Received: 27 April 2021 | Accepted: 2 July 2021 | Published: 26 July 2021
DOI:10.20870/oeno-one.2021.55.3.4695

Interannual and spatial variability of grape composition in the Rioja DOCa show better resilience of cv. Graciano than cv. Tempranillo under a warming scenario

María Concepción Ramos[1*] and Fernando Martínez de Toda[2]

[1] Department of Environment and Soil Sciences, University of Lleida-Agrotecnio CERCA Center, Lleida (Spain). Av Rovira Roure 191, E-25198 Lleida, Spain.
[2] ICVV (Universidad de La Rioja, CSIC, Gobierno de La Rioja), c/ Madre de Dios, 51, 26006 Logroño, Spain.

**corresponding author*: cramos@macs.udl.es

Associate editor: João Santos

ABSTRACT

Weather conditions affect vine development and grape composition, although the response may be different depending on the variety and altitude. Under scenarios of climate change, the knowledge of the relationships between grape composition and climate is therefore important to know the suitability of a given cultivar. In this research, the variability of the grape composition of two red varieties with different phenological timings (*Vitis vinifera* L. cv. Tempranillo and Graciano) cultivated in Rioja DOCa (Spain) and the climatic variables that have a higher effect on the response of each of them were analysed. Grape composition of both cultivars at technical maturity (considered when a probable volumetric alcoholic degree (PVAD) = 13 º was reached) was analysed during the period 2008–2020 in areas located at different elevations and related to the weather conditions recorded in those areas. The results show the effect of temperature and water availability in different periods during the growing cycle on grape composition and the potential benefits of cultivating at a higher elevation, under higher water availability. The anthocyanins were affected by the maximum temperatures recorded in the period before veraison and during ripening (period veraison to technical maturity), decreasing their concentrations with increasing temperatures. In addition, higher water availability gave rise to an increase in acidity. Graciano is shown as a variety more suitable than Tempranillo to be cultivated under warmer conditions.

KEYWORDS

anthocyanins, acidity, berry weight, climate variability, temperature, water availability

 © 2021 International Viticulture and Enology Society - IVES

INTRODUCTION

Climate plays an important role in berry composition (Sadras *et al.,* 2013; Webb *et al.,* 2012), but under similar climatic conditions, each cultivar can present a different response as each variety is adapted to a given range of temperatures (Jones, 2012). Temperature is considered as one of the main drivers of the evolution of the growing cycle and the final maturity and berry composition (Sadras *et al.,* 2007; Ovadia *et al.,* 2013; Greer and Weedon, 2014). In addition, water availability is another factor influencing grape development and berry composition (Castellarin *et al.,* 2007; Chalmers *et al.,* 2010; Tramontini *et al.,* 2013; Bonada *et al.,* 2018; Pérez-Álvarez *et al.,* 2021). Nevertheless, the response of each cultivar could be different due to their differences in the phenological timing, which means reaching maturation under different temperatures and different moisture conditions.

High temperatures negatively affect titratable acidity (Buttrose *et al.,* 1971; Barnuud *et al.,* 2014), which in addition decrease by dilution when the berry size increases under wet conditions. Contrary, an increase in temperature give rise to an increase in sugar concentration (Coombe, 1987). The concentration of anthocyanins are also affected by temperature (Tarara *et al.,* 2008; Greer and Weedon, 2014). Under high temperatures, lower accumulation and higher degradation can occur (Mori *et al.,* 2007) and an unbalanced ratio between anthocyanins and sugars can take place (Martínez De Toda and Balda, 2015). This fact has been observed in varieites such as Cabernet franc, Shyraz or Maturana Tinta or Tempranillo (Sadras *et al.*, 2013; Martínez De Toda and Balda, 2015; Martínez de Toda and Ramos, 2019). However, the effect could be different depending on the cultivar. In this respect, the comparative analy neyards. Its name comes from the Spanish 'temprano' meaning 'early' and it does in fact ripen quite early. It is very versatile from an oenological viewpoint being capable of producing wines that can withstand long ageing periods, with a good balance of alcohol content, colour, and an honest, smooth, fruity mouthfeel that turns velvety as it ages (Balda and Martínez de Toda, 2017). With respect to agronomic performance, it sets well but is highly sensitive to pests and disease and not very resistant to drought or high temperatures.

The other red varieties approved in the area are Grenache, Mazuelo, Maturana Tinta and Graciano. The last one, Graciano, is an autochthonous variety in Rioja. In France, it is known as Morrastel and in Portugal as Tinta Miúda. It had been traditionally used as a complement for Tempranillo in the ageing process. That special contribution as a complement to Tempranillo has made it a very interesting variety for Rioja, where the area of cultivation has recovered in recent years, accounting for 1.8 % of the total vineyard surface area. It has therefore overcome the danger of disappearing that threatened it during the whole of the 20th century. It is fairly resistant to diseases such as downy mildew and powdery mildew. It is late-ripening, so it needs to be grown in sufficiently warm areas. It offers wines with a marked acidity and polyphenolic content, ideal for ageing, with a unique aroma that is much more intense than those of other varieties in Rioja.

Under the projected changes in climate, the growing cycle of the vines can suffer an advance of the phenology and a shortening of the growing cycle, and the varieties with earlier phenology could be more negatively affected. Previous studies on the Tempranillo (Ramos and Jones, 2018; Ramos and Martínez de Toda, 2020; Ramos *et al.,* 2021) have pointed out that it is a variety that for its characteristics (earlier phenology and low acidity), could be negatively affected under warmer conditions. This suggests the need or adopting measures or looking for alternatives to maintain the suitability and quality of the wines, in particular for areas were the main cultivars could be threatened. Different studies are being carried out in the area exploring practices to mitigate the effect of climate change on the vines (Gutiérrez-Gamboa *et al.,* 2021; Zheng *et al.,* 2017). Other studies suggest the introduction of new plant material as an alternative to mitigate the effects (van Leeuwen *et al.,* 2019). For that reason, exploring in more detail the behaviour or other varieties under similar climatic conditions could be important for the suitability of the area as the changes can be different depending on the variety. This research was planned under this hypothesis and its objective was to analyse the potentiality of one minority variety that is autochthonous in the region and that offers additional characteristics. The properties that offer Graciano *vs.* Tempranillo regarding its marked acidity and its later phenology could make this variety an optimal candidate for the area when temperature increases. To develop this objective, a comparative analysis of the effect of the weather conditions on phenology and grape composition for Graciano and Tempranillo was done in three zones located at a different elevation within the Rioja DOCa during the period 2008–2020.

 © 2021 International Viticulture and Enology Society - IVES

MATERIALS AND METHODS

1. Vineyard features

The research was conducted in vineyards planted with *Vitis vinifera* cv. Tempranillo and Graciano, in three zones, located at about 325, 430 and 565 m.a.s.l. in the municipalities of Aldeanueva de Ebro-Alfaro (Z-325), Fuenmayor-Logroño (Z-430) and Ocón (Z-565). The information used in this research referred to two vineyards in each zone (Figure 1). The vines were planted between 1985 and 1996, following a pattern in agreement with the regulations established by the Consejo Regulador of Rioja (3000 vines/ha with an average pattern of 2.8 m × 1.2 m) and trained in trellis (double cordon). The vines were managed under rainfed conditions.

The dates of the phenological stages flowers separated, veraison and maturity were analysed for each area and variety during the period 2008–2020. The phenological survey for flowers separated and veraison was carried out in 10 plants in three different parts of each plot, at periodical intervals that ranged between four and seven days depending on the period analysed. The dates at which the vines in the survey plots reached 50 % of the stage (stages H and M according to Baillod and Baggiolini, 1993) were considered. The date of technical maturity was based on the date at which a given probable alcoholic degree (PVAD = 13 °), was reached. For grape composition, the sampling was carried out collecting berries in 40 randomly selected plants, at a rate of one cluster per plant and five berries per cluster from different parts (up, central and lower parts of the cluster).

