Ramiro Tachini[1]*, Valerie Bonnardot[2], Milka Ferrer[1] and Mercedes Fourment[1]

Topography interactions with the Atlantic Ocean and its impact on *Vitis vinifera* L. 'Tannat'.

Affiliations

[1]Facultad de Agronomía, Universidad de la República Oriental del Uruguay, Montevideo, Uruguay

[2]Université Rennes 2, LETG-UMR 554 CNRS, Rennes Cedex, France

Correspondence

Ramiro Tachini: rtachini@fagro.edu.uy, Valerie Bonnardot: valerie.bonnardot@univ-rennes2.fr, Milka Ferrer: mferrer@fagro.edu.uy, Mercedes Fourment: mfourment@fagro.edu.uy

Summary

Climate is one of the main factors conditioning the chemical composition of grapes and wine. At a vineyard scale, during the growing season, topography can explain spatial temperature variability. Furthermore, each topographical factor (altitude, slope, exposure) may have a different impact on grapevine production, even in low altitude terrains. This work aims to evaluate the mesoclimate of Uruguay's Atlantic region and determine the topography and ocean's effect on temperature and, thus on the response of the 'Tannat' grapevine. Data from 19 temperature sensors, installed in a coastal vineyard under contrasted topography conditions, were used over three growing seasons in order to study the relationships between bioclimatic indicators of different sites and the plant response of nine 'Tannat' plots under similar agronomical management and soil type. Mesoclimate, especially due to altitude and exposition to the ocean winds, mostly explained 'Tannat' variability. Significant differences in extreme temperatures (minimum and maximum) were observed: The plots at higher altitudes (118-140 m a.s.l.) exposed to oceanic winds had a lower daytime temperature than the plot sheltered at lower altitude (70-94 m a.s.l.). The average difference was 0.9 °C during the hottest summer, reaching 1,7 °C between the most contrasted sites. In particular, the local sea breeze circulation during heat waves of the ripening period, prevent extreme high temperatures in sites facing the ocean. Temperature drop of 4.3°C in upwind sites was noticed, against 0.9°C in sheltered plots. The plots at lower altitude presented a nighttime temperature lower than plots at higher altitude (up to 1.0°C lower, on average, during ripening), thus resulting in greater diurnal thermal amplitude (1.5 °C greater). A direct association between altitude, mesoscale temperature and 'Tannat' grape metabolites was observed for three consecutive years: plots at higher altitude recorded significative greater malic acid (+1.7 g L^{-1}), while plots at lower altitude recorded greater anthocyanin potential (ApH1) (+1920 mg L^{-1}). Other variables such as soluble solids, total titratable acidity, pH and polyphenols were differentiated at least over one growing season. No significant differences in agronomic response parameters such as yield, pruning weight and Ravaz Index were observed. Topographic differences less than 70 m a.s.l. but enhanced by the Atlantic Ocean influence, made it possible to differentiate plots with equal vine responses. Seasonal and spatial climatic characterization of the region at fine scale along with grapevine response will allow to optimize agronomic decisions especially in search of fresh terroirs where the vines can adapt to climate change.

Keywords

Mesoclimate, Sea Breeze, Tannat, Grape Quality, Uruguay

Introduction

Climate is one of the viticultural terroir's main components, and its interaction with wine production is studied worldwide. Among climate factors, the temperature turns out to be the component with the most significant impact on the plant (pl) and organoleptic quality of the grape (Blancquaert *et al.*, 2018; Kuhn *et al.*, 2013). Temperature accelerates plant development and phenological stages (Parker *et al.*, 2011, 2020), while temperature above 35°C affects photosynthesis and generation of soluble solids (Bergqvist *et al.*, 2001; Torregrosa *et al.*, 2017). Within grape organic acids, malic acid is affected by temperatures above 25°C during berry ripening (Lakso and Kliewer, 1975; Sweetman *et al.*, 2014), while tartaric acid is not affected by temperature during the maturation period (Blancquaert *et al.*, 2018). A positive balance of anthocyanins, phenolic compounds of oenological importance, occurs between nighttime values around 15°C and daytime values around 30°C (Mori *et al.*, 2007; Spayd *et al.*, 2002). Slow ripening under cool thermal conditions increases its intensity and avoids cooked fruity aromas (Mira De Orduña, 2010).

To understand in detail the grapevine's behavior and composition, several authors have developed climatic indicators that allow relating plant development to temperature: Growing Degree Days (GDD) (Winkler *et al.*, 1962), Mean January/July Temperature (MJT), Effective Degree Days (Gladstone, 2011), Heliothermal Index (HI) (Huglin, 1978), Cool Night Index (CNI) (Tonietto and Carbonneau, 2004), average temperature during

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the growing cycle (Tavg) (Jones *et al.*, 2005), the number of days with temperatures above 30 and 35 °C (ND30 and ND35) (Hunter and Bonnardot, 2016), Grapevine Sugar Ripeness Index (GSR) (Parker *et al.*, 2020) and Solar Radiation Index (Ferretti, 2021). These bioindicators were largely used by authors in different parts of the world to describe, characterize, predict and compare sites (e.g.: Tonietto and Carbonneau, 2004; Hall and Jones, 2010; Jones *et al.*, 2010; Bonnefoy *et al.*, 2013).

However, climate variability can be studied at different spatio-temporal levels. Mesoclimate covers areas from 100 meters to several kilometers with the temporal focus in hours or days. It is also known as "topoclimate" since topographic factors (altitude, slope and exposure) cause the spatial climate variability (Neethling *et al.*, 2019). The mesoclimate analysis contributes to improve knowledge of the regional climate by studying the influence of topography on the various climatic variables in a specific location such a vineyard (*i.e.*, the effect of terrain on the incidence of radiation, temperature and wind exposure)(Dumas *et al.*, 1997; Quénol and Bonnardot, 2014; De Rességuier *et al.*, 2020; Ferretti, 2021). This is the scale at which parameters are often studied for the zoning of appellations (*i.e.*, Calame *et al.*, 1977 to cite one example). Mesoclimatic conditions also include the role of the proximity to water bodies such as oceans, lakes or rivers, leading to local air circulation due to thermal differences between the air above the water and that of the continental surfaces. The climatic impacts of the arrival of the sea breeze in the coastal wine growing regions have been studied for example in countries such as South Africa, New Zealand or Australia (Bonnardot *et al.*, 2002, 2011; Lyons and Considine, 2007), where it was shown that the local maritime air circulation can prevent extreme temperatures, reducing heat stress during the vine cycle and berry ripening. Such studies have been led in Uruguay (Manta *et al.*, 2021) and specifically with impacts in the coastal wine region of Canelones (flat topography) (Fourment *et al.*, 2017) finding vine response to local climate.

Using the Köppen classification of climate, Uruguay experiences a “Cfa” type of climate: temperate, with regular rainfall throughout the year, humid and warm conditions; temperature of the warmest month being greater than 22 °C (INUMET, 2020). It is estimated that in the last 50 years, the ambient temperature has increased by 1 °C, accompanied by an increase in warm events and higher levels of precipitation in autumn (IPCC, 2021). Furthermore; the outlook for Uruguay under IPCC scenario SSP2 indicates an increase of 2°C by 2050 (IPCC, 2021), most likely impacting viticultural production. Taking into account that the interactions between topography and grapevine responses are studied mostly in regions of contrasted terrain with more than 200 m difference between studied plots (Blanco-Ward *et al.*, 2007; Falcão *et al.*, 2010; Rienth *et al.*, 2020), it was relevant to study a complex terrain at lower differences in altitude such as in Uruguay. Consequently, the objective of the study is to analyze the effect of the Atlantic Ocean in interaction with the fine-scale topography on mesoclimate and its impact on the production of 'Tannat' grapes during three growing seasons with the aim to extend knowledge on wine sustainability in Uruguay in a context of climate change.

Material and Methods

Site

A commercial vineyard was selected near Pueblo Garzón, Uruguay (34°57’S; 54°60’ W). Within the site, 19 temperature sensors Tiny Tag data logger ® (Gemini Data Loggers Ltd., UK) were installed at 2 m above ground level, located in different environmental situations, within a radius of 2 km at an average distance of 18 km from the Atlantic Ocean. To analyze the responses of 'Tannat', 9 productive plots were selected (Fig. 1).

