VARIABILITY OF TEMPRANILLO GRAPE QUALITY WITHIN THE RIBERA DEL DUERO DO (SPAIN) AND RELATIONSHIPS WITH CLIMATIC CHARACTERISTICS

María Concepción RAMOS[1], Gregory V. JONES[2], Jesús YUSTE[3]
[1]Department of Environment and Soil Science, University of Lleida-Agrotecnio, Avda. Rovira Roure 191, Lleida, Spain
[2]Deptartment of Environmental Science and Policy, Southern Oregon University, Ashland, Oregon, USA
[3]Instituto Tecnológico Agrario de Castilla y León, Valladolid, Spain
*Corresponding author: M.C. Ramos. E-mail:cramos@macs.udl.es

Paper presented at the XI International Terroir Congress, July 2016, McMinnville, Oregon (USA).

Introduction

Of all of the terroir components, climate is arguably one of the most important influencing vine growth and grape development. Accumulated temperatures above 10ºC (base temperature) are required for grapevine spring onset (Winkler 1974; Bonada et al. 2015), but they also affect grapevine development and growth throughout the growing season (Webb et al. 2012; Sadras and Moran 2013). While some days with temperatures above 30ºC may be beneficial during the ripening period, excessively high temperatures may induce plant stress and premature veraison and also reduce photosynthesis. Some winegrape physical and chemical characteristics, such as the accumulation of soluble solids and acid respiration, are in most cases more affected by warm weather/climate than by soils or other environmental factors. On the other hand, cooler conditions seem to favor color intensity, which varies significantly from year to year due to weather. In addition, available water during the growing season is a key factor for general suitability and optimum growth and productivity. The amount and distribution of precipitation may also differ from one place to another, and the spatial variation of the soil's capacity for water storage may play an important role on water availability. As such water availability determines the vine water status (Costantini et al. 2010), which can also influence the sensory characteristics of wines (Deloire et al. 2005).

Growing season temperatures define the suitability of each variety to be grown in a given area (Jones et al., 2010). However, at terroir scale, differences in temperature and precipitation occur and are linked to topographic effects, which give rise to differences in the phenology and the ripening processes of a given variety.

The Ribera del Duero DO of Spain covers approximately 115 km along the Duero River, with elevations that range between 720 to more than 1000 m a.s.l. The history of viticulture in the Ribera del Duero area is strongly tied to landscape, climate and culture. This area has been cultivated with vines for centuries, but expansion of the vineyards from higher elevation landscapes (higher than 900 m and steeper slopes), to new growing areas has resulted in the location of many vineyards at lower elevations and on more fertile soils (between 750 and 800 m). These changes require additional attention to vine management and the microclimatic aspects that affect the health and maturation of grapes. In the Duero region the dominant variety is Tempranillo and most vineyards are cultivated under rainfed conditions. For this reason, temporal climate variability may affect grape development and production. In this research we analyzed the variability of ripening characteristics of the Tempranillo variety in relation to climate conditions within the Ribera del Duero Designation of Origin (Spain).

Materials and methods

Study area

The Ribera del Duero DO covers approximately 115 km along the Duero River (Fig. 1). Geologically the Ribera del Duero is part of the large septentrional plateau formed by a large basement filled with Tertiary deposits, which consist of layers of loamy and sandy ochre and red clays, and mean and low terraces from the Duero River (Quaternary). The main soil types in the Ribera del Duero area are *Typic Xerofluvent* (in the alluvial deposits) and *Typic Xerochrept, Calcixerollic Xerochrept and Calcic Haploxeralf* (from the mid-level to the lower Duero terraces). Within the Ribera del Duero DO boundary, differences in elevation from about 700 m to more than 1000 m a.s.l. can be found. The climate is temperate with dry or temperate summers in the western portion of the DO and temperate with a dry summer season in the eastern portion of the DO. The mean annual temperature ranges between 10.2 and 12.0ºC, with mean maximum temperatures around 18.4 ºC and mean minimum temperatures ranging between 4.5 and 5.0ºC. The mean annual precipitation ranges between 413 and 519 mm with the main rainfall periods in April-May and October-November-December (Botey et al. 2013). The vine training system has evolved from the historically used free vegetation shape (bush vine or gobelet), into vines trained to a vertical trellis system, however while both systems are in use today gobelet training is still more common (Yuste 2008).