The grape composition [berry weight (BW), total soluble solids, expressed as probable alcoholic degree (PVAD), titratable acidity (AcT), malic acid (AcM), anthocyanins (AntT), polyphenols (IPT) and colour intensity (CI)] were evaluated between veraison and maturity for each variety and location during the period 2008–2020. The values corresponding to the defined technical maturity was considered in the further analysis. All vine information was supplied by the Consejo Regulador of Rioja DOCa and the grape parameters were measured following the OIV official methods (OIV, 2004). The changes of each variable during ripening were analysed.

2. Climatic data and analysis

The weather conditions during the period of analysis were evaluated using daily data recorded in weather stations located in Alfaro, Logroño and Ausejo, which were near and at similar elevations (315, 450 and 550 m.a.s.l, respectively) than the analysed vineyards (Figure 1). These weather stations belong to La Rioja Government.

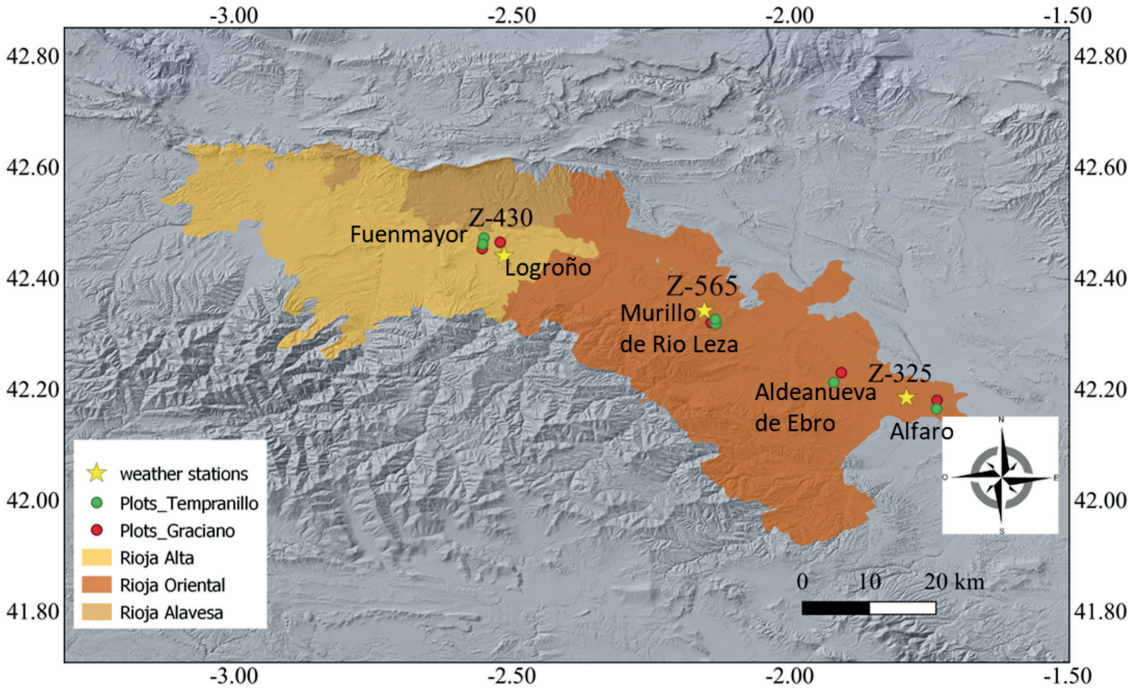


FIGURE 1. Location of the studied plots and weather stations.

© 2021 International Viticulture and Enology Society - IVES

The meteorological information included daily maximum and minimum temperatures (Tmax and Tmin), precipitation (P) and potential evapotranspiration (ETO) estimated according to Penman-Monteith. Crop evapotranspiration was then estimated using the crop coefficients proposed by Allen and Pereira (2009), and the precipitation minus crop evapotranspiration (P-ETc) was considered as an index of water availability. The daily data were averaged for the growing season (GS: budbreak-harvest) and periods between phenological stages (BB-BL: budbreak-bloom; BL-V: bloom-veraison; V-H: veraison-harvest). These variables were used to analyse the response the vine under different weather conditions.

3. Variability in the vine response and its relationship with climatic variability

To evaluate the relationship between grape composition and climate variability, a multivariate analysis was done using the average grape composition recorded for each variety at each location in each year. Among the multivariate techniques, a hierarchical cluster analysis was applied. This technique allows the classification of observations taking into account its similarity, and it has been applied for different purposes, such as the analysis of the similarity of the phenolic complex in berries in different varieties (Levchenko *et al.,* 2021) or to differentiate between grape cultivars according to their phenolic contents and antioxidant properties (Sridhar and Charles, 2018), or the identification of vineyards in different locations which give rise to similar grape composition (Ramos and Martínez de Toda, 2019). The cluster analysis was applied using the Euclidean distance to measure the similarity between the objects and using two methods (Ward and Group average) to optimise the number of clusters to be retained. All the data were standardised. The number of clusters to be retained was defined by taking into account the agglomeration distance. A cut-off point was established when the distance between one step and the next was greater than twice the average distance. Once the number of the cluster was determined, the centroids were evaluated (average values of the grape parameters) and the characteristics of the years that gave rise to a similar response were analysed. In addition, the grape composition was related to the climate variables that showed differences between clusters to know the differences in the effect that temperature and water availability could have in grape composition for each cultivar.

RESULTS

1. Spatial and temporal variability in the weather conditions

The weather conditions recorded at the three zones of Rioja included in this research in the period 2008–2020, during the growing season (usually mid April–mid August), are summarised in Figure 2. The average TmaxGS during the period analysed varied between 21.8 and 25.3 °C in the coolest area (Z-565) and between 24.1 and 27.2 °C in the warmest area (Z-325), which means differences between years higher than 3 °C between the coolest and the warmest years, and also differences of the same order of magnitude between areas. For TminGS, the differences between zones were smaller than for TmaxGS, with TminGS ranging between 11.4 and 12.8 °C in the coolest area and between 11.8 and 13.6 °C in the warmest one. Regarding precipitation, high variability from year to year could be observed during the period analysed, with PGS (growing season precipitation) ranging between 126 and 440 mm, and with greater values in the zones Z-430 and Z-565 than in the zone Z-325 for most of the years analysed.

2. Spatial and temporal variability in the vine response

2.1 Phenology variability

Figure 3 shows a summary of the phenological dates (separated flowers, veraison and maturity) recorded at each location. Differences between years of up to 18 and 30 days in stage H, up to 33 and 28 days for stage M, and up to 39 and 40 days for maturity, were found respectively for Graciano and Tempranillo. In addition, some differences in the average phenological dates were observed between the three zones analysed for both varieties, with the earliest phenological dates in the area Z-325 and the latest in the zone Z-565. For maturity, considered as the date at which a given probable alcoholic degree (PVAD = 13 º) was reached, it can be observed the advance of that stage in the area located at a lower elevation, for both varieties, and also the earlier dates for Tempranillo compared to Graciano within each location.