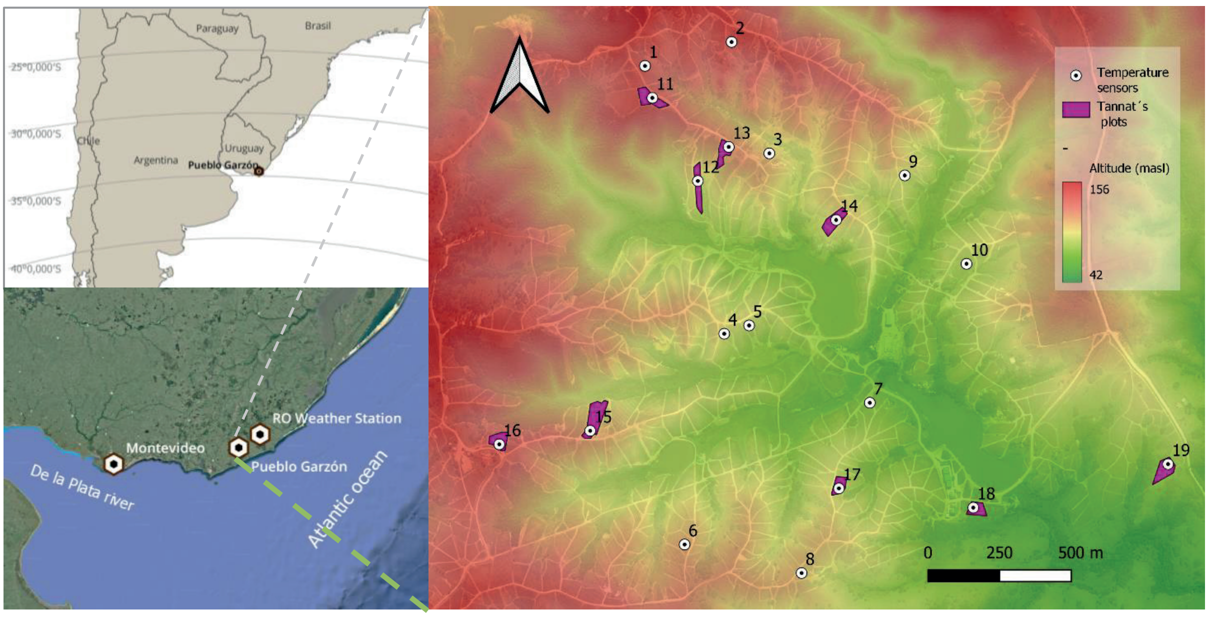

Figure 1: Location of Uruguay on the South American continent, location of the vineyard under study and of the Rocha meteorological reference station “RO” (left). Topography of the studied vineyard and location of the 19 temperature sensors and nine selected 'Tannat' plots (right).

Climatic and topographical data analysis

For describing regional climate and its temporal variability, we used daily data from the INUMET weather station in Rocha (RO; Uruguayan Institute of Meteorology), located at 34°49'S and 54°31'W, 30 km from the vineyard under study. We studied three growing seasons (2018-19, 2019-20 and 2020-21), referred to further in the text as 2019, 2020 and 2021 respectively (corresponding of the year of harvest). Precipitation (PP) and air temperature were analyzed during the growing season (September 1 – March 15), and several bioclimatic indices adapted to grapevine cultivation (HI, CNI, GSR, ND30, ND35 and Tavg) were calculated.

To analyze topoclimate in the commercial vineyard, a daily temperature dataset was obtained from the thermal sensors that recorded hourly air temperature during the vegetative cycles of the three growing seasons. In order to have experimental repetition, the sensors were divided into three classes of equal intervals for altitude and slope (e.g.: ((*max altitude plot value – min altitude plot value)/3*)); resulting in: Altitude: Low (70-94 meters above sea level (m a.s.l.)), Medium (94-117 m a.s.l.) and High (118-140 m a.s.l.); Slope: 1 (2.9-5.8°), 2 (5.9- 8.7°) and 3 (8.7-11.6°). Soil exposure was classified into the main four directions: N (North), S (South), E (East), and W (West) (Tab. 1). In order to assess thermal conditions of 'Tannat' growing and ripening, the classical bioclimatic indices (HI, CNI and Tavg) were calculated for each topographical condition while thermal amplitude (TeAm as expressed in °C) and average of maximum and minimum temperature (Tx, Tn; °C) were calculated during grape ripening (January 15 to March 15).

To assess the temperature evolution during the day, we used the hourly mean temperature of two topographical contrasted plots (plot 7 and plot 2) for the ripening period (15 January to 15 March) and for the three growing seasons under study. To assess the thermal differences under specific atmospheric circulations during grape ripening, two hot days (with temperature above 30°C) were selected (1/2/2020 and 26/1/2020) for which the hourly temperature of the 19 sensors were plotted along with the hourly relative humidity (%), precipitation (PP), temperature (°C), wind speed (m s^{-1}) and wind direction (°) recorded by RO weather station.

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 2.5 m × 2.5 m and was used to calculate the values of altitude, slope, and soil exposure.

Vine response analysis

Vine response was analyzed on 'Tannat' plots 11 to 19 (Fig. 1; Tab. 1), conduced as high trellis system, 2 m row spaces, 1 m between plant and 100% drip irrigation. In each plot 21 plants were selected for agronomic and metabolic grape analyses. The selection of the plots, based on topographic conditions, represent the most significant variability in terms of slope,

Table 1: Topographical and soil description of the plots (Altitude, slope, exposure). Altitude: Low (70-94 m a.s.l.), Middle (94-117 m a.s.l.) and High (118-140 m a.s.l.). Slope: 1 (2.9-5.8°), 2 (5.9- 8.7°) and 3 (8.7-11.6°). Soil exposure: N (North), S (South), E (East) and W (West).

Sensor/'Tannat' plot*	Altitude (m a.s.l.)	Slope (°)	Exposure (°)	Altitude classes	Exposure classes	Slope classes	Sup (ha)	Date platantion	Soil type	Soil depth (cm)
1	140	9.4	110	High	E	3	0.6	2009	Brunosol	88
2	135	11.2	187	High	S	3	0.4	2009	Brunosol	70
3	108	9.3	43	Middle	N	3	0.2	2009	Brunosol	67
4	95	11	122	Low	E	3	0.2	2009	Brunosol	81
5	92	11.6	160	Low	S	3	0.2	2009	Brunosol	92
6	110	7.5	323	Middle	N	2	0.2	2009	Brunosol	73
7	77	5.7	345	Low	N	1	0.4	2009	Brunosol	75
8	106	5.5	135	Middle	S	1	0.2	2009	Brunosol	89
9	96	7.9	128	Middle	E	2	0.2	2013	Brunosol	74
10	88	4.4	172	Low	S	1	0.2	2013	Brunosol	92
11	136	8	41	High	N	3	0.4	2009	Brunosol	91
12	97	10.6	114	Middle	E	3	0.3	2009	Brunosol	82
13	118	6.8	214	High	S	2	0.3	2009	Brunosol	88
14	103	6	278	Middle	W	2	0.4	2009	Brunosol	68
15	112	8.7	46	Middle	E	2	0.6	2008	Brunosol	81
16	134	11.4	35	High	N	3	0.3	2008	Brunosol	90
17	93	5.8	95	Low	E	1	0.2	2009	Brunosol	72
18	72	5.7	157	Low	S	1	0.3	2009	Brunosol	77
19	85	2.9	245	Low	W	1	0.4	2013	Brunosol	88

* In bold: 'Tannat' plots + thermal sensor, in italics: other cultivars plots + thermal sensor.

altitude and exposure situations. We analyzed the vine responses during the same three growing seasons used for the mesoclimate study.

To measure physiological conditions of the vines, we determined: yield (Yield), pruning weight (Pw) and Ravaz index (RI) (Ravaz, 1911) in 21 plant per plot. The harvest date was determined around pH 3.3 and was March 15 in 2019, March 3 in 2020 and March 13 in 2021.