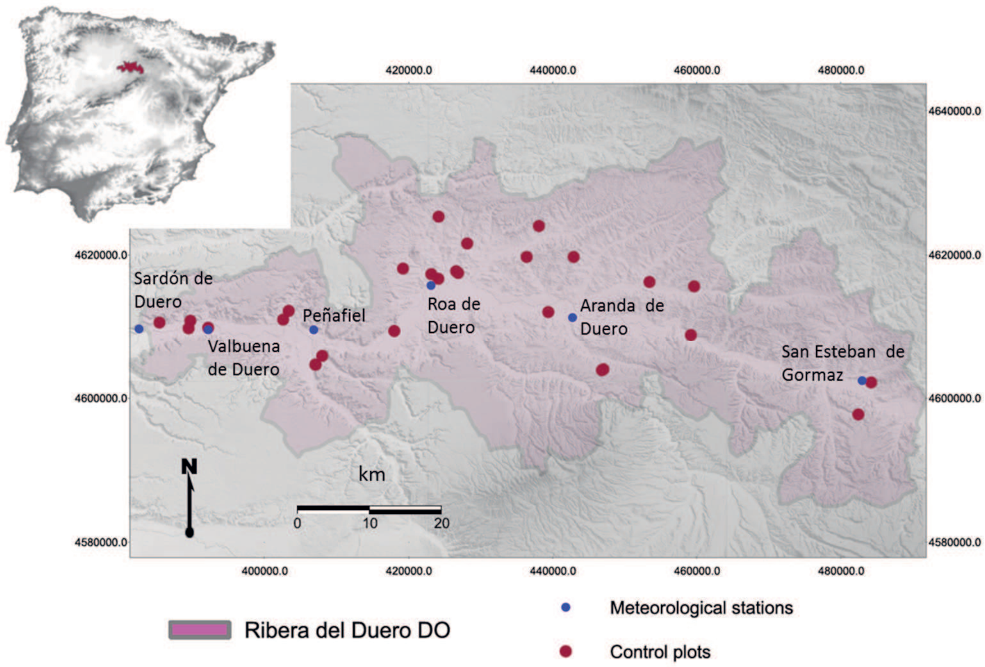

Figure 1: Location of the study area, meteorological stations and plots used in the analysis.

Data and analysis

Climate data: for this analysis, daily temperature and precipitation data for the period 1980-2012 from five meteorological stations belonging to the AEMET were used: Sardón de Duero (41.609ºN, 4.4336ºW; 723 m a.s.l.); Valbuena de Duero (41.6397ºN, 4.2925W; 733 m a.s.l.); Roa de Duero (41.6969ºN, 3.9278ºW; 811 m a.s.l.); Aranda de Duero (41.67139ºN, 3.6892W; 798 m a.s.l.); San Esteban de Gormaz (41.5753ºN, 3.20805ºW; 876 m a.s.l.) (Fig.1). A shorter series recorded during the last 10 years at Peñafiel (41.5964ºN, 4.11861ºW; 754 m a.s.l.) was also used. For each meteorological observatory the following indices were evaluated. The average values of maximum temperature (Tmax), minimum temperature (Tmin) and precipitation (P) for the growing season and for each phenological period [bud break-bloom (PBB), bloom-veraison (PBV) and veraison-harvest (PVH)] were averaged. The bioclimatic indices calculated were: the Winkler index (WI) and Huglin index (HI); Number of frost days (FD) and number of days with T > 30ºC (NDT30) as well as growing season evapotranspiration estimated according to Penman Monteith equation and using the crop coefficients proposed by Allen et al. (1998) (ETcGS) were evaluated for each year.

Grape quality data: parameters such as pH, titratable acidity (AcT) and malic acid (AcM), total (AntT) and extractable (AntE) anthocyanins, color intensity (CI), sugar content and berry weight recorded in twenty-six plots distributed throughout the Ribera del Duero area (Fig. 1) were evaluated for the period 2003 to 2013. This information was provided by the Consejo Regulador of Ribera del Duero DO. The data of each plot recorded during the time period were evaluated and related to climate variables. The relationships between grape and climate variables were evaluated using a factor analysis variable. The analysis was done by separating the plots into two groups for which differences in responses were previously observed. The first group corresponded to the plots located on the river terraces and the second group included the plots located on the hillslopes. The relationship between these parameters and climatic variables was carried out by regression analysis for each group of plots.