The earliest phenological dates were recorded in years like 2011, 2015 and 2017, and the latest in the years 2013, 2016 or 2018, which corresponded

 © 2021 International Viticulture and Enology Society - IVES

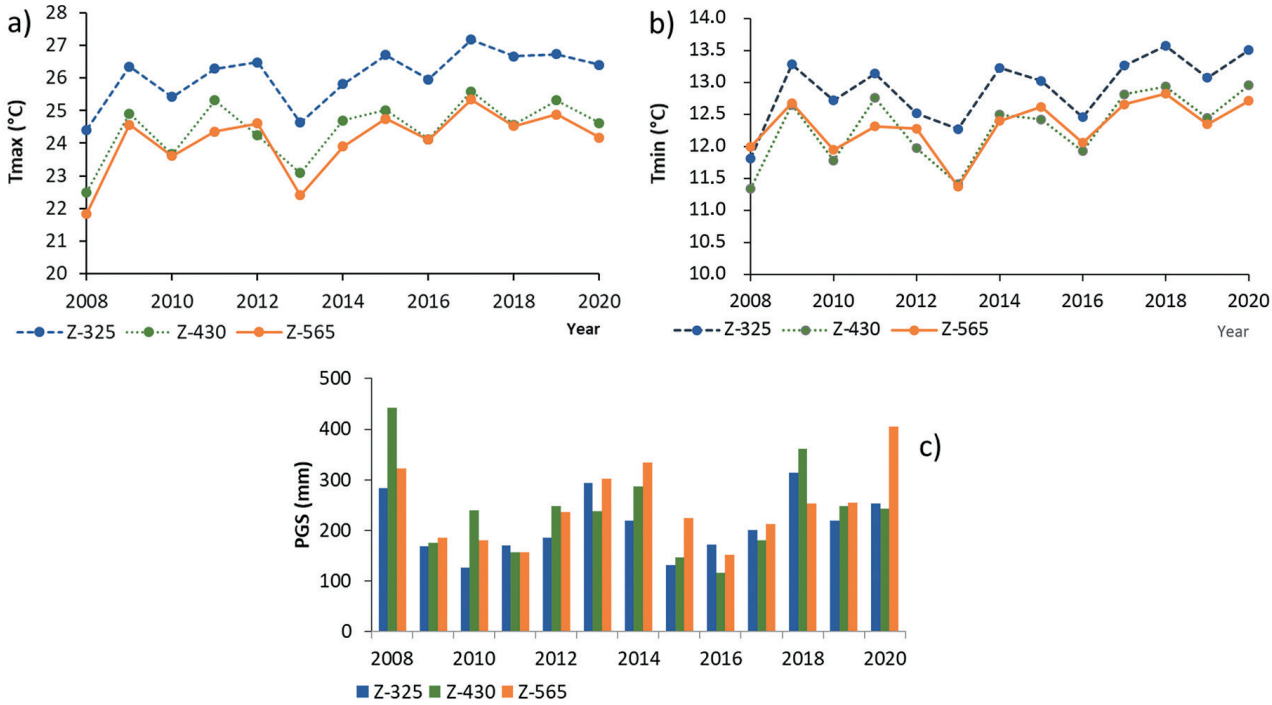


FIGURE 2. Variability of growing season (budbreak to maturity) climatic variables during the period analysed in the three selected zones. A) maximum temperature (TmaxGS); B) minimum temperature (TminGS); and C) precipitation (PGS).

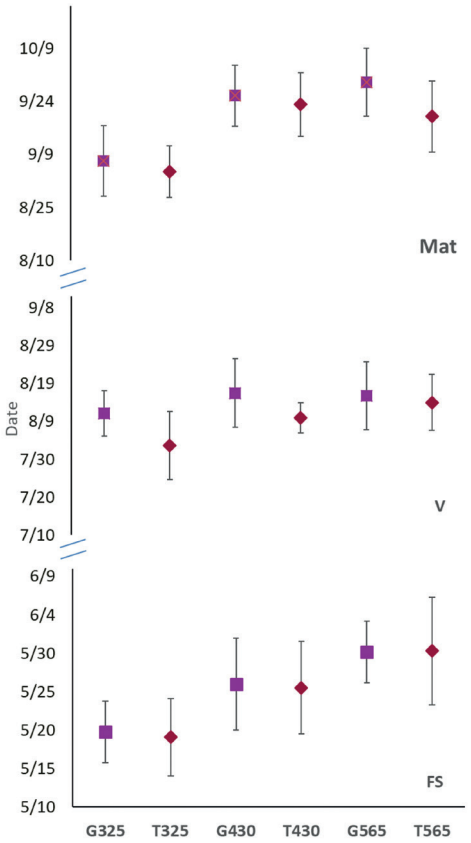


FIGURE 3. Average and standard deviation of the phenological dates for stages H, M and maturity (dates at which PVAD = 13 ° was reached) recorded for Graciano and Tempranillo at each of the three locations analysed in the Rioja DOCa during the period 2008–2020.

© 2021 International Viticulture and Enology Society - IVES

TABLE 1. Average values, standard deviations and range of variation of selected grape parameters at maturity (PVAD = 13 º) for Graciano and Tempranillo in each zone (period 2008–2020)

Zone	Variety	BW - 100b (g)	pH	AcT (g/L)	AcM (g/L)	AntT (mg/L)	ratio AntT/ PVAD	TPI	CI
Z - 325	Graciano	146 ± 25	3.6 ± 0.2	5.6 ± 0.8	1.4 ± 0.6	664 ± 104	43.5 ± 6.3	47.7 ± 6.0	19.4 ± 3.7
		109 - 197	*3.4 - 3.9*	*4.4 - 6.6*	*0.5 - 2.7*	*501 - 799*	*33.1 - 55.9*	*36.6 - 55.4*	*13.4 - 24.6*
	Tempranillo	208 ± 18	4.0 ± 0.1	4.6 ± 0.5	2.7 ± 0.7	497 ± 115	36.7 ± 6.3	40.6 ± 5.6	10.5 ± 2.8
		178 - 234	*3.9 - 4.2*	*3.9 - 5.9*	*1.6 - 4.0*	*355 - 726*	*29.7 - 49.8*	*32.3 - 51.0*	*8.0 - 16.4*
Z - 430	Graciano	168 ± 24	3.4 ± 0.1	6.8 ± 0.7	1.8 ± 0.5	502 ± 81	40.8 ± 5.5	34.6 ± 5.5	15.0 ± 2.9
		121 - 206	*3.2 - 3.5*	*5.9 - 8.1*	*1.3 - 3.0*	*377 - 657*	*32.9 - 48.9*	*27.4 - 44.6*	*10.6 - 16.9*
	Tempranillo	205 ± 31	3.9 ± 0.1	5.2 ± 0.7	3.3 ± 0.7	458 ± 82	36.0 ± 5.0	30.8 ± 3.4	9.6 ± 2.3
		157 - 282	*3.7 - 4.0*	*4.3 - 6.6*	*2.3 - 4.4*	*397 - 600*	*28.0 - 42.8*	*23.4 - 37.9*	*5.6 - 12.9*
Z - 565	Graciano	168 ± 31	3.4 ± 0.1	7.1 ± 1.1	2.5 ± 1.0	631 ± 108	49.4 ± 6.1	44.8 ± 6.1	21.3 ± 4.8
		106 - 221	*3.2 - 3.5*	*6.0 - 9.7*	*0.6 - 4.6*	*456 - 832*	*40.1 - 63.9*	*27.6 - 54.9*	*11.9 - 30.2*
	Tempranillo	238 ± 36	3.7 ± 0.1	5.6 ± 0.7	3.0 ± 0.8	473 ± 85	35.7 ± 6.3	49.8 ± 10.6	12.0 ± 2.5
		179 - 301	*3.4 - 3.9*	*4.1 - 7.9*	*1.5 - 4.9*	*365 - 641*	*26.8 - 45.6*	*33.3 - 70.3*	*6.9 - 18.9*

Titratable acidity (AcT); malic acid (AcM), pH, anthocyanins (AntT); total polyphenol index (TPI) and colour intensity (CI).

to warm years, and cooler and wetter years, respectively. The differences in the phenological dates between both varieties were greater for stages M and for maturity rather than for flowering. In years like 2013, one of the coolest and wettest of the series, however, the differences in the harvest dates between both varieties were of 19 days in the zone Z-325 and about 7 days in the other two zones with harvest in mid-October in those zones while in Z-325 took place in the last third of September.