Grape chemical composition was analyzed to determine primary metabolites according to the OIV protocol (OIV, 2009), where 100 berries were taken randomly from grapes harvested and by duplicate. We determined Total Soluble Solids (TSS g L^{-1}) by refractometry (Hanna® HI 96801 refractometer), Total Titratable Acidity (TTA g sulfuric acid L^{-1}) by titration, pH measurement by potentiometry (pH meter Oakton® 11 series) and berry weight (BW g). To quantify the organic acids of berries, we conducted high-performance liquid chromatography (HPLC) determined by OIV (2009) protocol from a sample of 100 berries taken at random from the grapes harvested and in duplicate. To determine secondary metabolites in 'Tannat' grapes, we applied the (Glories and Agustin, 1992) extraction method modified by González-Neves *et al.* (2004) of a sample of 250 berries randomly and in duplicate. We determined total potential in anthocyanins (ApH1), potential in extractable anthocyanins (ApH3.2) and total polyphenols index (TPI) with Unico S-2150 (Dayton, United States) spectrophotometer.

Statical analysis

We performed a statistical variance analysis (ANOVA) using a p-value <0.05 (**) and p-value <0.01 (***) to assess the spatial variability and grape composition values between topographical classes. We used Tukey`s test to order the classes based on different letters with a p-value <0.05. We established Person's correlations using a p-value < 0.05 to determine the relationships between climatic variables and grape composition. To determine multivariate relationships between the different climate parameters and plant responses, we conducted a principal component analysis (PCA) in two ways: 1) with absolute data and 2) with standardized data by years to determine spatial differences. The SAS® software was used to perform the statistical analysis and the graphs were made using OriginLab®.

Results

Regional climate and interannual climate variability

Precipitations of the growing season varied from 929 mm in 2019 to 574 mm in 2020 and 404 mm in 2021. The 2020 growing season had the driest grape ripening period (January 15 – March 15), with 87 mm less on average. The 2021 harvest presented the lowest rainfall amount during the total growing seasons with 404 mm; however, this was concentrated over the grape ripening period with 234 mm. The growing season temperature was 19.1 °C in 2019 and 2020, and 18.3 °C in 2021. The 2020 growing season showed the highest GSR value (+132 than 2021), highest HI (+143 than 2021), the greatest ND30 (+ 13 than 2019), and the lowest CNI (-0.7 than 2021). The 2021 growing season did not record any days with temperatures > 35 °C, the 2020 showed 1 day and 2019, 4 days (Tab. 2).

Topoclimate and spatial variability

Bioclimatic indicators classified by altitude showed statistical differences (p value < 0.05) in Tavg (2021), TeAm (3 years), Tn (3 years), Tx (2020) (Tab. 3). The topographic classification referring to slope showed significant differences in Tavg (2021), TeAm (2020), and Tn (2020 and 2021). The plots organized by exposure did not show significant differences (Tab. 3).

Average temperature of the growing period (Tavg) showed one significant difference (p value < 0.05) between topographic classes only for 2021, being lower for the plots at lower altitude and slope class 1. There were no statistical differences between plots in terms of HI over the three studied years (Tab. 3).

Significant spatial differences (p value < 0.05) were found between the altitude classes, and constantly for the three years, in the TeAm, CNI and Tn bioclimatic indicators. Systematically, the plots at lower altitudes was the one that recorded the lowest CNI and the greatest thermal amplitude due to lower Tn compared to the plot at middle and higher altitude. The maximum differences were of the order of 1.5°C for TeAm and 0.9°C for Tn. The maximum temperature (Tx) was lower at plots at higher altitudes during all 3 periods; however, it was statistically significant only in 2020 with a difference of 0.8°C (Tab. 3).

Table 2: Climatic indicators: precipitation in the growing season (PP_{gs}), precipitation in the ripening period (PP ripening), average temperature of the period (Tavg), Grape Sugar Ripeness Index (GSR), Huglin Index (HI), Cool Night Index (CNI), and the number of days with temperatures above 30 and 35°C (ND30) (ND35) calculated for the growing season 2019, 2020 and 2021 based on the RO weather station.

Growing season	PP_{gs}	$PP_{ripening}$	Tavg	GSR	HI	CNI	N30	N35
2019	929	300	19.1	3392	2092	15.9	23	4
2020	579	137	19.1	3470	2131	15.9	36	1
2021	404	234	18.3	3338	1988	16.6	23	0
Average	637	224	18.8	3400	2070	16.2	27	2
C.V. (%)	42	37	2	2	4	3	27	125

Table 3: Evaluation of bioclimatic indicators for grapevine cultivation: average temperature of the growing season (Tavg), Heliothermal index (HI), and Cool night index (CNI) and thermal indices for the ripening period: thermal amplitude (TeAm), minimum temperature (Tn) and maximum temperature (Tx) based on the topographic conditions of the vineyard: altitude, slope and exposure, for 2019, 2020 and 2021 harvest.

	Altitude	2019	2020	2021	Slope	2019	2020	2021	Exposure	2019	2020	2021
Tavg (°C)	High	19.1 a	19.7 a	19.1 a	3	19.1 a	19.7 a	19.0 a	S	19.2 a	19.7 a	18.9 a
	Middle	19.1 a	19.8 a	19.0 a	2	19.2 a	19.8 a	19.1 a	E	19.1 a	19.3 a	18.9 a
	Low	19.1 a	19.7 a	18.8 b	1	19.1 a	19.6 a	18.7 b	O	19.1 a	19.9 a	18.9 a
									N	19.1 a	19.8 a	19.0 a
	Year		***		Year		***		Year		***	
	Altitude		ns		Slope		***		Exposure		ns	
HI	High	2174 a	2264 a	2102 a	3	2107 a	2272 a	2192 a	S	2099 a	2270 a	2169 a
	Middle	2197 a	2299 a	2100 a	2	2109 a	2298 a	2196 a	E	2116 a	2284 a	2177 a
	Low	2172 a	2264 a	2112 a	1	2103 a	2277 a	2157 a	O	2114 a	2312 a	2177 a
									N	2100 a	2282 a	2203 a
	Year		***		Year		***		Year		***	
	Altitude		ns		Slope		ns		Exposure		ns	
TeAm (°C)	High	11.3 b	12.8 b	11.1 b	3	11.7 a	13.4 ab	11.9 a	S	11.9 a	13.6 a	11.7 a
	Middle	11.5 ab	13.4 b	11.7 ab	2	11.6 a	13.1 b	11.3 a	E	11.6 a	13.5 a	11.6 a
	Low	12.2 a	14.3 a	12.1 a	1	12.1 a	14.2 a	11.9 a	O	12.4 a	13.5 a	11.7 a
									N	11.5 a	13.8 a	11.9 a
	Year		***		Year		***		Year		***	
	Altitude		***		Slope		***		Exposure		ns	
CNI	High	16.4 a	16.4 a	17.3 a	3	16.2 a	16.2 a	16.9 ab	S	16.1 a	16.1 a	16.7 a
	Middle	16.4 a	16.3 a	16.9 ab	2	16.4 a	16.4 a	17.1 a	E	16.3 a	16.3 a	16.9 a
	Low	15.8 b	15.5 b	16.5 b	1	15.9 a	15.7 b	16.5 b	O	15.8 a	16.0 a	16.8 a
									N	16.3 a	16.1 a	16.9 a
	Year		***		Year		***		Year		***	
	Altitude		***		Slope		***		Exposure		ns	
Tx (°C)	High	27.9 a	29.1 b	28.3 a	3	28.1 a	29.7 a	28.6 a	S	28.3 a	29.6 a	28.3 a
	Middle	28.0 a	29.7 ab	28.5 a	2	28.1 a	29.6 a	28.4 a	E	28.0 a	29.7 a	28.4 a
	Low	28.4 a	29.9 a	28.5 a	1	28.3 a	29.7 a	28.3 a	O	28.4 a	29.4 a	28.4 a
									N	28.0 a	29.9 a	28.7 a
	Year		***		Year		***		Year		***	
	Altitude		ns		Slope		ns		Exposure		ns	
Tn (°C)	High	17 a	16.3 a	17.5 a	3	16.7 a	16.1 a	17.0 ab	S	16.9 a	15.8 a	16.8 a
	Middle	16.8 ab	16.1 a	17.0 ab	2	16.9 a	16.2 a	17.2 b	E	17.1 a	16.0 a	17.0 a
	Low	16.5 a	15.5 a	16.5 b	1	16.5 a	15.4 a	16.5 a	O	16.6 a	15.7 a	16.9 a
									N	17.1 a	15.9 a	17.0 a
	Year		***		Year		***		Year		***	
	Altitude		***		Slope		***		Exposure		ns	

Altitude: Low (70-94 m a.s.l.), Middle (94-117 m a.s.l.) and High (118-140 m a.s.l.). Slope: 1 (2.9-5.8°), 2 (5.9- 8.7°) and 3 (8.7-11.6°). Soil exposure: N (North), S (South), E (East) and W (West). Ns= differences not significant, ** differences with p-value <0.05, ***differences with p-value <0.01. Different letters mean statistical differences between topographic conditions in the same growing season with p-value <0.05.

