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

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Abstract
The aim of this research was to evaluate the variability of ripening characteristics of the Tempranillo variety within the Ribera del Duero Designation of Origin (Spain) and it relationships with soil characteristics. This area covers approximately 115 km along the Duero River with elevations from about 700 m to more than 1300 m a.s.l. The climate is temperate with dry or temperate summers in the western portion of the DO area and temperate with a dry summer season in the eastern portion of the DO area. The mean annual temperature ranges between 10.2 and 12.0°C, with mean maximum temperatures around 18.4°C and mean minimum temperatures ranging between 4.5 and 5.0°C. The mean annual precipitation ranges between 413 and 519 mm with the main rainfall periods in April-May and October-November-December. The main soil types in the Ribera del Duero area are *Calcaric Cambisol*, *Calcic Luvisol*, *Calcaric Fluvisol*, *Lithic Leptosol* and *Calcaric Regosol*. The analysis includes the information recorded during the period 2003-2013 in 26 plots throughout the Ribera del Duero DO for parameters such as berry weight (g), sugar content (°Baumé), titratable acidity (AcT) and malic (AcM) acid (gL^{-1}), total (AntT) and extractable (AntE) anthocyanins (mgL^{-1}) and the color index (CI) (in absorbance units). Despite the high variability driven by year to year in climate characteristics, it was possible to indentify the soil and plot characteristics that affect ripening characteristics within the Ribera del Duero. The highest acidity values in grapes were recorded in soils with slightly higher clay and organic matter contents. These plots were located above the river terraces. Additionally, the highest anthocyanins concentrations were also found in plots with the highest organic matter content and with slightly lower soil pH. The effect was greater in the wet years and in those with intermediate characteristics. The highest anthocyanins and color index values were found in the plots located at lower elevations on the river terraces, while the lower values were recorded in vineyards located on the hillslopes at higher elevation. The results were highly dependent on wet or dry conditions. In dry years high clay and organic matter content gave rise to greater anthocyanin concentrations while in wet years the relationships were the opposite.

Keywords: viticulture, enology, terroir, acidity, berry weight, anthocyanins, clay content, elevation, hillslopes, organic matter content, river terraces

1 INTRODUCTION

Soil characteristics together with climate and topography influence grapevine growth and fruit quality and constitute one of the elements of the "terroir effect" (Reynard et al. 2011; van Leeuwen et al. 2004). Within a specific climate zone, soil is the most important environmental factor affecting vine development and fruit or wine quality (Sotés and Gomez-Miguel 2003). Grape-growing is not very demanding in terms of soil chemistry and conditions, but there are numerous important factors for optimum grape development. Previous studies have demonstrated the relationship between some soil properties and grape and wine characteristics. In particular, soil physical properties essentially govern the potential volume of soil that can be explored by roots. Soil particle distribution and the associated pores between them affects, both directly and indirectly, many physical, chemical and biological aspects of the soil, including soil strength, water and nutrient movement, soil aeration, soil hydraulic properties and drainage conditions (Seguin 1986; Costantini et al. 2006). Relatively deep, well-drained soils are required for limiting waterlogged vine roots ultimately forcing deep root penetration to find water during times of seasonal drought stress. Poor soils usually promote smaller yields of grapes with more concentrated flavors, while fertile soils lead to overgrown vines, which has an important impact on berry quality (optimum berry quality is seldom achieved if vines are excessively vigorous). In addition, soil properties such as pH and organic content have been highlighted among those with particularly strong influences (Gómez-Míguez et al. 2007).