Results and discussion

Climatic characteristics of the study area

Significant differences in temperature during the growing season were observed within the area, in particular between locations at the east-west extremes of the region, with the lowest temperatures recorded in the eastern part of the Ribera del Duero. The highest differences were found between Sardón de Duero and San Esteban de Gormaz for Tmax and between Aranda de Duero and San Esteban de Gormaz for Tmin (Table 1). There were also differences in the number of extremes found in the area, with Roa de Duero having the highest warm and cold extremes. The WI index varied between 1191 and 1579 GDD, without significant differences between the locations, while significant differences were found for the HI index, which varied between 1973 and 2328 DD. The HI gives more weight to Tmax than does the WI and Tmax varied more across the region.

During the period analyzed, years with different climate characteristics were recorded. Differences greater than 2ºC in the maximum temperature during the growing season (TmaxGS) and up to 5ºC in the minimum temperature (TminGS) were observed between years, with similar differences in the number of extremes. Within the time period, 2007 and 2008 were the coolest and wettest years, in contrast with other years in the 2000s, which were the warmest (2000, 2003, 2005, 2006, 2010, 2011 and 2012) and driest years (2002, 2005, 2009 and 2012), in comparison with longer climate series examined by Ramos et al. (2015).

Table 1. Mean values and standard deviation (m ±std) of the climatic characteristics recorded at six weather stations distributed along the Ribera del Duero area during the period 2003-2013.

Station	TMaxGS (ºC)	TMinGS (ºC)	ndT0 (days)	ndT30 (days)	PGS (mm)	WI (GDD)	HI (DD)
SD	25.7±1.3	9.0±0.7	51.9±14.9	53.4±13.5	172.4±98.0	1579±210	2328±195
VD	25.7±1.0	9.3±0.9	83.8±12.9	50.6±14.1	158.7±70.2	1397±197	2180±188
P	24.9±1.2	9.3±0.7	83.4±12.7	41.5±11.7	144.6±49.8	1350±166	2104±181
AD	24.7±1.9	8.5±0.5	66.8±18.2	52.9±14.2	183.4±50.8	1271±228	2080±283
RD	24.9±1.0	8.9±2.1	91.5±23.9	43.5±13.1	191.7±57.9	1191±378	1973±482
SEG	24.7±1.2	9.1±1.4	87.6±16.2	42.5±11.2	229.3±112.0	1279±164	2055±194

(SD: Sardón de Duero; VD: Valvuena de Duero; P: Peñafiel; RD: Roa de Duero; AD: Aranda de Duero; SEG: San Esteban de Gormaz) (TmaxGS (maximum temperature during the growing period), TminGS (minimum temperature during the growing period), ndT0 (number of frost days), ndT30 (number of days > 30°C), PGS (precipitation during the growing period); PBB (precipitation during the budburst to bloom period), PBV (precipitation during the bloom to veraison period), PVH (precipitation during the veraison to harvest period), WI (Winkler index), HI (Huglin index).

Grape quality variability and climate relationships

During the period analyzed (2003-2013), grape quality parameters varied from year to year and among plots in each year. At maturity the pH ranged between 3.18 and 3.91, with the lowest values recorded in most plots during the years 2004, 2007, 2008 and 2013. Titratable acidity in those years had the highest values, while the lowest were recorded in years 2005, 2006, 2009, 2011 and 2012. Malic acid concentration varied between 1.37 and 5.45 gL^{-1}. The lowest values were also recorded in 2005, 2006, 2011 and 2012, while the highest values recorded in 2004, 2007, 2008 and 2010. The sugar content (ºBaumé values) ranged between 10.6 and 15.0º, with the highest values recorded in 2007, 2008 and 2013. Berry weight did not show significant differences between plots. The results related to anthocyanins (total and extractable anthocyanins and color index) exhibited differences between the same groups of years. The highest values were recorded in wetter and cooler years (2007, 2008, 2010) while the lowest values corresponded to the driest and warmest years (2003, 2005, 2006, 2009).