These temperature differences were further analyzed considering the mean diurnal temperature of the two greatest contrasted plots in altitude over the ripening periods of the three studied seasons (Fig. 2). The thermal difference intensified during the afternoon, whatever the growing seasons considered, with 17:00 LT being the time at which the most significant difference is recorded. The greatest mean differences were for 2020 with a difference of 1.7°C in maximum temperature and 1.1°C in minimum temperature (Fig. 2B).

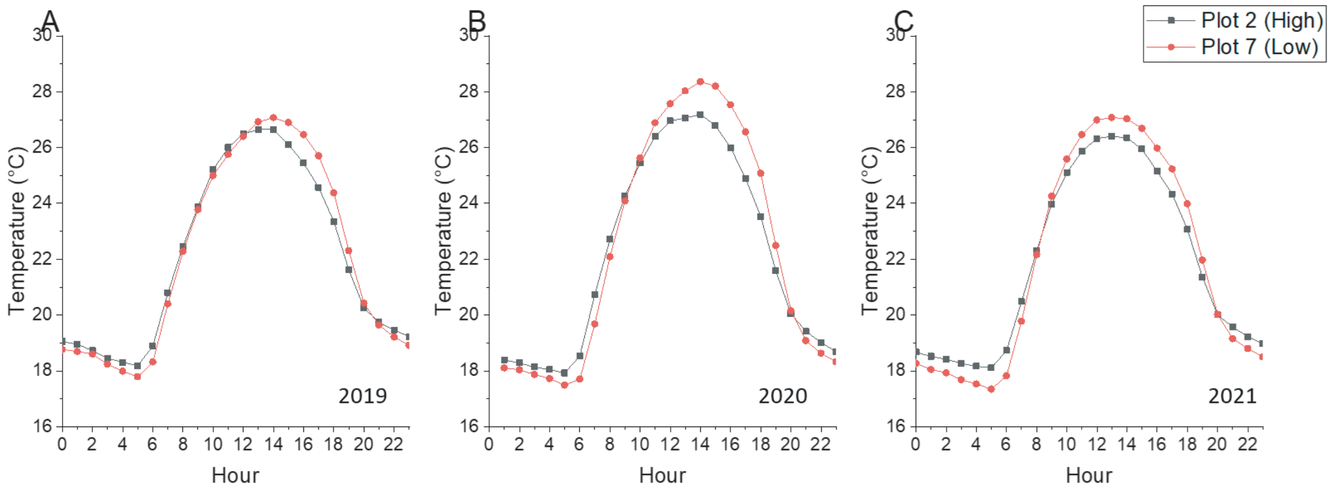

Figure 2: Hourly air temperature for two plots in contrasted topography (plot 2: altitude 72 m a.s.l., slope 11.2, exposure 187°; plot 7: altitude 135 m a.s.l., slope 5.7, exposure 347°) during three grape ripening periods: A) 2018-19, B) 2019-20, and C) 2020-2021.

Spatial differences of typical coastal phenomena under warm conditions during the maturation period (Local *vs* synoptic atmospheric circulation)

Going into detail on the mesoclimatic behavior on a daily scale, two warm days during the maturation period were taken as a reference, where on February 1, 2020, the maximum temperature was reached at 15:00 LT with a maximum of 32.3 °C (such as in Plot 9). After the daily high was recorded, a sudden drop in temperature (of 2.6 °C on average) was observed between 15:00 and 16:00 LT. At the same time, the RO weather station recorded an increase in relative humidity of 13% that stabilized before increasing again at night (Fig. 3C). This was also associated with an increase in wind speed from 2.6 to 6.1 m s^{-1} with a predominant SE component (Fig. 3D). This typically could materialize the onset of a local air circulation (sea breeze circulation), being plot 9 the most exposed to the sea winds recording a decrease of 4.3°C and plot 14 less exposed with a decrease of 0.9°C (Fig. 3A).

On January 26, 2020, the atmospheric conditions seem different compared to those previously. The temperature exceeded 31°C (maximum of 34.0 °C at Plot 5) and all the temperature sensors recorded a temperature drop of 10°C. That rather corresponds to synoptic conditions with either the development of a storm or the passage of a cold front. The increase in relative humidity, from 40 to 90% (Fig. 3D) and the increase in wind speed, from 0 to 6.7 m s^{-1}, are greater than on 1/2/2020 (Fig. 3F) and it was rainy (17 mm was recorded at RO weather station, Fig. 3B).

Spatial and seasonal variability of 'Tannat' agronomic variables (yield, plant balance and oenological potential) and its relation to topography and climate

In the region, the average of the nine plots and the three growing seasons resulted in a mean berry weight (BW) of 1.71 g, a mean yield of 2.8 kg/pl, a mean Pw of 389 g/pl and a mean IR of 7.1. Plant physiological variables yield, Pw and RI showed no significant differences according to any topographic factors whatever the growing season considered. Berry weigh showed significant differences (p value < 0.05) considering the slope category, yet for the 2019 growing season only. Berries from plots with slope class 3 had up to 0.18 g/berry more than those originated from plots with slope class 2 (Tab. 4).

The mean value of primary berry metabolites was: 225 g/L TSS, 4.8 g sulfuric acid L^{-1} TTA, 3.60 g L^{-1} tartaric acid, 8.76 gL^{-1} malic acid and 3.28 pH. The values of secondary metabolites were 56 TPI, 2787 mg L^{-1} ApH1 and 1078 mg L^{-1} ApH3.2. (Tab. 5). Classification of plant responses based on topographic classes showed differences at p value < 0.05 for altitude in TTA (2020 and 2021), Malic acid (2019 and 2020), pH (2021), TSS (2019), TPI (2020), ApH1 and ApH3.2 (3 years). Slope differentiated classes in TPI (2019 and 2020), ApH1 (3 years), and ApH3.2 (2020 and 2021). Exposure showed differences in TTA (2020 and 2021), malic acid (2019), pH (2021), and TSS (2019) (Tab. 5).

The maximum TTA values were recorded at plots at higher altitudes for the three studied years. However, the differences were significant (p value < 0.05) for the 2020 and 2021 growing seasons only. The maximum difference occurred in 2020 and was of 0.8 g sulfuric acid L^{-1} between the plots at higher and middle altitudes. TTA were the greatest at plots facing north in three growing seasons, with a maximum difference in 2020 of 1.0 g sulfuric acid L^{-1} compared to the plots facing East. In that sense, in all three years, no differences were found between the north and south faces. Malic acid presented the highest values in the plots at higher altitudes, with the maximum difference of 1.7 g L^{-1} versus the plots at lower altitude for the 2020 growing season. Tartaric acid showed no statistical differences between topographic classes and climate seasons (Table 5). TPI responded significantly to altitude in the 2020 growing season (p value < 0.05) with greater values recorded at plots at lower altitudes and a maximum difference of 7.3 with the plots at higher altitudes. It also responded to slope with the class 1 obtaining significantly higher polyphenol values. The maximum difference obtained was 13.4 versus plots at slope class 3 in the 2019 cycle. The absolute value of TSS was higher in the plots at lower altitudes in all 3 growing seasons, with the difference being significant in