2.2. Grape composition variability

Regarding the grape composition, the mean values for each variety analysed at each zone are shown in Table 1. As it was aforehand mentioned, in the area located at a lower elevation, maturity was reached before, and the grapes were usually harvested with a higher probable alcoholic degree (higher than 14º), while in other areas that value was not reached in most of the analysed years. When the threshold PVAD = 13° was reached, higher AcT was observed for Graciano than for Tempranillo at each location, while it was opposite for AcM. The concentration of AntT, the TPI and the CI were also higher for Graciano than for Tempranillo, at each location while berry weight was higher for Tempranillo than for Graciano, although with high variability from year to year.

The relationship between some grape parameters, such as AcT, AcM and AntT and the probable alcoholic degree during ripening for both varieties and the three locations is shown in Figure 4. It can be observed that the AcT, not only reached lower values in Tempranillo than in Graciano but they were reached faster. It can be observed, that the evolution of AcT with an increasing probable alcoholic degree for Tempranillo was smaller in the area located at lower elevation (Z-325) than in the other two zones, while for Graciano the differences were smaller, although the final AcT was much lower in that area where the probable alcoholic degree was higher (Figure 4a).

For AcM, as it was previously commented, the values were higher for Tempranillo than for Graciano. For Tempranillo, there was higher variability in the AcM values reached for a given probable alcoholic degree and lesser differences were observed from the beginning to the end of the ripening period.

For Graciano, a greater concentration range was recorded, with a similar evolution in the three zones but reaching smaller values at harvest in the zone located at lower elevations as the grapes were harvested with a higher probable alcoholic degree (Figure 4b).

For AntT, the increase in AntT with an increasing probable alcoholic degree was similar in the three areas for Tempranillo and similar to Graciano at the lowest elevation, but for that variety, the increase was greater in the other two zones, where higher anthocyanin concentrations were recorded at harvest (Figure 4c).

 © 2021 International Viticulture and Enology Society - IVES

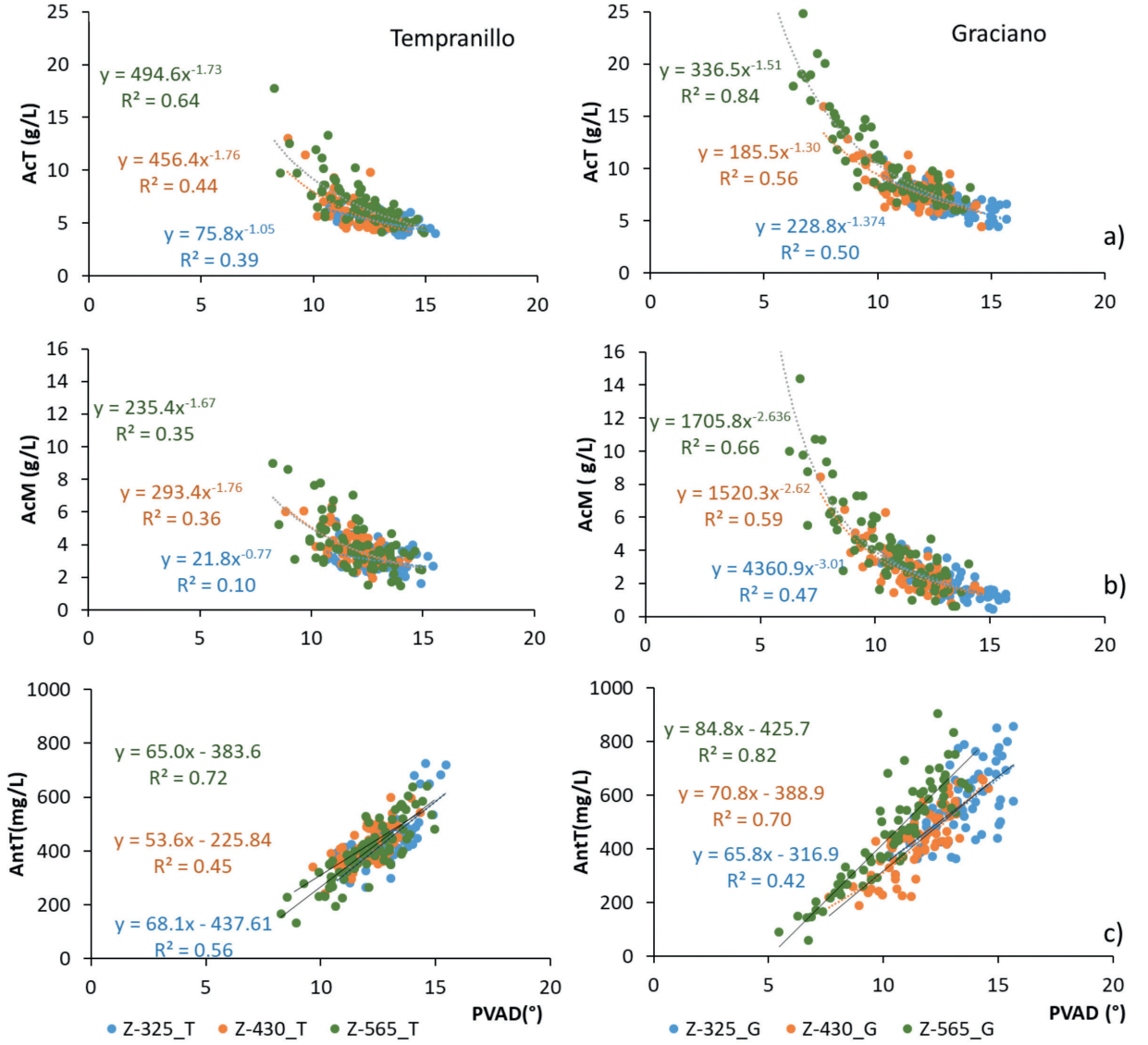


FIGURE 4. Evolution of a) titratable acidity (AcT), b) malic acid (AcM) and c) anthocyanins (AntT) with probable volumetric alcoholic degree (PVAD) for Tempranillo and Graciano in the three selected zones of the Rioja DOCa.

3. Relationship between grape composition and weather conditions

The differences in grape composition and its relationship with the weather conditions between years were analysed with the establishment of groups of a similar response. The cluster analysis performed on the grape composition at technical maturity recorded at each location allowed for the establishment of those groups. The classification of the years into groups are presented in Figure 5 and the centroids and the characteristics of the years included in each group are shown in Tables 2 and 3, for Graciano and Tempranillo, respectively.

In the lowest elevation (Z-325), for Graciano, the years that showed the highest berry weight, the highest AcT and AcM, and the lowest PVAD at maturity were clustered in cluster C1 (2008–2013–2014). Those years were the coolest and wettest in the series. They had the smallest average temperature (both minimum and maximum temperatures) in all periods between phenological stages. On the contrary, the years included in cluster C4 (2011, 2012, 2016, 2017) recorded the lowest berry weight, lower AcT and the lowest anthocyanin concentration and colour intensity. The years included in cluster C4 recorded the highest temperatures, reaching average maximum temperatures in the ripening period that were on average 4.4 °C higher than in the years included in cluster C1 and minimum temperatures 3 °C higher, on average.