The Ribera del Duero DO is a viticulture area with long tradition. This area has been cultivated with vines since the Roman period, with significant fluctuations in production throughout the centuries. The history of viticulture in the Ribera del Duero is strongly tied to landscape, climate and culture. The present DO Ribera del Duero was established in 1982 and since then the surface area planted has increased from 6,460 ha of vineyards officially registered in 1985 to approximately 21,700 ha in 2013 (Consejo Regulador DO Ribera del Duero, 2013). At the same time the Duero has become world renowned for being one of the highest quality red wine producing regions. In this area, the dominant variety is Tempranillo, which represents about 90% of total surface cultivated with vines and its proportion in the red wines produced in the DO are required to be 85% or more (www.riberadelduero.es, Regulation of DO). Furthermore, the Ribera del Duero DO is listed as the world's grape growing region with largest contribution and importance of Tempranillo in its wines (Anderson, 2010). In this research we analyzed the variability of ripening characteristics of the Tempranillo variety in relation to soil and plot characteristics within the Ribera del Duero Designation of Origin (Spain).

2 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 average elevation to lower terraces from the Duero River (Quaternary). Within the Ribera de Duero 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).

Data and analysis

Soil characteristics: In this study, soil characteristics from 26 plots spatially distributed throughout the Ribera del Duero DO area (Fig. 1) were selected. Most plots were located along the Duero river terraces and in the central part of the area, where soils are ochre and red sands and clays from the Tertiary era. All plots were located in areas suitable for vine cultivation according to the classification done by Gómez-Miguel (2003). Soil characteristics of the study plots were obtained from the Castilla y León Soil map (IRNASA_400k) and completed with soil properties for each study plot for which grape quality data were obtained. Soil samples were taken from the surface (0-20 cm) in each plot at different points to prepare a composite sample. Three composite samples were analyzed for each plot. Each sample was homogenized, air dried and sieved through a 2 mm mesh. Soil particle distribution, organic matter content, pH, electrical conductivity (1:5 water extract), structure and permeability of the soil surface of each plot were considered in this study. Measures were performed following the methods proposed by the Soil Survey Laboratory Staff (1996). In addition, the coarse element fraction was also evaluated.

Grape quality data: Vine information was provided by the Consejo Regulador of the Ribera del Duero DO. All plots analyzed were planted with the Tempranillo variety, and covered different geographical landscapes, vine age and training systems used, but are overall very representative of the vineyards in the region. The vineyards included in this study are representative of the Tempranillo variety in all these areas. Parameters such as pH, tartaric (AcT) and malic (AM) acids, total (AntT) and extractable (AntE) anthocyanins, color intensity (CI), sugar content and berry weights recorded in twenty-six plots distributed throughout the Ribera del Duero (Figure 1) were evaluated for the period 2003 to 2013. This information was provided by the Consejo Regulador de la Ribera del Duero. The data of each plot recorded along the period were evaluated and related to soil and plot characteristics.

Variability analysis: The spatial variability in grape quality parameters and their relationships to soil properties were analyzed using principal component analysis. Due to the high variability observed in the grape quality values recorded over the different years of the period studied, the years analyzed were classified into three groups according to water availability in each phenological stage in each year. The corresponding dates of each phenological stage were evaluated in previous research (Ramos et al., 2015). The years were classified into three groups: wet years, in which water restriction was small; dry years with high water deficits in all phenological stages; and years related to intermediate conditions. The years included in the three groups were respectively: 2007-2008-2010; 2005-2009-2011-2012-2013; and 2003-2004-2006. The establishment of these groups of years was done in previous research conducted in the region (Ramos et al. 2014). The plots were then classified in a cluster analysis based on the year classification (wet, dry or intermediate) and according to two groups of grape quality parameters: acidity and anthocyanins. The average values of soil and grape characteristics for the plots included in each cluster were evaluated.