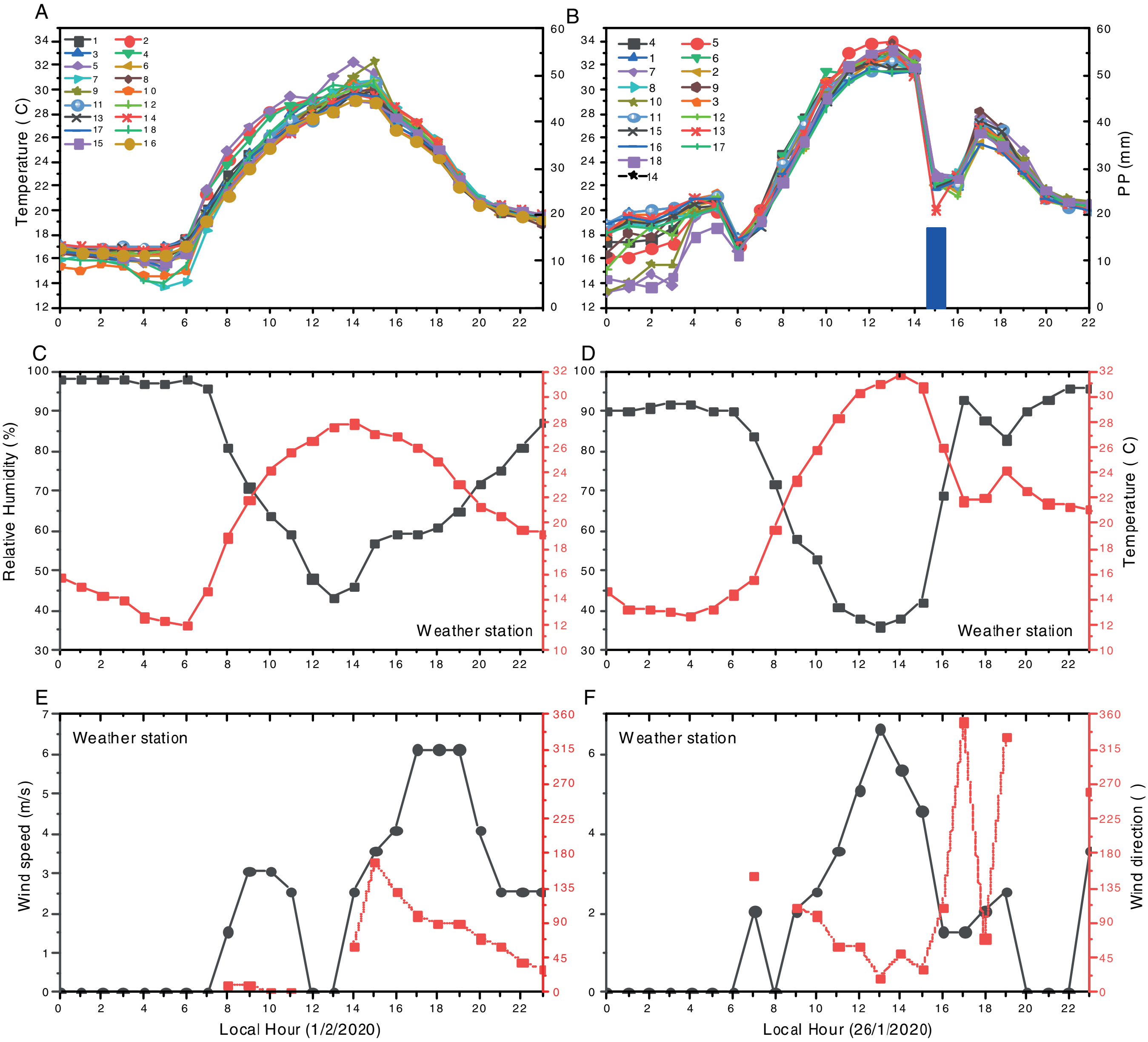

Figure 3. (A) Hourly temperature recorded by the temperature sensors on 1/2/2020 and (B) thermal sensor on 1/26/2020 with RO weather station precipitation (PP). (C) Temperature and Relative humidity and (E) wind speed and direction recorded by the RO weather station on 1/2/2020. (D) Temperature and Relative humidity and (F) wind speed and direction recorded by the RO weather station on 1/2/2020.

2019 (p value < 0.05). This difference was 23 g L-1 more than that obtained by plots at higher altitudes, corresponding to a 1.3° v/v increase in probable alcohol. Anthocyanins, both potential (ApH1) and extractable (ApH3.2), were the only variables that responded to altitude conditions over the three years. Systematically, the plots at lower altitudes were those with the highest anthocyanin levels as opposed to the plots at higher altitudes. The most significant difference was recorded in the 2019 cycle reaching 1929 mg L^{-1} evaluated at ApH1 and 766 mg L^{-1} at ApH3.2. These differences corresponded to 90 % at ApH1 and 105 % at ApH3.2 more in the plots at lower zones.

Associating the grape metabolic response to climatic variables, we found that total titratable acidity concentration (TTA) was negatively sensitive to mean maximum summer temperature (Tx) with a Pearson's r of -0.70 (Fig. 4 D) and positively with the cool night index (CNI) with a Pearson's r of 0.51 (Fig. 4C). In addition, Potential anthocyanins (ApH1) were negatively correlated with CNI with a Pearson's r of -0.52 (Fig. 4A), while Tx was not significantly impact on ApH1 (Fig. 4B).

Results of the PCA showed a clear separation of the three growing seasons within the quadrants (Fig. 5 A). The cumulative percentage of the variance between the first two axes was 68.9%, with 44.5% corresponding to the first axis. On this axis, most of the plots for the 2019 and 2020 growing seasons were located within the positive quadrants, and those for the 2020-21 growing seasons within the negative quadrants. The main factors with the greatest weight on axis 1 were TSS (coefficient 0.41), CNI (-0.38), and ApH3.2 (0.35). On axis 2 the factors TTA (0.46), TeAm (-0.43), and Tx (-0.39) gained relevance and allowed discrimination mainly

Table 4: Plant (pl) response (Yield, BW: berry weight, RI: ravaz index, Pr: pruning weight) of *Vitis vinifera* L. 'Tannat' based on vineyard topographic conditions (altitude, slope, and soil exposure) for 2019, 2020, and 2021 growing cycles. Altitude: Low (70-94 m a.s.l.), Middle (94-117 m a.s.l.), and High (118-140 m a.s.l.). Slope: 1 (2.9-5.8°), 2 (5.9- 8.7°) and 3 (8.7-11.6°). Soil exposures: N (North), S (South), E (East), and W (West). Different letters mean statistical differences between values

	Altitude	2019	2020	2021	Slope	2019	2020	2021	Exposure	2019	2020	2021
Yield (kg/pl)	High	3.1 a	2.6 a	2.7 a	3	3.2 a	2.6 a	2.7 a	S	2.5 a	2.0 a	2.7 a
	Middle	2.8 a	2.4 a	2.7 a	2	2.8 a	2.4 a	2.7 a	E	3.0 a	2.5 a	2.7 a
	Low	3.0 a	2.5 a	3.6 a	1	3.0 a	2.5 a	3.6 a	O	2.7 a	2.6	3.9 a
									N	3.5 a	2.8 a	2.9 a
	Year		ns		Year		ns		Year		ns	
	Altitude		ns		Slope		ns		Exposure		ns	
BW (g)	High	1.63 a	1.72 a	1.81 a	3	1.76 a	1.79 a	1.82 a	S	1.52 a	1.73 a	1.76 a
	Middle	1.57 a	1.67 a	1.73 a	2	1.52 b	1.65 a	1.75 a	E	1.66 a	1.76 a	1.75 a
	Low	1.58 a	1.75 a	1.92 a	1	1.58 b	1.75 a	1.87 a	O	1.51 a	1.64 a	1.88 a
									N	1.70 a	1.69 a	1.83 a
	Year		***		Year		***		Year		***	
	Altitude		ns		Slope		***		Exposure		ns	
RI	High	8.8 a	5.2 a	7.7 a	3	8.3 a	5.1 a	7.2 a	S	7.6 a	5.3 a	7.7 a
	Middle	8.8 a	8.1 a	10.7 a	2	9.1 a	7.3 a	10.4 a	E	8.9 a	5.1 a	9.1 a
	Low	7.0 a	6.2 a	9.1 a	1	7.0 a	6.2 a	9.1 a	O	7.1 a	6.4 a	10.1 a
									N	8.7 a	4.7 a	7.6 a
	Year		**		Year		**		Year		**	
	Altitude		ns		Slope		ns		Exposure		ns	
Pw (g/pl)	High	382 a	468 q	354 a	3	451 a	617 a	411 a	S	335 a	387 a	355 a
	Middle	383 a	410 a	278 a	2	347 a	413 a	315 a	E	420 a	538 a	315 a
	Low	418 a	421 a	391 a	1	417 a	420 a	390 a	O	375 a	351 a	319 a
									N	433 a	587 a	386 a
	Year		ns		Year		ns		Year		ns	
	Altitude		ns		Slope		ns		Exposure		ns	

Ns = differences not significant, ** differences with p-value <0.05, *** differences with p-value < 0.01. Different letters mean statistical differences between topographic conditions in the same growing season with p-value <0.05.