© 2021 International Viticulture and Enology Society - IVES

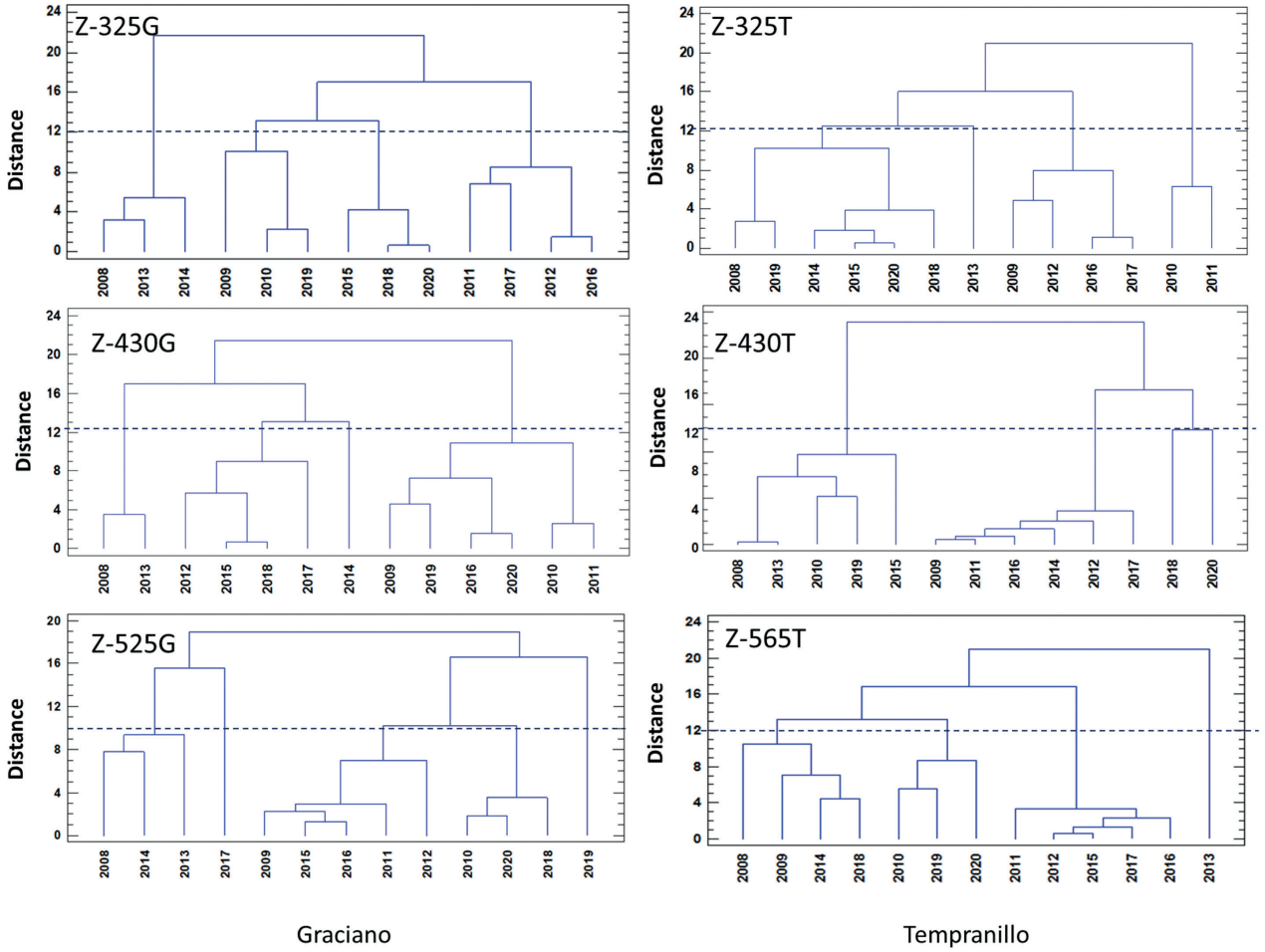


FIGURE 5. Classification of years based on grape composition referring berry weight, AcT, AcM, anthocyanins, TPI and CI, recorded in the period 2008–2020, for Graciano and Tempranillo cultivated in three zones of Rioja DOCa located at different elevation.

Regarding the other two clusters, there were some differences between them, with higher titratable acidity, but lower malic acid and lower concentration of AntT and TPI in cluster C2 (2009–2010–2019) than in cluster C3 (2015–2018–2020), being also berry weight smaller in cluster C2. The years included in those clusters recorded average growing season temperatures between 1.0 and 1.7 °C higher than years included in cluster C1, but with higher differences in the temperatures in periods between phenological stages. Tmax in the period BL-V and V-Mat, which were 1.3 and 2 °C, respectively, were higher than those recorded in years in cluster C1, and the Tmin in the same periods were 1 and 2.3 °C higher than in cluster C1. In addition, there were some differences in water availability, which was smaller in cluster C2 and C3 than in cluster C1, in particular in the period BL-V (Table 2).

For Tempranillo in the same area (Z-325), the warmest years were grouped in cluster C3 (2009–2012–2016–2017), quite similar to what was obtained for Graciano (cluster C4), but the cooler years were distributed into three clusters: C1 (2008–2014–2014–2015–2018–2019–2020), C2 (2013) and C4 (2010–2011). It can be marked that the lowest BW was recorded in cluster C4, which grouped the years in which the highest PVAD was reached at harvest, and those years recorded the highest concentration of AntT, and the highest TPI and CI. The lowest AntT, TPI and CI were reached in the years included in cluster C1, years in which the lowest PVAD was reached at harvest. The years included in the clusters C1 and C2 recorded the lowest maximum and minimum temperatures during all growing seasons and those of cluster C1-1 recorded also lower temperatures than those included in the other clusters, in two of the three periods considered in this analysis.

 © 2021 International Viticulture and Enology Society - IVES

TABLE 2. Centroids of the clusters obtained in year classification at the three analysed locations for Graciano and average climatic characteristics of the years included in each cluster.

Zone	Cluster	BW-100b	PVAD	AcT	pH	AcM	TPI	AntT	CI	
Z-325	C1	179.6	14.0	6.5	3.6	2.2	44.8	682.5	20.9	
	C2	136.9	15.3	6.0	3.6	0.9	46.3	651.0	21.1	
	C3	156.2	15.1	4.6	3.8	1.4	54.3	710.9	20.4	
	C4	126.4	14.8	5.4	3.6	1.1	46.0	558.7	16.3	
		P-ETc BB-BL	P-ETc BL-V	P-ETc V-H	Tmax BB-BL	Tmax BL-V	Tmax V-H	Tmin BB-BL	Tmin BL-V	Tmin V-H
	C1	23.6	–155.7	–87.6	20.2	27.2	26.5	7.7	13.1	11.6
	C2	11.3	–225.2	–74.3	20.0	29.5	28.5	6.7	14.1	13.9
	C3	61.6	–163.8	–111.9	20.8	29.5	29.2	8.0	14.5	13.3
	C4	17.9	–177.9	–84.0	20.6	28.2	30.9	7.3	13.1	14.6
Z-430	Cluster	BW-100b	PVAD	AcT	pH	AcM	TPI	AntT	CI	
	C1	183.8	11.1	8.4	3.3	3.4	30.4	467.5	15.0	
	C2	161.1	12.6	6.5	3.3	1.4	29.2	448.0	13.3	
	C3	153.3	14.0	5.9	3.5	1.7	42.5	637.6	19.5	
	C4	184.3	12.5	6.7	3.4	1.7	33.8	475.8	15.3	
		P-ETc BB-BL	P-ETc BL-V	P-ETc V-H	Tmax BB-BL	Tmax BL-V	Tmax V-H	Tmin BB-BL	Tmin BL-V	Tmin V-H
	C1	57.3	–115.2	–81.3	17.4	26.3	24.1	7.7	14.3	13.6
	C2	18.1	–190.0	–60.8	19.8	27.7	26.7	9.0	14.7	14.0
	C3	–15.1	–214.7	–87.9	20.3	29.2	26.4	8.6	15.3	14.1
	C4	16.9	–174.5	–72.3	19.2	27.8	26.6	8.4	15.0	14.0
Z-565	Cluster	BW-100b	PVAD	AcT	pH	AcM	TPI	AntT	CI	
	C1	204.8	11.5	8.6	3.4	3.7	37.6	567.8	20.1	
	C2	171.3	13.0	7.6	3.3	2.5	51.9	779.6	27.7	
	C3	131.9	14.1	8.2	3.2	3.2	27.6	654.9	12.0	
	C4	153.3	12.4	7.8	3.4	2.4	44.6	587.0	20.2	
	C5	156.2	11.4	8.4	3.3	2.7	39.3	456.6	15.1	
		P-ETc BB-BL	P-ETc BL-V	P-ETc V-H	Tmax BB-BL	Tmax BL-V	Tmax V-H	Tmin BB-BL	Tmin BL-V	Tmin V-H
	C1	29.9	-76.5	-40.6	18.2	25.8	23.5	8.1	14.2	13.0
	C2	43.3	-185.6	-76.3	19.6	28.0	25.4	9.4	15.0	13.3
	C3	-27.6	-182.1	-36.8	21.7	30.5	23.9	9.6	16.3	12.8
	C4	30.5	-199.5	-72.8	18.3	26.9	26.3	7.8	14.1	14.0
	C5	5.8	-145.4	-41.3	22.0	28.9	25.2	9.2	15.5	13.6