The factor analysis confirmed the relationships between some climate and grape ripening variables (Fig. 2). The results presented differences between the plots located on the river terraces and those located on the hillslopes. For the plots located on the terraces the CI values exhibited positive correlation with water availability and negative correlation with the extreme temperature variables. However, anthocyanins did not exhibit any correlation with temperature variables. Acidity parameters (AcT and AcM) and berry weight showed positive correlation with water availability, but no correlation was found with most temperature variables. Sugar content (ºBaumé) correlated positively with the HI and WI indexes and negatively with water availability during the bud break-bloom period.

In the plots located on the hillslopes, the acidity parameters (AcT and AcM) and CI were correlated with the available water during the bud break-bloom period, while sugar content (ºBaumé values) was inversely correlated with this parameter. Temperature variables (Tmax, WI, HI and the number of days with T > 30ºC) correlated positively with sugar content (ºBaumé values) and negatively with CI and acidity. The anthocyanins did not exhibit significant correlations with any of the climate parameters. However, CI was strongly related to the differences between day and night temperatures (DTR).

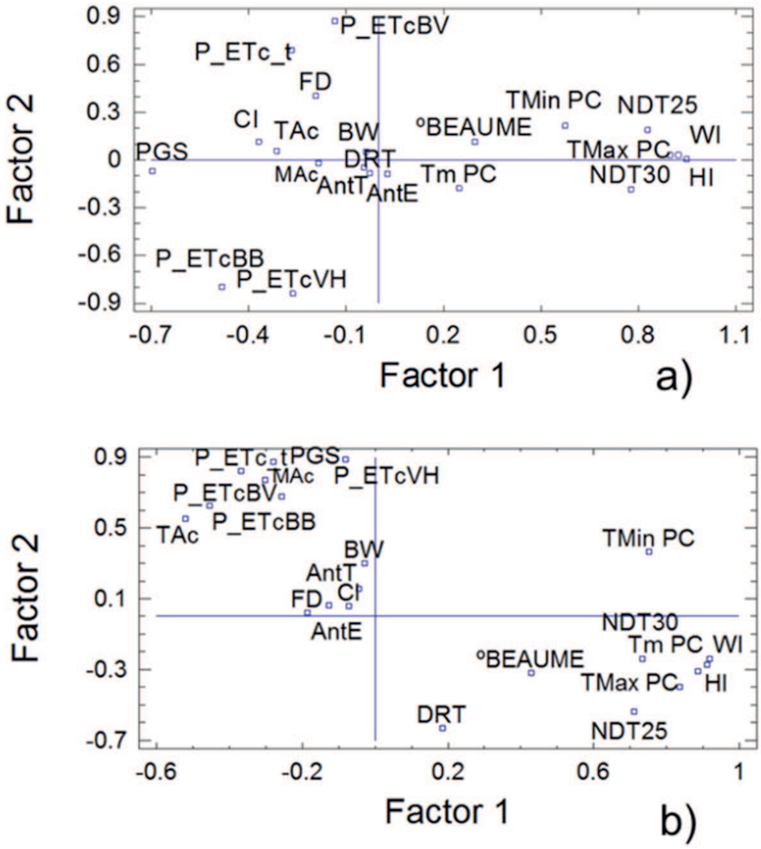

Figure 2. Relationship between climate and grape ripening variables:
a) plots on the river terraces; b) plots on the hillslopes.

The average response of each group of plots to changes in each parameter is shown in Table 2. Higher impacts were observed in the plots located on the hillslopes than in the plots located on river terraces. According to the results observed during these years, CI is likely to decrease between 1.00 and 0.52 absorbance units per 100 mm of water deficit, respectively in the two groups of plots. Berry weights, for the same change in water availability, is commonly five times higher on the hillslopes compared to the terrace locations. Both AcT and AcM showed changes with temperature. However, the effect on the fruit ripening characteristics was higher when located on the river terraces for some parameters. CI was observed to change between -0.73 and -0.27 units for 1 ºC change in temperature, respectively in both situations; AcT changes between -0.453 and -0.287 gL^{-1}; and AcM change between -0.234 and -0.252 gL^{-1} for 1ºC change in temperature. Berry weights and sugar content (ºBaumé) showed similar relationships to temperature in all areas.

Differences in the ripening variables among years and among plots within the Ribera del Duero DO were observed. There was less variability for each plot in the wet years than in the dry years for all acidity parameters (AcT, AcM and pH) and for berry weights. However, the differences were opposite for sugar content (ºBaumé values) and anthocyanins. Regarding the variability within the DO, in most years, pH values were greater in the western portion of the DO than in the central or eastern portions of the region. Similarly, sugar content and anthocyanins were also greater in the western than in the eastern portion of the DO.

Table 2: Response of each grape quality parameter to changes in climatic parameters for plots located on the river terraces and on the hillslopes

	Plots on the river terraces				Plots on the hillslopes				
	100 mm deficit BV	1ºC ΔTmaxGS	100 GDD ΔWI	100 DD ΔHI	100 mm deficit BB	1ºC ΔTmaxGS	100 GDD ΔWI	100 DD ΔHI	1ºC ΔDTR
pH	-0.093	0.038	0.02	0.02	-0.083	0.047	0.03	0.03	
AcT (gL^{-1})	0.34	-0.453	-0.20	-0.24	0.959	-0.287	-0.36	-0.296	
AcM (gL^{-1})	0.17	-0.234	-0.06	0.10	0.556	-0.252	-0.20	-0.167	
ºB (º)	-0.11	0.338	0.19	0.2	-0.407	0.29	0.18	0.157	
100BW (g)	2.1	-2.90	-2.38	-1.23	10.23	-3.22	-2.04	-1.64	
CI (Abs.units)	0.52	-0.753	-0.51	-0.49	1.03	-0.269	-0.35	-0.21	0.62

(100 mm deficit BB: water deficits of 100 mm during the bud break-bloom period; 100 mm deficit BV: water deficits of 100 mm during the bloom-veraison period; 1ºC ΔTmaxGS: increase of 1ºC on TMaxG growing season; 1ºC ΔDRT: increase of 1ºC on daily range temperature; 100GDDΔWI: increase of 100 growing degree-days on the Winkler index; 100DDΔHI: increase of 100 degree-days on the Huglin index).

It is known that grapes grown in warmer climates tend to have lower acidity at maturity than grapes grown in cooler climates. On the other hand, the warmer the climate the higher the sugar content of the grapes, so that the alcohol degree will be higher. In addition, water deficits could affect berry weights and anthocyanin accumulation in grapes. The results observed in this study partially agree with results indicated by other researchers. In this study, berry weights were related to water availability during the bud break-bloom period, while the total and extractable anthocyanins did not show any relationships with climate parameters. In this respect, Downey et al. (2006) indicate that water deficits are related to berry size reduction and changes in the ratio of skin/berry weight, which would affect phenolic concentrations. Other authors have shown that water deficits increased anthocyanins and procianidin concentrations in berries (Nadal and Arola 1995; Ojeda et al. 2002; Roby and Matthews 2004; Castellarin et al. 2007), while other authors did not find significant effects of water deficits on the accumulation of these compounds (Kennedy et al. 2002).

Conclusions

The results confirmed the spatial and temporal variability on grape ripening within the Ribera del Duero DO influenced by the climatic conditions. The acidity levels, total soluble solids, berry weights and color intensity were the most affected variables in each area although the relationships change throughout the DO. The results show the role of the spatial variability in warmer temperatures and higher water deficits (bud break to bloom and bloom to veraison periods) in the grape quality parameters, which ultimately affect fruit production and wine quality.

Acknowledgments: authors thank the Consejo Regulador of Ribera del Duero DO by the information related to all the plots and the AEMET by the climatic information used in this study.

LITERATURE CITED

Allen, R.G., L.S. Pereira, D. Raes and M. Smith. 1998. Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements. Irrigation and Drainage Paper 56. FAO, Rome

Bonada, M., D.W. Jeffery, P.R. Petrie, M.A. Moran and V.O. Sadras. 2015. Impact of elevated temperature and water deficit on the chemical and sensory profiles of Barossa Shiraz grapes and wines. Australian Journal of Grape and Wine Research 21: 240–253.

Botey, R., J.A. Guijarro and A. Jiménez. 2013. Agencia Estatal de Meteorología. Valores normales de precipitación mensual 1981-2010. Catálogo de Publicaciones de la Administración General del Estado. http://publicacionesoficiales.boe.es/

Castellarin, S.D., M.A. Matthews, G. Di Gaspero and G.A. Gambetta. 2007. Water deficits accelerate ripening and induce changes in gene expression regulating flavonoid biosynthesis in grape berries. Planta 227(1):101-12.

Downey, M.O. N.K. Dokoozlian and M.P. Krstic. 2006. Cultural practice and environmental impacts on the flavonoid composition of grapes and wine: A review of recent research. American Journal of Enology and Viticulture 57: 257-268.

Jones, G. V., A.A. Duff, A. Hall and J.W. Myers. 2010. Spatial analysis of climate in winegrape growing regions in the western United States. American Journal of Enology and Viticulture, 61(3): 313–326.

Kennedy, J.A., M.A. Matthew and A.L. Waterhouse. 2002. Effect of maturity and vine water status on grape skin and wine flavonoids. Am. J. Enol. Vitic. 53: 268-274.

Nadal, M. and L. Arola. 1995. Effects of limited irrigation on the composition of must and wine of Cabernet Sauvignon under semiarid conditions. Vitis, 34: 151-154.

Ojeda, H., C. Andary, E. Kraeva, A. Carbonneau and A. Deloire. 2002. Influence of pre-and postveraison water deficit on synthesis and concentration of skin phenolic compounds during berry growth of Vitis vinifera cv. Shiraz. Am. J. Enol. Vitic. 53: 261-267.

Ramos, M.C., G.V. Jones and J.Yuste. 2015. Spatial and temporal variability of cv. Tempranillo phenology and grape quality within the Ribera del Duero DO (Spain) and relationships with climate. Inter. J. Biometeorol. 59(12): 1849-1860.

Roby, G. and M.A. Matthews. 2004. Relative proportions of seed, skin and flesh in ripe berries from Cabernet Sauvignon grapevines grown in a vineyard either well irrigated or under water deficit. Aust. J. Grape Wine Res. 10: 74-82.

Sadras, V.O. and M.A. Moran. 2013. Nonlinear effects of elevated temperature on grapevine phenology. Agricultural and Forest Meteorology 173: 107–115.

Webb, L.B., P.H. Whetton, J. Bhend, R. Darbyshire, P.R. Briggs and E.W.R. Barlow. 2012. Earlier wine-grape ripening driven by climatic warming and drying and management practices. Nature Climate Change 2: 259–264.

Winkler, A.J., J.A.Cook, W.M. Kliere and L.A. Lider. 1974. General Viticulture (2nd ed.). University of California Press.

Yuste J. 2008. Proceedings of II International Congress Ribera del Duero: pp. 25 -33.

Abstract

The aim of this research was to analyze the variability of ripening characteristics of the Tempranillo variety in relation to climate conditions within the Ribera del Duero Designation of Origin (Spain). Grape characteristics measured at ripening [berry weight, total soluble solids, pH, acidity (titratable and malic), anthocyanins (total and extractable) and color index (CI)], recorded from 2003 to 2013 in twenty-six plots distributed throughout the Ribera del Duero region were related to climate conditions [temperature, precipitation and different bioclimatic indexes (WI and HI)]. Differences in these parameters were found between years with different climatic conditions (dry and wet years and warm and cool conditions) as well as between the plots located on the terraces and on the hillslopes. The variability for all acidity parameters and for berry weight between plots was smaller in the wet years than in the dry years. However, the differences were opposite for sugar content and anthocyanins during the dry years. Sugar content, pH values and anthocyanins were consistently greater in the western portion of the DO region than in the central or in the eastern portion, in agreement with the differences in temperature observed between both area's extremes. In the plots located in the terraces, the CI values exhibited positive correlations with water availability and negative correlations with extreme temperatures. Acidity parameters and berry weight showed positive correlation with water availability in the earlier stages (bud break-bloom), but no correlation was found with most temperature variables. Sugar content correlated positively with the HI and WI indexes (heat accumulation) and negatively with water availability during the bud break-bloom period. In the plots located on the hillslopes, the acidity parameters and the CI were correlated with the available water during the bud break-bloom period, while sugar content was inversely correlated with this parameter. Temperature variables and indexes – maximum temperature (Tmax), Winkler Index (WI), Huglin Index (HI) and the number of days with Temperature > 30ºC (NdT30) – correlated positively with sugar content and negatively with the CI and acidity levels. However, anthocyanins did not exhibit any significant correlations with climate parameters in any location within the study area.

Keywords: viticulture, enology, terroir, acidity, anthocyanins, berry weight, hillslopes, precipitation, river terraces, temperature