Table 5: Primary and secondary berry metabolites (TTA: total titratable acid, malic acid, tartaric acid, pH, TSS: total soluble solids, TPI: total polyphenols index, ApH1 and ApH3.2: anthocyanins pH 1 and pH 3.2) of *Vitis vinifera* L. 'Tannat' based on vineyard topographic conditions (altitude, slope, and soil exposure) for 2019, 2020, and 2021 growing cycles. Altitude: Low (70-94 m a.s.l.), Middle (94-117 m a.s.l.), and High (118-140 m a.s.l.). Slope: 1 (2.9-5.8°), 2 (5.9- 8.7°) and 3 (8.7-11.6°). Soil exposures: N (North), S (South), E (East), and W (West). Different letters mean statistical differences between values

	Altitude	2019	2020	2021	Slope	2019	2020	2021	Exposure	2019	2020	2021
SST (g L^{-1})	High	223 b	238 a	197 b	3	218 b	242 a	199 a	S	245 a	243 a	202 a
	Middle	232 ab	241 a	200 b	2	232 ab	239 a	200 a	E	233 ab	248 a	200 a
	Low	246 a	242 a	207 a	1	246 a	242 a	206 a	O	238 ab	233 a	204 a
									N	219 b	237 a	200 a
	Year		***		Year		***		Year		***	
	Altitude		***		Slope		***		Exposure		ns	
TTA (g sulfuric acid L^{-1})	High	5.3 a	4.9 a	5.6 a	3	5.1 a	4.6 a	5.1 a	S	5.1 a	4.7 ab	5.4 ab
	Middle	5.0 a	4.0 b	4.8 b	2	5.2 a	4.5 a	5.3 a	E	4.8 a	4.0 c	4.8 b
	Low	4.9 a	4.0 b	5.2 ab	1	4.9 a	4.3 a	5.2 a	O	5.0 a	4.1 bc	5.3 ab
									N	5.3 a	5.0 a	5.5 a
	Year		***		Year		***		Year		***	
	Altitude		***		Slope		ns		Exposure		***	

Table 5: Continued.

	Altitude	2019	2020	2021	Slope	2019	2020	2021	Exposure	2019	2020	2021
Malic ($g\ L^{-1}$)	High	9.4 a	9.8 a		3	8.1 a	9.1 a		S	9.8 a	10.0 a	
	Middle	8.2 b	8.4 b		2	8.2 a	9.2 a		E	8.3 b	8.5 a	
	Low	8.7 ab	8.1 b		1	8.7 a	8.1 a		O	8.3 b	7.9 a	
									N	9.0 ab	8.8 a	
	Year	ns			Year	ns			Year	ns		
	Altitude	**			Slope	ns			Exposure	**		
Tartaric ($g\ L^{-1}$)	High	3.7 a	3.5 a		3	4.3 a	3.6 a		S	3.8 a	3.4 a	
	Middle	4.1 a	3.2 a		2	3.7 a	3.2 a		E	4.1 a	3.2 a	
	Low	4.0 a	3.1 a		1	4.0 a	3.1 a		O	4.0 a	2.9 a	
									N	3.8 a	3.5 a	
	Year	***			Year	***			Year	***		
	Altitude	ns			Slope	ns			Exposure	ns		
ApH1 ($mg\ L^{-1}$)	High	2101 b	2474 b	2059 b	3	3302 ab	2886 a	2143 b	S	2025 a	2827 a	2537 a
	Middle	3307 ab	2585 ab	2259 b	2	3022 b	2351 b	2165 b	E	2596 a	2748 a	2430 a
	Low	4030 a	3020 a	2851 a	1	4030 a	3020 a	2851 a	O	3587 a	2477 a	2491 a
									N	3151 a	2542 a	1883 a
	Year		***		Year		***		Year		***	
	Altitude		***		Slope		***		Exposure		ns	
ApH3.2 ($g\ L^{-1}$)	High	730 b	974 ab	857 b	3	1496 a	1080 a	842 b	S	790 a	1051 a	952 a
	Middle	1242 ab	955 a	847 b	2	1254 a	927 b	855 b	E	1321 a	1009 a	932 a
	Low	1496 a	1089 a	1051 a	1	1469 a	1088 a	1051 a	O	1335 a	996 a	937 a
									N	1094 a	1006 a	800 a
	Year		***		Year		***		Year		***	
	Altitude		***		Slope		***		Exposure		ns	
TPI	High	58.6 a	54.3 b	64.3 a	3	50.6 b	54.6 b	60.8 a	S	68.4 a	56.6 a	61.3 ab
	Middle	55.3 a	52.5 b	60.1 a	2	60.1 ab	53.1 b	62.6 a	E	54.3 b	54.1 a	61.1 ab
	Low	63.4 a	59.8 a	59.5 a	1	64.0 a	59.8 a	60.6 a	O	62.1 ab	56.1 a	58.7 b
									N	54.9 ab	56.1 a	66.0 a
	Year		**		Year		**		Year		**	
	Altitude		***		Slope		***		Exposure		**	

Ns = differences not significant, ** differences with p-value < 0.05, *** differences with p-value < 0.01. Different letters mean statistical differences between topographic conditions in the same growing season with p-value < 0.05.

between the 2019 and the 2020 growing seasons. For TTA, a negative correlation is observed with TeAm and Tx and a positive correlation with CNI. TSS and pH are shown to be opposite to CNI while BW correlates negatively with phenol indicators (TPI, ApH1 and ApH3.2), pH and TSS. The second PCA (Fig. 5 B) with the standardized data by years showed spatial segregation and mainly the opposition between the plots at lower and higher altitudes, the middle-ones being spread around the intersection of axis. The cumulative percentage of the variance between the first two axes was 51.1 %, with 29.4 % corresponding to the first axis. Most of the plots at higher altitudes were located within the negative quadrants on axis 1 and the plots at lower altitudes within the positive quadrants. The main factors with the greatest weight on axis 1 were CNI (coefficient -0.49), ApH1 (0.46), and TeAm (0.46). On axis 2, the factors TPI (0.48), TTA (0.41) and TSS (0.37) gain relevance. BW is close to the center of the PCA, pH is positively associated with CNI and negatively associated with Tx and TeAm and anthocyanins (ApH1) is positively associated with TeAm.

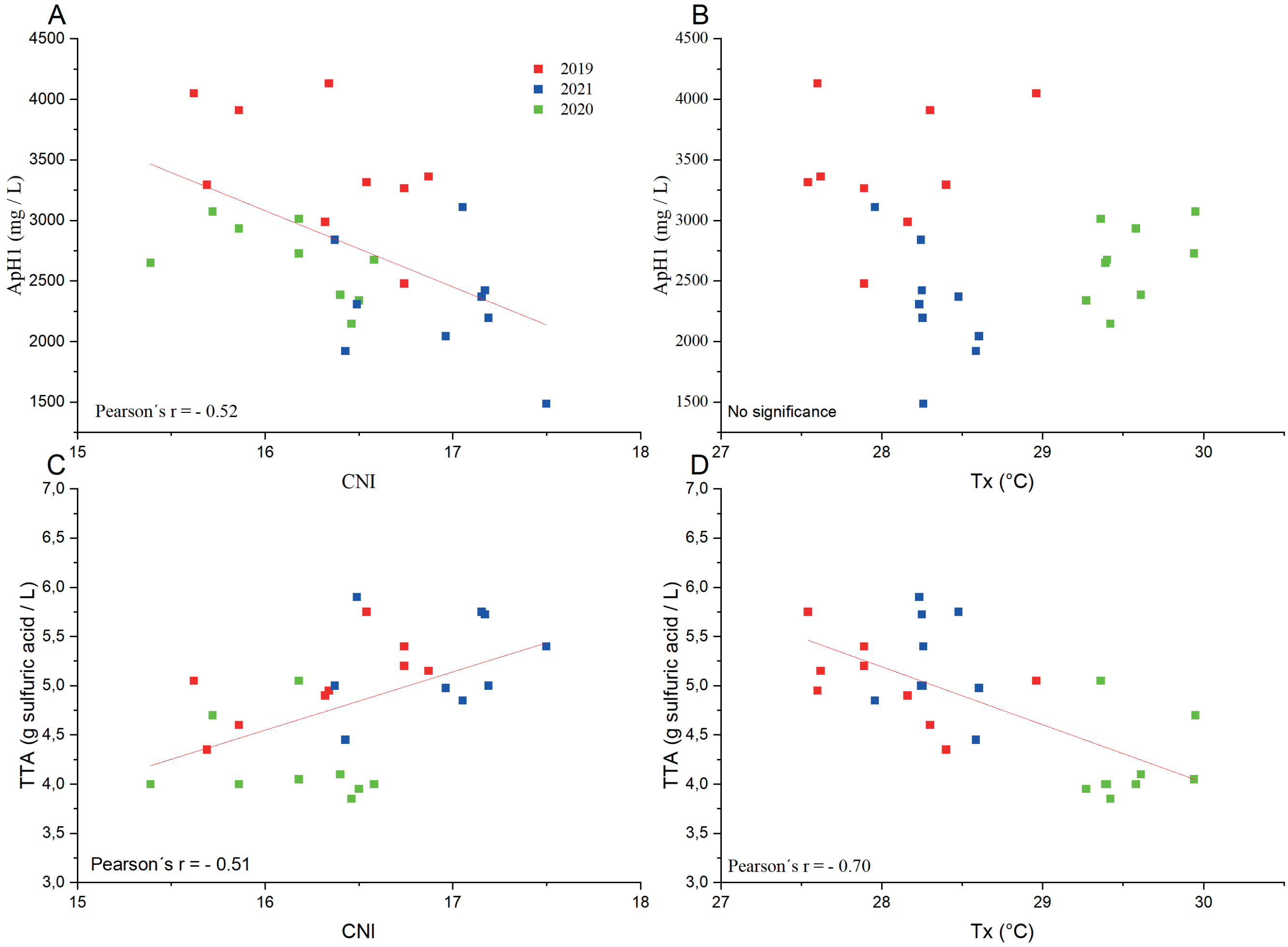

Figure 4: (A) Pearson`s correlation between potential anthocyanin concentration at harvest (ApH1; mg L^{-1}) and Cool Night Index (CNI), (B) ApH1 with temperature maximum during ripening period (Tx; °C), (C) Total titratable acidity (TTA; g sulfuric acid L^{-1}) at harvest related with CNI and (D) TTA at harvest with Tx (°C). Colors distinguish the three growing seasons.

Discussion

Regional climate and interannual climate variability

The Atlantic wine region of Uruguay, based on three growing seasons, experiences a "temperate" climate according to the Huglin index (IH3) with temperate nights for viticulture (CNI2) during the grape ripening period based on the climate classification of Tonietto and Carbonneau (2004), allowing a correct maturation of 'Tannat' and late ripening cultivars such as 'Cabernet Sauvignon', 'Ugni Blanc' or 'Syrah'. Regarding temperature thresholds for physiological functioning of vine plant, the region had an average of 25 days with temperature above 30°C. Nevertheless, the presence of the ocean kept the temperature below 35°C, where only 2 days on average per growing season exceeded this threshold. This agrees with a study on the climatology of sea breeze in Uruguay by Manta *et al.* (2021), who describes the role of the Atlantic Ocean preventing the coastal region from temperatures above 33°C. The 35°C threshold indicates the onset of photosynthesis problems and increases the degradation rate of malic acid, anthocyanins, and aromatics, all desired compounds for wine production (Bergqvist *et al.*, 2001; Gaiotti *et al.*, 2018; Torregrosa *et al.*, 2017). In the context of a warm regional climate and/or global warming, maritime areas exposed to sea breezes emerge with relevance as a location providing suitable environmental conditions for grape ripening (Bonnardot *et al.*, 2005, 2011).

Nevertheless, precipitation, a highly variable climatic factor from one growing season to another (C.V. 42%), may be the primary determinant of vintages (differences between growing seasons). The occurrence of precipitation in coastal areas is one of the determining factors in the chemical composition of 'Tannat' and, in excess, can cause sanitary problems such as the occurrence of pathogens (Ferrer *et al.*, 2020). However, the temperature decreases during and after a rainfall event, which can be a positive factor since it may relieve the grapevine plant from high thermal pressure during warm days of the grape ripening period.

Topoclimate and spatial variability

We found that altitude in interaction with exposure to the Atlantic Ocean winds generated the most significant thermal differences at fine scale. Significant temperature variation for

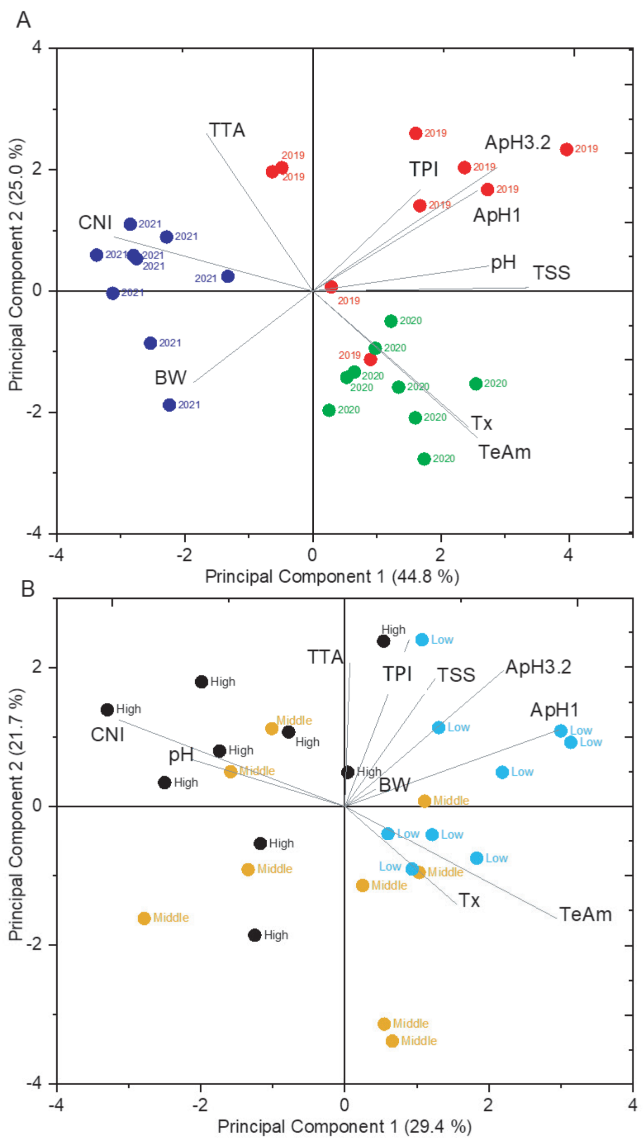

Figure 5:. Multivariate relationship between climate components: Cool Night index (CNI), average maximum temperature during ripening period (Tx), thermal amplitude during ripening period (TeAm); and 'Tannat' cultivar responses: total titratable acidity (TTA), pH, berry weight (Bw), total polyphenol index (TPI), total soluble solids (TSS) and anthocyanins at pH 1 (ApH1) and pH 3.2 (ApH3.2) for (A) absolute data colored by growing season and (B) standardized data by growing season and colored by altitude category: Low (sky blue; 70-94 m a.s.l.), Middle (brown; 94-117 m a.s.l.) and High (black; 118-140 m a.s.l.).

viticulture (responses observed on 'Tannat') occurred within short elevations (average difference in 50 m) due to the presence of the Atlantic Ocean. Previous work performed in South Africa (Bonnardot *et al.*, 2005) has described the effect of the ocean in interaction with the complex terrain and high elevation (hills of 450 m altitude and mountain ranges of 1000 to 1800 m altitude), but complex terrain at lower altitudes, such as the small hills of 140 m a.s.l., as in Uruguay, can affect the intensity of sea breeze penetration in vineyards, generating fine-scale thermal variability at time of daily maximum temperature. In the Southern hemisphere, the northern soil exposure along with the steepest slopes are described as the topographic conditions that provide the highest radiation and, consequently, the highest temperature (Jones and Hellman, 2003). However, this could not be observed in the work, which can be attributed to the overweight that altitude represents in the general thermal results, which masked the soil exposure effect.

The effect of altitude does not contribute to differentiate all climate indicators equally. For example, Tavg and HI, seasonal indicators used to describe global wine production sites (Tonietto and Carbonneau, 2004), showed no differences in general based on these topographic conditions. Therefore, using these two indicators alone would be insufficient to analyze the potential of a mesoscale vineyard as found in other studies such in the Loire Valley in France (Bonnefoy *et al.*, 2013).

When observing the TeAm, Tx, Tn, and CNI indicators, significant differences were generated by altitude. Plots at lower altitudes associated with concave slope profiles are those that reach the lowest minimum temperatures. Due to land breezes at night, cool air flows accumulate in low areas, thus lowering the minimum temperature and thus amplifying the diurnal thermal amplitude. The cool air in valley zones was reported by Bonnardot *et al.* (2012) in the complex terrain of the Stellenbosch wine district in South Africa, where a difference of 3.2°C on average during the ripening period was recorded between plots situated at a 440 m difference in altitude. Within a non-mountainous region like the one in Uruguay, this effect was also retrieved with 1.0 °C in a difference of 50 m (which is relatively greater).

The effect of altitude on maximum temperatures (Tx), as manifested in the warmest growing season of the three studied years, may indicate a thermal buffering effect of the ocean on extreme warm events. The topographic difference indicates that the plots at higher altitudes are more exposed to ocean winds, mainly to the local sea breeze, which causes the temperature afternoon to be considerably reduced in a couple of hours as reported in other countries (Bonnardot *et al.*, 2005) or wine regions of Uruguay (Fourment *et al.*, 2017). This reduction is observed under all topographic conditions in the study domain but can reach up to 4.7 °C on a hot day in the high zones, as shown in Fig. 4, and generates an environment more conducive to the preservation of acidity and the generation of fresh aromas in the grapes (Mira de Orduña, 2010).

Thus, during calm and radiative type of weather and depending on the synoptic scale atmospheric circulation, the combination of fresh air drainage at night and the arrival of the cool sea breeze in the afternoon results in two phenomena that condition temperature at vineyard level. Therefore, the knowledge of these dynamics gives the farmer information to manage his vineyard in the short, medium, and long term.

Spatial variability of 'Tannat' agronomic variables (yield, plant balance and oenological potential) and its relation to topography and mesoclimate

The mean response of 'Tannat' in the Atlantic region of Uruguay shows similar patterns to those reported in the traditional Uruguayan wine region in TSS (Ferrer *et al.*, 2014), yield and IR (Ferrer *et al.*, 2020). The differences lie in a higher prevalence of anthocyanins (+ 428 mg L^{-1} ApH1, Ferrer *et al.* 2014), TTA (+0.8 g L^{-1}, Ferrer *et al.*, 2014) and malic acid (+1.5 g L^{-1}, Ferrer *et al.*, 2020) and a lower record of tartaric acid (-1.5 g L^{-1}, Ferrer *et al.* 2020) and TPI (González-Neves *et al.*, 2010). Thus, the oceanic climate appears as a possible typifying agent of grape organoleptic quality, being an opportunity for wineries to explore new environmental conditions that allow them to differentiate their products.

Vitis vinifera L. is reported to be a temperature-sensitive plant, as temperature affects the metabolic composition of its grapes. The thermal effect on grapes shows that the 'Tannat' variety is no stranger to this as reported by Ferrer *et al.* (2020), Fourment *et al.* (2017) and Gustavo González-Neves *et al.* (2010). Based on the PCA analysis, when the values are grouped by year, it is found that the primary determinant of variability in the vineyard is the seasonal climate effect. This situation is already reported by Ferrer *et al.* (2020) and Fourment *et al.* (2017) for 'Tannat' in the traditional region of Uruguay. While, by standardizing the values by year, the importance of topography in interaction with the ocean, as a generator of variability at the vineyard scale, is revealed. Therefore, these site-specific changes can provide different products from the same variety on the same site, depending on the topographic conditions.

Under the oceanic climate, altitude is the topographic component that generates the most significant metabolites variability, followed by slope and soil exposure. The differences shown by slope and exposure is given by being directly linked to plots in altitude conditions that determined the result and not by the factor itself. This can be observed mainly in the soil exposure where the northern conditions are those that reach higher levels of TTA. However, the opposite is reported in the literature (Jones et al., 2003).

Regarding altitude as a differentiating factor in grape composition, its effect on total titratable acidity can be observed. Plots at higher altitudes maintain the highest acidity level due to a lower degradation of malic acid. This acid is closely related to the maximum temperature of the ripening period. Lakso *et al.* (1975) state that temperatures above 25°C accelerate cellular respiration using malic acid as an input, among others. Therefore, high cool topographic conditions exposed to the sea breeze during the afternoon may generate conditions more conducive to maintaining this acidity than low areas. Acidity is a factor valued by consumers as it generates "fresh" wines that are increasingly sought after by new generations (Mora *et al.*, 2021). Tartaric acid is not affected by temperature during the ripening period (Blancquaert *et al.*, 2018; Conde *et al.*, 2007). Therefore, it is correct not to expect changes attributed to topography.

Polyphenols, compounds desired in the final composition of the wine for their antioxidant activity and beneficial to human health (Xia *et al.*, 2010), are determined by altitude conditions. Among the polyphenols, anthocyanins are the compounds responsible for giving color to red wine, where the most significant accumulation of these compounds occurs around 30°C during the day and 15°C at night (Mori *et al.*, 2005; Spayd *et al.*, 2002). The plots at lower altitudes had the greatest thermal amplitude, with values close to the optimum reported in the literature. Mori *et al.* (2005) mention that above 30°C this compound begins to degrade. However, the general effect of the ocean (including the plots at low levels) prevented from to high temperatures, thus impacting on the anthocyanin balance. Therefore, the determining factor for these compounds is the minimum temperatures represented by the CNI, as mentioned by (Tonietto and Carbonneau, 2004), being a relevant indicator for the characterization of this region in terms of this metabolite.

The effect of topography on temperature and grape metabolite composition is reported in mountainous conditions, with a high level of variation in altitude conditions (more than 200 m) (Mansour *et al.*, 2022; Rienth *et al.*, 2020). Nevertheless, at the vineyard scale, with differences of 50 m in altitude and thanks to the ocean, significant differences can be found that can have an impact on the composition of the 'Tannat' grape. Therefore, knowing the topography and how it is associated with temperature is fundamental to understand the terroir system. In this way, geographic information systems (GIS) in interaction with climate data, can generate and apply knowledge of a promising region in the context of global warming, allowing the winegrower to make decisions more efficiently.

Conclusion

The mesoclimatic study at the vineyard scale described the interaction between altitude and ocean effect as the main factor generating thermal variability in the vineyards under study. Variability was observed in the indicators using maximum and minimum temperature values, with the most remarkable and most significant differences revealed during a warm growing season. The plots at lower altitudes were the coolest in the morning due to the cool air circulation at night, achieving a difference of up to 1°C within a short elevation difference. The plots at higher altitudes were the coolest during the day because of the vertical temperature gradient and exposition to cool oceanic winds. The combining of both circumstances allowed the low plots to present the most significant thermal amplitude, the most stable indicator throughout the three growing seasons under study.

The temperature at the vineyard scale impacted the 'Tannat' grapes' metabolic composition. In that sense, plots at higher altitudes retained up to 17% more malic acid than plots at lower altitudes, while plots at lower altitudes had up to 48% more ApH1 than plots at higher altitudes. Therefore, identifying the potential of each zone and their variability through growing seasons allows the generation of strategies at the plot level, such as differentiation of the type of wine (maximum terroir expression) or different vinification types depending on grape composition at harvest. In perspective, it is necessary to verify the results observed on grapes in future vinifications that can evaluate the effects of terroir on the wine.

Continuing with studies focused on understanding the behavior of the terroir, will prepare the wine sector for a highly competitive national and global market. Therefore, the importance of the Atlantic Ocean as an element that generates typicity in wines is gaining importance in the search for new land cultivation and new markets that demand fresh, aromatic wines with low alcohol content. In this way, oceanic terroirs become relevant in the search for cool sites that contribute to the vineyard in a process of adaptation to climate change and rising global temperatures.

Conflicts of interest

The authors declare that they do not have any conflicts of interest.

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