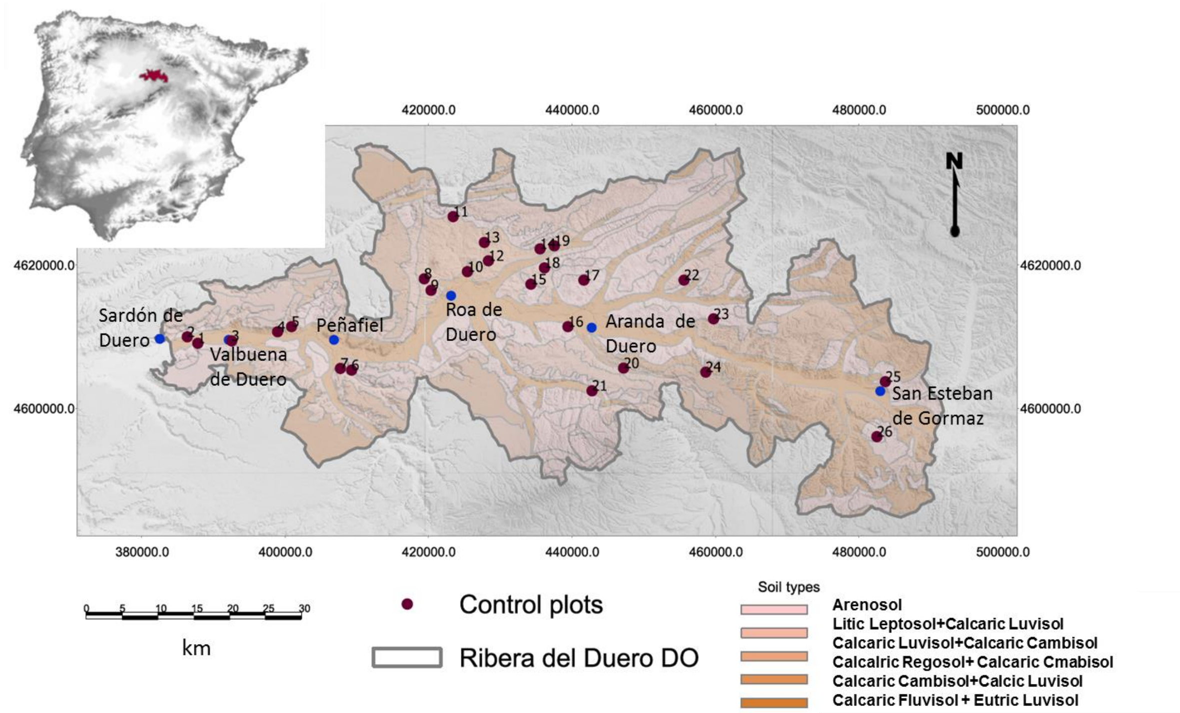

Figure 1: Location of the study area, main soil types and location of the control plots.

3 RESULTS AND DISCUSSION

Plot and soil characteristics

The plots were distributed throughout the DO, covering elevations between 749 and 985 m a.s.l., with moderate slopes that average roughly 5 percent, and that have distances to the Duero River between 259 and 11,343 m. About 40% of plots have the gobelet training system and the rest have vertical trellis training system and the majority are not irrigated. The age of the vines ranged between 10 and 70 years. The main soil types found in the studied plots were *Calcaric Cambisol, Calcic Luvisol, Calcaric Fluvisol, Cambic arenosol, Lithic Leptosol* and *Calcaric Regosol* (see Figure 1), with textures that ranged between sandy and sandy loam to clay loam. Clay contents ranged between 4.7 and 47.0%; silt content ranged between 2.5 and 69.0% and sand content ranged between 10.0 and 77.9%, with soil permeabilities between very low (< 0.15 cm/h) and moderate (2-6 cm/h). The pH values ranged between 8.0 and 8.8. The organic matter content varied between very low values (< 0.5%) and values higher than 4.0%, and the electrical conductivity had values between 0.09 and 0.25 dSm^{-1}.

The results of the PCA allowed us to confirm the relationship between the variables included in the analysis and the complex relationships between the soil and grape quality variables. Five components were retained in the PCA. The first component was related to color and anthocyanins, although pH and soluble solids were also correlated. It represented between 28 and 32% of the total variance. The second component was related to soil texture and represented between 18 and 22% of variance. The third component was related to grape acidity (titratable acidity and malic acid) and represented between 12 and 15% of variance. The fourth component was related to soil organic matter and pH, and represented 11% of variance. Finally, the fifth component was related to the berry weights. The results for the three groups of years in the PCA analysis are shown in Figure 2. The lack of correlation between grape and soil variables was confirmed in all groups of years analyzed and in addition the distribution of the variables was different for the three groups of years.