BW-100b: weight of 100 berries (g); PVAV: probable volumetric alcoholic degree (°); AcT: titratable acidity (g/L); AcM: malic acid (g/L); AntT: concentration of anthocyanins (mg/L); TPI: total polyphenol index; CI: colour intensity; Tmax: maximum temperature; Tmin: minimum temperature; P-ETc: precipitation-evapotranspiration; BB-BL: period budbreak to bloom; BL-V: period bloom to veraison; V-H: period veraison to harvest

 © 2021 International Viticulture and Enology Society - IVES

TABLE 3. Centroids of the clusters obtained in year classification at the three locations analysed for Tempranillo and average climatic characteristics of the years included in each cluster.

Zone	Cluster	BW-100b	PVAD	AcT	pH	AcM	TPI	AntT	CI	
Z-325	C1	210.3	13.0	4.6	3.9	2.7	37.0	447.2	8.9	
	C1-1	199.5	13.6	4.3	4.0	3.2	32.7	479.9	8.8	
	C1-2	220.4	12.7	4.9	3.8	2.6	39.4	407.9	8.7	
	C2	202.9	14.4	4.3	4.1	2.1	42.7	478.1	10.2	
	C3	234.2	13.3	5.9	3.8	3.9	34.4	517.1	11.8	
	C4	190.3	15.0	4.6	4.0	3.3	49.9	722.3	16.0	
		P-Etc BB-BL	P-Etc BL-V	P-Etc V-H	Tmax BB-BL	Tmax BL-V	Tmax V-H	Tmin BB-BL	Tmin BL-V	Tmin V-H
	C1	17.4	-183.9	-114.9	21.3	29.1	29.1	7.9	13.9	13.5
	C1-1	16.9	-185.7	-81.6	20.6	28.7	28.0	7.1	13.3	12.8
	C1-2	9.2	-153.1	-140.9	21.8	28.6	29.7	8.3	14.0	14.0
	C2	45	-122.8	-115.8	18.1	27.4	27.7	6.4	13.0	12.3
	C3	-43.5	-157.6	-113.0	20.9	29.5	30.5	7.5	14.0	14.5
	C4	38.3	-166.7	-124.0	20.9	27.7	29.9	8.5	13.0	14.5
Z-430	Cluster	BW-100b	PVAD	AcT	pH	AcM	TPI	AntT	CI	
	C1	190.7	12.9	5.9	3.8	3.9	32.9	532.6	11.9	
	C2	230.4	11.6	5.7	3.9	4.0	30.4	355.8	7.1	
	C3	203.1	12.7	4.7	3.9	2.8	30.1	418.3	8.2	
		P-Etc BB-BL	P-Etc BL-V	P-Etc V-H	Tmax BB-BL	Tmax BL-V	Tmax V-H	Tmin BB-BL	Tmin BL-V	Tmin V-H
	C1	32.2	-153.3	-102.8	19.3	27.7	25.9	8.4	14.5	13.6
	C2	10.4	-124.1	-109.5	20.1	27.4	27.9	9.7	15	15.0
	C3	-2.1	-168.2	-108.5	20.6	27.3	28.0	9.3	14.5	15.0
Z-565	Cluster	BW-100b	PVAD	AcT	pH	AcM	TPI	AntT	CI	
	C1	257.3	13.5	5.4	3.8	2.8	46.0	483.1	13.1	
	C2	211.1	14.6	4.9	3.8	3.2	60.2	564.8	14.6	
	C3	261.2	12.1	7.9	3.4	4.9	33.3	265.2	6.9	
	C4	213.0	13.0	5.0	3.8	2.4	45.9	413.6	10.2	
		P-Etc BB-BL	P-Etc BL-V	P-Etc V-H	Tmax BB-BL	Tmax BL-V	Tmax V-H	Tmin BB-BL	Tmin BL-V	Tmin V-H
	C1	22.4	-163.8	-67.8	21.7	25.7	25.1	10.9	13.8	13.9
	C2	22.3	-150.7	-70.4	21.3	28.8	24.3	10.1	15.3	12.9
	C3	78.4	-163.3	-58.5	15.9	27.6	23.2	7.1	14.8	12.4
	C4	-5.0	-189.5	-78.0	23.3	27.4	26.3	11.5	14.3	13.8

BW-100b: weight of 100 berries (g); PVAV: probable volumetric alcoholic degree (°); AcT: titratable acidity (g/L); AcM: malic acid (g/L); AntT: concentration of anthocyanins (mg/L); TPI: total polyphenol index; CI: colour intensity; Tmax: maximum temperatures; Tmin: minimum temperatures; P-ETc: precipitation-evapotranspiration; BB-BL: period budbreak to bloom; BL-V: period bloom to veraison; V-H: period veraison to harvest.

 © 2021 International Viticulture and Enology Society - IVES

There were, however, differences of about 1 °C in the maximum temperatures between the subgroups of cluster C1. An additional difference between clusters was referred to as the water deficits. The cluster C2 presented the lowest water deficits during the whole growing season, with the highest water deficits in the period BL-V. The differences in water deficits between the other clusters were mainly recorded during the ripening period (Table 3).

For the other two zones, a similar influence of temperature and water availability on grape parameters (both acidity and phenolic composition) was observed. In zone Z-430, for Graciano, cluster C1 (2008–2013) grouped the years with the highest AcT and AcM, while cluster C3 (2009–2012–2015–2017) grouped the years that recorded the lowest AcT, which were the ones that reached the highest PVAD and the highest concentration of AntT, TPI and CI. Regarding the characteristics of the years of each group, cluster C1 grouped the wettest and coolest years of the series, with average growing-season temperatures about 1.7 °C lower than the average in the series and up to 2.4 °C lower than the average of the warmest years, included in cluster C3. The years included in cluster C3 recorded particularly high temperatures (both maximum and minimum temperatures) in the period BL-V and also higher water deficits in that period than the rest of the years. Cluster C2 (2010–2011–2019–2020) grouped years with similar characteristics regarding temperatures to those of cluster C4 (2014–2016–2018), with average maximum temperatures in the period BL-V, which were about 1.3–1.4 °C higher than those corresponding to cluster C1, and about 1.5–1.4 °C lower than the ones corresponding to cluster C3 (Table 2).

For Tempranillo in zone Z-430, cluster C1 (2008–2010–2013–2015–2019) grouped years with the highest AcT and AcM, and concentrations of AntT, CI and TPI slightly higher than the years included in the other clusters. The years included in cluster C3 (2009–2011–2012–2014–2016–2017) recorded the lowest AcT and AcM and also a lower concentration of AntT compared to cluster C1. However, the lowest concentration of AntT was reached in the years included in cluster C2 (2018–2020), which were the ones with the lowest PVAD and the highest berry weight. Although the average growing season maximum temperatures of the years included in the three clusters were similar, there were differences in the average temperatures in some specific periods between phenological stages.

Thus, the years grouped in cluster C1 recorded lower temperatures during the ripening period than the years grouped in other clusters (about 2 °C lower than in cluster C2 and 2.1 °C lower than in cluster C3). The average minimum temperatures during ripening were also lower in cluster C1 (about 1.4 °C lower than in cluster C2 and cluster C3). In addition, the years included in cluster C3 recorded on average higher water deficits (Table 3).

In the area located at the highest elevation (Z-565), the cluster analysis gave rise to a year classification that differed in some way from the ones obtained in the other two zones. For Graciano, the years were classified into five clusters. Cluster C1 (2008–2013–2014) grouped the years with the highest AcT and AcM and BW. The years grouped in that cluster were the ones that recorded the lowest maximum temperatures during the whole growing season. The years included in cluster C3 (2019) and cluster C5 (2017) recorded slightly lower acidity than the years of cluster C1, but differed in the berry weight (being the lowest BW recorded in 2019) and in the concentration of AntT (higher AntT in cluster C3 than in C1 and C5), TPI (higher TPI in C5 than in C1 and in C3) and CI (lower CI in C3 than in C5 and in C1). The year 2019 recorded the highest temperatures (both maximum and minimum) in the period BL-V, but lower values during ripening (similar to those recorded in the years groped in cluster C1, which were the coolest years). On the other side, the lowest AcT were recorded in the years included in cluster C2 (2010, 2018 and 2020) and cluster C4 (2009–2011–2012–2015–2016), but both clusters differed in the concentration of AntT, which was higher in years included in C2 than in cluster C4. The years grouped in these two clusters recorded higher temperatures than the ones grouped in cluster C1, but lower than in clusters C3 and C5, in particular during the period BL-V. In addition, water deficits were also higher in those years than in the years included in the other clusters (Table 2).

For Tempranillo at the highest elevation (Z-565), the year that recorded the highest acidity was separated in cluster C3 (2013), while the rest of the years that reached similar AcT values were classified into three clusters. Among them, cluster C2 (2010–2019–2020) recorded slightly lower AcT higher AcM and the highest AntT TPI and CI. The years in clusters C1 (2008–2009–2014–2018)

© 2021 International Viticulture and Enology Society - IVES

and C4 (2011–2012–2015–2016–2017) showed intermediate values of all parameters.

The maximum and minimum temperatures of the year 2013 (cluster C3) were lower in almost all periods considered than in the rest of the years, and the climatic characteristics of the years included in the different clusters differed in the maximum and minimum temperatures in some specific periods. Thus, the years included in cluster C2 recorded the highest maximum and minimum temperatures in the period BL-V, but the lowest minimum temperatures during the ripening period, while the years included in cluster C4 recorded the highest maximum temperatures and high minimum temperatures in the ripening period. Water deficits in that area located at higher elevation were smaller than in other areas located at a lower elevation, being the years included in cluster C4 the ones with the highest values, in particular in the period BL-V (Table 3).

DISCUSSION

1. Phenology variability between cultivars under different weather conditions

Despite the high variability in the weather conditions recorded during the period analysed, the results allowed confirming differences between the zones located at a different elevation (between 325 and 565 m.a.s.l.) and extracting information about the vine response of the studied cultivars under a wide range of temperature and precipitation values.

The averages dates for stage H were quite similar for both varieties, with higher variability for Tempranillo than for Graciano (Figure 2). Higher differences existed for veraison between both varieties, with earlier dates for Tempranillo than for Graciano, being the advance higher at the lowest elevation. The earlier veraison in that area implies that ripening occurs under very hot and dry conditions, and maturity was reached also earlier. The average date at which the 13 º were reached, did not differ so much between both varieties but the variability was higher for Graciano than for Tempranillo and the advance was usually greater in the two zones located in Rioja Oriental (Z-325 and Z-565) than in the zone located in Rioja Alta. These results confirmed the different responses in the zones with the Atlantic and Mediterranean influence and, despite the variability that existed from year to year, Graciano is shown as the variety that could maintain the delay at maturation, which seems to be higher at the highest elevation.

Under hot conditions, the differences in the response gave rise to the very earlier phenology of Tempranillo. A representative year of that situation was the year 2017. In that year harvest of Tempranillo took place in mid-August in Z-325 while for Graciano took place 14 days later. The same difference in the dates was found between both varieties in the other zones but harvesting taking place 14 days later. The differences in phenology between years with different temperatures agree with the average advances at the beginning of bloom, veraison and harvest for an increase of 1 °C (3.1. 5.2 and 7.4 days, respectively) given by Ruml *et al.* (2016) and results of other authors (Fraga *et al.,* 2016; Ramos *et al.,* 2015; van Leeuwen and Darriet, 2016; Ramos and Martínez de Toda, 2019), who linked phenological dates and temperature and indicated that ripening under warmer conditions and higher water deficits can affect the grape composition. It is important, however, to mark the differences in the response of both cultivars.

2. Grape composition variability

The results found during the period of analysis allowed confirming some differences in grape composition between both cultivars. For a given PVAD, the final titratable acidity values (AcT) reached in Graciano were higher than in Tempranillo, and the decrease of AcT was slowly for Graciano than for Tempranillo when the PVAD increased (Figure 4a). AcM, however, reached lower values in Graciano than in Tempranillo. The AcT presented an increasing gradient with elevation. For Tempranillo, however, although AcM increased from the zone at the lowest (Z-325) to the highest (Z-565) elevation in Rioja Oriental, the maximum values were recorded in the zone located in Rioja Alta (Z-430), which was at an intermediate elevation. This could be justified by the effect of the higher temperatures in zone Z-325 recorded in the period BL-V. Sugiura *et al.* (2020) related acidity to temperatures in sensitive periods after flowering, and taking into account that the increase of AcM usually takes place just before veraison (Volschenk *et al.,* 2006) the increase in the high temperatures in that period will give rise to lower final acid concentrations in the grapes. The differences in acidity found between the clusters and the average climatic values that characterised each of them indicated that higher maximum temperatures in the whole growing season give rise to a decrease in acidity and in particular the maximum temperature in the period veraison to maturity.

 © 2021 International Viticulture and Enology Society - IVES

These results point in the same direction as those of Costa *et al.* (2020), who found strong correlations with the temperatures recorded in the months that included part of the ripening period, and agree with that pointed out by other authors regarding the effect of high temperatures on acidity (Coombe, 1987; Sadras *et al.,* 2013; Keller, 2015; Barnuud *et al.,* 2014; Vršič *et al.,* 2014). The effect was slightly higher for AcT for Tempranillo than for Graciano in zones Z-430 (–33 *vs*. –0.14 g AcT/L per 1 ºC) and in Z-565 (–0.36 *vs.* 0.31 g AcT/L per 1ºC) and similar in Z-325 (–0.15 *vs.* 0.19 g AcT/L per 1 ºC). For AcM, the effect was negative and slightly greater for Tempranillo than for Graciano in the three zones: Z-325 (–0.26 *vs.* –0.22 g AcM/L per 1 ºC); Z-430 (–0.26 *vs.* 0.16 g AcM/L per 1 ºC) and Z-565 (0.29 *vs*. 0.21 g AcM/L per 1 ºC). These results mean that under warmer conditions, Tempranillo will have even lower acidity values and that, although Graciano could also decrease in acidity, its decrease will be smaller.

The average concentration of AntT was also higher in Graciano than in Tempranillo and higher in both zones of Rioja Oriental (Z-325 and Z-656) than in the zone located in Rioja Alta (Z-430), for both varieties. This confirms again the different responses of the vines in Rioja Alta and Rioja Oriental. However, in that case, higher values were found in zone Z-325 than in zone Z-565. The gradient in the levels of AntT between locations were in agreement with the sugar contents reached, which had the lowest values in zone Z-430 and the highest in Z-325, for both varieties. The results were consistent with the smaller berry weight recorded in zone Z-325 and the highest in zone Z-565, which in addition was smaller for Graciano than for Tempranillo. Berry weight was mainly driven by water availability, as confirmed by the higher values recorded in wet years and it was also in agreement with the higher berry weight in the zones located at higher elevations where the index P-ETc was higher. The effect of temperature and water availability on the concentration of anthocyanins has been indicated by other authors in different varieties (Mori *et al.,* 2007; Barnuud *et al.,* 2014; Pastore *et al.,* 2017; de Rosas *et al.,* 2017; Shinomiya *et al.,* 2015). Increasing temperatures could produce a decrease in the concentration of anthocyanins, but water deficits could favour its increase (Hochberg *et al.,* 2015; Castellarin *et al.,* 2007). In the study case, the effect of temperature and water deficits pointed out in the same direction for both varieties, although with differences between them and between zones. The effect of increasing temperatures during ripening was significant and higher in zone Z-430 for Tempranillo than for Graciano (–36 *vs*. –21 mg/L AntT per 1 ºC increase in Tmax during ripening), while it was not significant for the other two zones. The effect of water availability was appreciable in the zone located at a higher elevation, indicating that in that area the concentration increased when the water deficit increased, and in higher proportion for Graciano than for Tempranillo (1.48 mg/L per 1 mm *vs.* 0.52 mg/L AntT per 1 mm (P-ETc).

Regarding the other two parameters related to phenolic composition, TPI and CI, there were also greater for Graciano than for Tempranillo and there was not a clear trend with elevation although, for both cultivars, the highest values were found in Z-565 and the lowest in Z-430. Nevertheless, the response differed between years and the relationship between those variables and the climatic variables presented some differences between zones and between both varieties. While for Graciano, TPI was positively influenced by maximum temperature during ripening in both zones located on Rioja Oriental (Z-325 and Z-565), its effect was not significant for that variety in zone Z-430. For Tempranillo, however, the effect was significant and opposite in zone Z-430 (located in Rioja Alta) and not significant in the other two zones. The effect of temperature on CI was only appreciable for Tempranillo and higher in the warmest zone (Z-325) than in the zone located at intermediate elevation (Z-430) (–1.8 *vs*. 0.65 colour units per 1 ºC increase) and not significant at the highest elevation.

In addition to the direct effects of the climatic conditions on acidity and on the phenolic composition, which could be different between both varieties, a significant effect on the decoupling between anthocyanins and sugar might be remarked. The observed ratio AnT/PVAD was smaller for Tempranillo than for Graciano in the three zones (average values for Graciano 43.5, 40.8 and 49.4, respectively, for the zones Z-325, Z-430 and Z-565, while for Tempranillo the averages were 36.7, 36.0 and 35,7, respectively). The accumulation of sugar in Tempranillo seemed to reach the maximum value more quickly than in Graciano (Figure 4), which could suppose that Graciano continued to accumulate anthocyanins at high temperatures while in Tempranillo the accumulation of anthocyanins stopped. This effect was also confirmed when the responses in the coolest and the warmest zones were compared.

© 2021 International Viticulture and Enology Society - IVES

It was also confirmed that an increase in Tmax during the ripening period would produce a decrease in the ratio, greater for Tempranillo than for Graciano (2.4 *vs*. 2.11 for 1 ºC increase), and greater at the lowest elevation, which means even higher decoupling between anthocyanins and sugars. Thus, the comparative analysis of the response of Graciano and Tempranillo in the analysed zones of the Rioja DOCa confirmed, that the impacts on acidity and on the decoupling between anthocyanins and sugars that are expected under warmer conditions, could be smaller for Graciano than for Tempranillo, which enhance the potentiality the minority variety.

CONCLUSIONS

The results of this research, carried out in the zones of the Rioja DOCa during a 13 year period, showed the high variability in the response of different well-adapted varieties cultivated in the area, due not only to the weather conditions but also to the location. The results confirmed the later phenological timing of Graciano *vs.* Tempranillo and between zones at different elevations. In addition, the grape composition regarding acidity and anthocyanins that offer Graciano compared to Tempranillo and the lower decoupling between anthocyanins and sugars that it suffers with the temperature in all analysed zones, show the potentiality of Graciano as an autochthonous variety to be considered under warmer scenarios. All the observed results represent significant treats under the climate change perspective that could be relevant for winemakers in the area.

Acknowledgements: Authors thanks the Consejo Regulador of Rioja DOCa for the vine information related to all the plots and the Government of La Rioja for the climatic information used in this study.

REFERENCES

Allen, R. G., & Pereira, L. S. (2009). Estimating crop coefficients from fraction of ground cover and height. *Irrigation Science*, *28*(1), 17–34. https://doi.org/10.1007/s00271-009-0182-z

Baillod, M., & Baggiolini, M. (1993). Les stades repères de la vigne. *Revue Suisse Viticulture, Arboriculture, Horticulture, 25*(1), 7-9.

Balda, P., & Martínez de Toda, F. (2017). *Variedades Minoritarias de Vid en La Rioja*. ISBN 978-84-8125-686-4. Ed. Gobierno de La Rioja, 193 pp.

Barnuud, N. N., Zerihun, A., Mpelasoka, F., Gibberd, M., & Bates, B. (2014). Responses of grape berry anthocyanin and titratable acidity to the projected climate change across the Western Australian wine regions. *International Journal of Biometeorology*, *58*(6), 1279–1293. https://doi.org/10.1007/s00484-013-0724-1

Bonada, M., Buesa, I., Moran, M. A., & Sadras, V. O. (2018). Interactive effects of warming and water deficit on Shiraz vine transpiration in the Barossa Valley, Australia. *OENO One*, *52*(2), 135–148. https://doi.org/10.20870/oeno-one.2018.52.2.2141

Buttrose, M.S., Hale, C.R., & Kliewer,W.M. (1971). Effect of Temperature on the Composition of Cabernet Sauvignon Berries. *American Journal Enology Viticulture, 22*, 71–75.

Castellarin, S. D., Matthews, M. A., Di Gaspero, G., & Gambetta, G. A. (2007). Water deficits accelerate ripening and induce changes in gene expression regulating flavonoid biosynthesis in grape berries. *Planta*, *227*(1). https://doi.org/10.1007/s00425-007-0598-8

Chalmers, Y. M., Downey, M. O., Krstic, M. P., Loveys, B. R., & Dry, P. R. (2010). Influence of sustained deficit irrigation on colour parameters of Cabernet Sauvignon and Shiraz microscale wine fermentations. *Australian Journal of Grape and Wine Research*, *16*(2), 301–313. https://doi.org/10.1111/j.1755-0238.2010.00093.x

Coombe, B.G. (1987). Influence of temperature on composition and quality of grapes. *Acta Horticulturae 206*, 23–36. https://doi.org/10.17660/ActaHortic.1987.206.1

Costa, C., Graça, A., Fontes, N., Teixeira, M., Gerós, H., & Santos, J. A. (2020). The interplay between atmospheric conditions and grape berry quality parameters in Portugal. *Applied Sciences (Switzerland)*, *10*(14). https://doi.org/10.3390/app10144943

de Rosas, I., Ponce, M. T., Malovini, E., Deis, L., Cavagnaro, B., & Cavagnaro, P. (2017). Loss of anthocyanins and modification of the anthocyanin profiles in grape berries of Malbec and Bonarda grown under high temperature conditions. *Plant Science*, *258*, 137–145. https://doi.org/10.1016/j.plantsci.2017.01.015

Fraga, H., Santos, J. A., