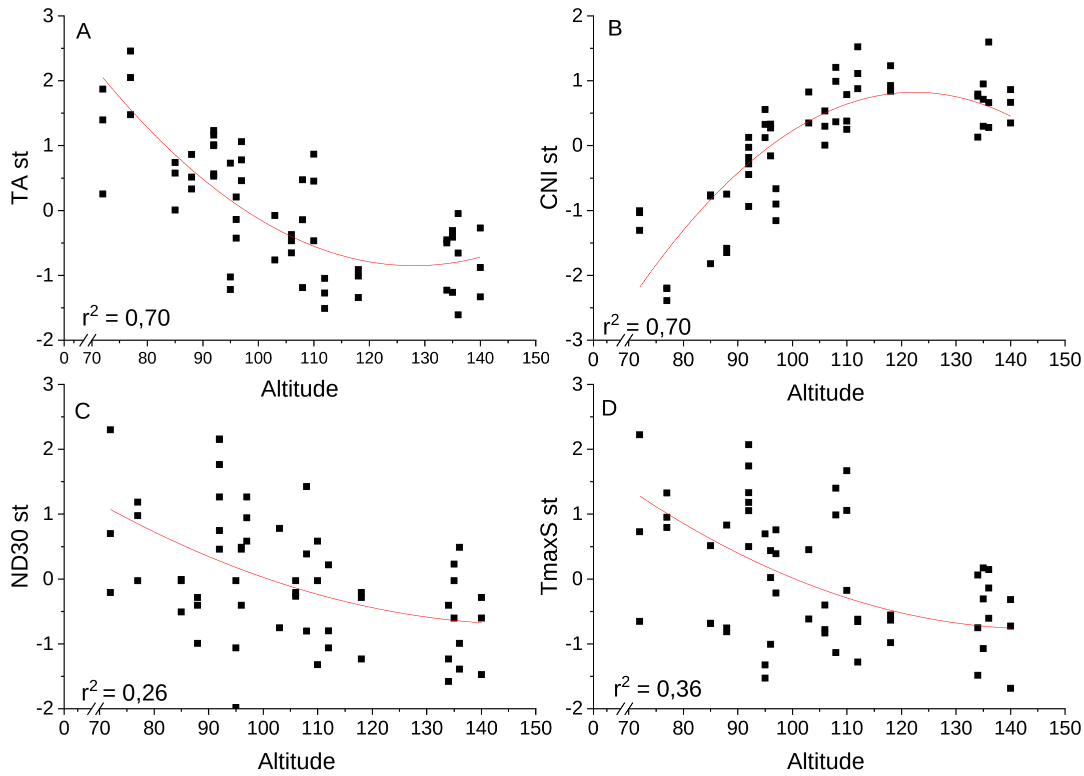

Figure 2. Correlations between plots' topography and standardized bioclimatic indices between years: A) Correlation between thermal amplitude and altitude; B) Nighttime coolness index vs altitude; C) ND30 in relation to altitude; D) Mean maximum summer temperature vs altitude

Grape responses

The response of Tannat to temporal variability could be observed in the concentration of TSS with a maximum difference of 41 g/l in favor of the 2019-20 season compared to 2020-21 and the accumulation reached 0.044 g/berry. Total acidity for the 2019-20 season was 1.0 g/l lower than that of the 2020-21 season, differing mainly by the accumulation of tartaric acid. Total phenols and anthocyanins evaluated at pH1 and pH 3.2 recorded a higher concentration in 2018-19 with 59.3, 3.539 g/l and 1.300 g/l respectively.

Table 2. Primary and secondary composition of Tannat berry metabolites at harvest for three growing seasons (pooled 9 plot) and for different topographic conditions (pooled vintages).

Grape variables	Growing season			Altitude		
	2018-19	2019-20	2020-21	High	Middle	Low
TSS (g/l)	233 a	242 a	201 b	216 a	223 a	229 a
TSS (g / berry)	0.337 b	0.378 a	0.334 b	0.343 a	0.338 a	0.363 a
pH	3.38 a	3.35 a	3.13 b	3.29 a	3.26 a	3.25 a
Tirtable acidity (gH_2SO_4 /l)	5.0 a	4.2 b	5.2 a	5.2 a	4.6 b	4.8 ab
Malic acid (g/l)	8.7	8.8	s/d	9.75 a	8.30 b	8.38 b
Tartaric acid (g/l)	3.9**	3.3	s/d	3.60 a	3.64 a	3.55 a
t/m	0.45**	0.38	s/d	0.37 a	0.44 a	0.42 a
IPT	59.3 a	55.1 b	52.8 b	56.4 a	52.3 b	58.5 a
ApH 1 (g/l)	3.539 a	2.628 b	2.309 c	2.555 b	2.649 b	3.221 a
ApH 3.2 (g/l)	1.300 a	1.052 b	0.888 c	1.030 b	0.997 b	1.183 a
%EA	63.2 a	58.8 b	61.4 ab	58.0 b	62.1 a	62.7 a

When observing the response of Tannat to the meso-climate conditions, total acidity depended on topography, with higher elevations reaching 5.2 g/l. Among the organic acids, malic acid showed the greatest sensitivity to

meso-climatic conditions, with a difference of 1.37 g/l in favor of the higher elevations. Malic acid, a compound affected by temperatures above 20°C during the grape ripening period (Sweetman et al., 2014) was positively correlated with altitude. High, cool daytime areas, exposed to higher wind intensities during the day, were able to conserve acidity to a better extent than plots in lower altitudes areas.
As for secondary metabolites, anthocyanins showed a greater accumulation in the lower zones with a difference of 0.67 g/l at pH 1 and 0.15 g/l at pH 3.2 compared to the plots in the higher zones. This is due to the greater thermal amplitude, lower CNI and night temperatures close to 15°C, as reported by Mori et al. (2005), which are necessary for anthocyanin accumulation. Although lowland areas have higher maximum temperatures, these do not exceed the 30°C threshold cited by Spayd et al. (2002) for anthocyanin degradation due to thermal excess.

Conclusion

Results of this research, carried out in the eastern wine region of Uruguay, showed the importance of summer rainfall to differentiates vintages while the effect of topographic conditions of the vineyard plots affected mesoscale temperature and thus spatial thermal variability during the season. In special terms, altitude was the main factor and conditioned the exposure of the plots to oceanic wind, causing in the 3-year average a difference of 0,8 °C in TmaxS during the months of grape ripening between plots located in high and low areas. This spatial variability in temperature had an impact on the quality of the Tannat grapes at harvest. Berries from vineyards located at higher altitudes were associated with malic acid and plots in low situations with total phenols and anthocyanins.
Therefore, by knowing in detail the topography and how it interacts with vine cultivation, agronomic strategies can be proposed to enhance terroir typicity. In this way, productive efforts will be more efficient with the resources employed and will make it possible to anticipate future problems caused by climate change.

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