In order to evaluate the spatial variability within the area, the analysis focused on using two main groups related to acidity and anthocyanins separately and the 26 plots were classified for each of the defined groups of years. The plots were classified into three groups according to anthocyanins and into two groups according to acidity. The classification is shown in Fig. 3. The average values for the plots assigned to each cluster for the three groups of years are shown in Tables 1 and 2. The plots were classified in a similar manner for the three types of years (80%) and the rest were included in the same cluster in two of the three groups of years analyzed.

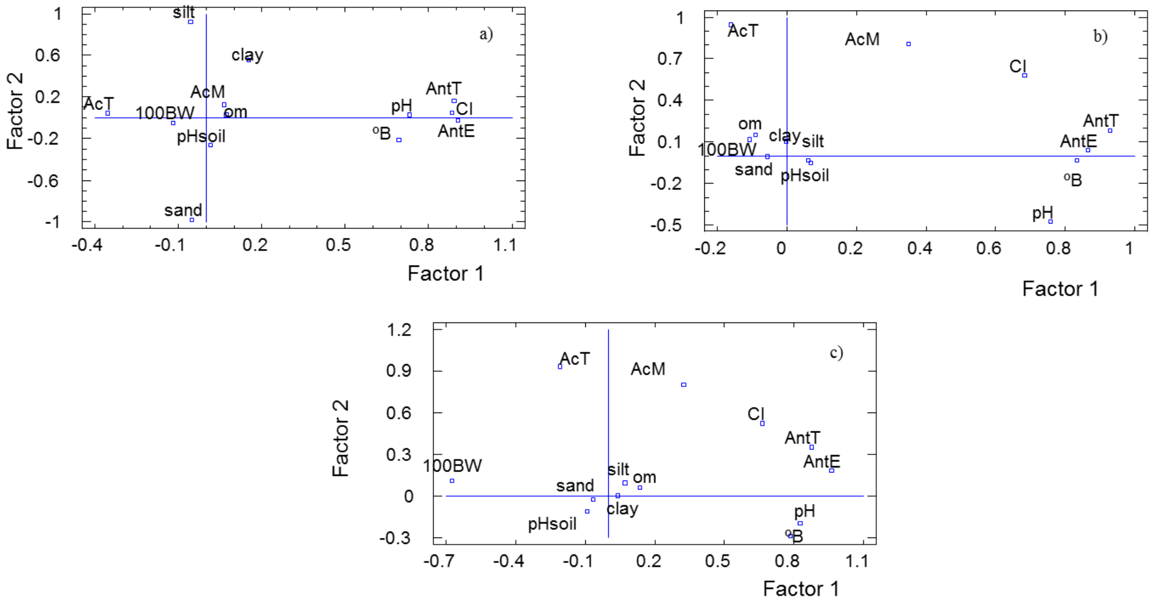

Figure 2. Relationship between soil and grape composition variables for the three groups of years with different water availability a) wet; b) dry and c) intermediate conditions

Regarding anthocyanin concentrations and color, significant differences were found between the wet and the dry years. Total anthocyanin values ranged between 507 and 661 mg/l in the dry years and between 540 and 723 mg/l in the wet years. However, the highest values were found in the years with intermediate characteristics (ranging between 666 and 758 mg/l). Similarly, the highest extractable anthocyanin concentrations were found in the intermediate year group, with values ranging between 253 and 311 mg/l, while in the wet years values ranged from 234 to 277 mg/l. However, in the dry years the differences among the groups of plots established were greater (from 227 to 290 mg/l). Similar behavior was found for the color intensity values. Furthermore, it was also observed that the lowest anthocyanin concentrations were recorded in the plots with the lowest grape pH. The highest values of anthocyanin concentrations were observed in plots located at lower elevations and at shorter distances to the river (distances up to 2,500 m and elevation up to 800 m a.s.l.).

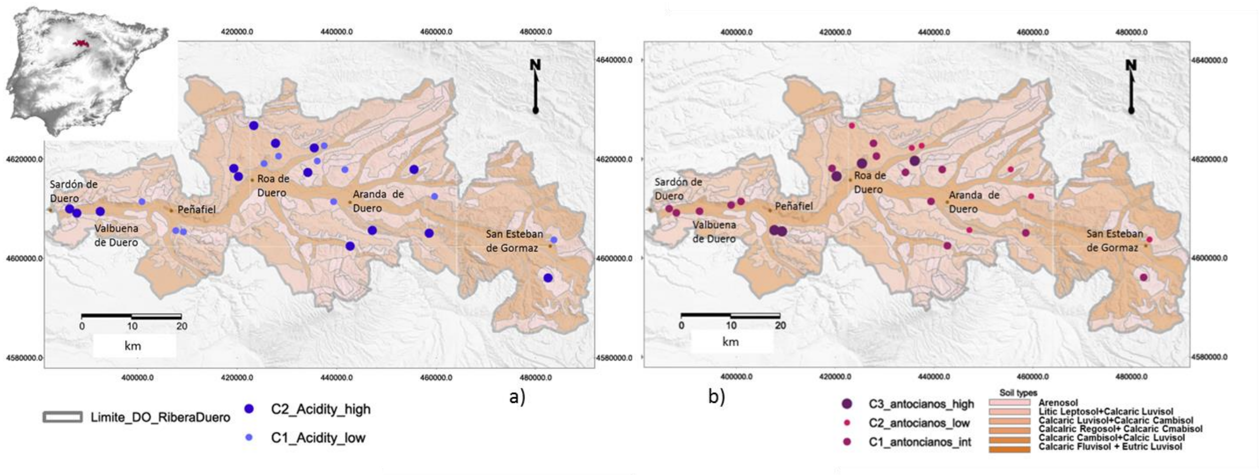

Figure 3. Spatial distribution of plots included in each cluster classified based on a) acidity properties (low and high); b) anthocyanin concentrations and color properties (low, intermediate, and high).

The soluble solids concentrations were greater in the dry (between 12.8 and 13.6 °Baumé) and in the intermediate years (between 12.9 and 13.5 °Baumé) compared to the wet years (11.9 and 12.3 °Baumé). Higher moisture conditions have associated greater water availability for the vines, which tend to show greater vegetative development and production. This fact typically involves a higher production of sugars, but its concentration in the grape can be lower.

Table 1. Mean value of each variable in each group of plots for wet (w_i), dry (d_i) and intermediate (i_i) years related to anthocyanins and color (h=high, l=low, i=intermediate).

Cluster	w_h	w_l	w_i	d_h	d_l	i_i	i_h	i_l	i_i
Grape pH	3.57 a	3.36 a	3.47 a	3.68 a	3.50 b	3.71ac	3.71 a	3.52 b	3.57 b
°B	12.3 a	11.9 a	12.3 a	13.6 a	12.8 b	13.2 c	13.3 a	12.9 a	13.1 a
AntT (mg/l)	723 a	540 b	682 c	661 c	507 b	616 c	758 c	666 b	730 c
AntE (mg/l)	273 b	234 a	277 b	290 b	221 a	275 b	311 b	253 a	297 b
CI	8.7 b	6.9 b	8.6 b	8.9 b	6.3 a	7.2 b	6.7 ab	5.9 a	6.8 ab
100 BW (g)	173 a	204 b	194 b	166 a	184 b	164 a	176 a	187 b	199 b
Clay (%)	21.5	21.5	18.3	25.2	31.8	21.0	21.3	21.5.9	18.5
Silt (%)	35.7	36.7	37.2	33.8	31.7	36.5	33.5	35.9	35.1
Sand (%)	43.5	40.6	39.1	41.1	36.5	42.4	45.2	37.32	46.8
o.m. (%)	2.04	2.2	1.7	2.1	2.5	1.8	2.03	2.2	1.7
Elev. a.s.l.(m)	789 a	831 b	862 b	803 a	818 a	855 b	787 a	833 a	875 b
Dist. River (m)	2530 a	5835 b	5308 b	2472 a	4149 a	6291b	2542 a	5826 b	5114 b

* different letters mean significant differences at 95% level.

For the classification based on acidity characteristics, the differences between the two established groups for titratable acidity and malic acid were greater in the wet (AcT between 5.6 and 7.0 g/l and AcM between 3.9 and 4.5 g/l) than in the dry (AcT between 4.9 to 5.5 g/l and AcM 2.7 and 2.8 g/l) or intermediate years (AcT between 5.0 to 5.7 g/l and AcM between 2.7 and 2.8 g/l). No significant differences among groups were found in the average pH. The highest acidity values were found in the plots located near the river (distances up to 2,500 m and elevation up to 800 m a.s.l.), whose soils may have greater soil moisture conditions. The results agree with the fact that greater water availability to the vine results in higher acid concentrations in the grape (Sebastian et al. 2015; Luciano et al. 2013) while water deficits reduce acidity as berries contain less malic acid (van Leeuwen et al. 2004).

Table 2 Mean value of each variable in each group of plots for wet (w_i), dry (d_i) and intermediate (i_i) years related to acidity (l=low, h=high).

Cluster	w_l	w_h	d_1	d_h	i_1	i_h
Grape pH	3.6 a	3.4	3.7 a	3.7 b	3.7 a	3.62 b
AcT (mg/l)	5.6 a	7.0 b	5.9 a	5.5 b	5.1 a	5.7 b
AcM (mg/l)	3.9 a	4.5 b	2.7 a	3.3 a	3.3 a	3.8 a
100 BW (g)	183 a	185 b	171 a	168 a	183 a	186 b
Clay (%)	21.2	27.7	22.3	28.1	21.3	28.2
Silt (%)	37.5	31.7	34.7	33.2	38.4	30.9
Sand (%)	41.2	40.6	42.9	38.7	40.3	40.9
o.m. (%)	2.2	2.2	2.1	2.1	2.0	2.2
Elev a.s.l. (m)	822 a	823 b	820 a	825 a	822 a	823 a
Dist. River (m)	3295 a	4647 b	3600 a	4654 b	3299 a	4647 b

* different letters mean significant differences at 95% level

The berry weights (100 berries) varied between 164 and 204 g, with higher values in the wet and intermediate years compared to the dry years. This result was consistent with the fact that berry size is dependent on vine water status. Berry weights, which did not exhibit correlations with other parameters in the PCA analysis, was slightly higher in the plots with lower grape pH and in those where the lowest anthocyanin concentrations and lower color intensity was observed. Among soil characteristics, clay, sand and organic matter contents showed differences among the groups of plots, although they were not statistically significant. Despite the lack of relationships between grape composition variables and soil characteristics observed in the PCA, some relationships were found when the plots were separated in the clusters (Tables 1 and 2). The highest acidity values in grapes were recorded in soils with slightly higher clay contents. The amount of acid and the acid concentration of the grape are usually favored by the vigor of the vine and its foliar development, which tend to be higher in soils with a higher clay and organic matter content. These plots were located on the hillsides above the river terraces. Additionally, the highest anthocyanin concentrations and color intensities were found in plots with slightly higher sand content. These plots also had the lower berry weights. Nevertheless, the differences in soil characteristics among groups were not significant. Regarding the soluble solids, there were only differences between clusters in the dry years, with higher values in the soils with higher sand content.

4 CONCLUSIONS

The results confirmed that despite the variability of grape quality parameters associated with climatic conditions, soil type contributed to spatial variations in grape quality, in particular acidity, anthocyanins and color. The soil characteristics that showed higher effects were clay, sand and organic matter contents. The highest acidity values in grapes were recorded in soils with slightly higher clay and organic matter contents, while the highest anthocyanin concentrations and color intensities were found in plots with slightly higher sand content. Differences in berry weights and in total soluble solids were also associated to the soil sand content.

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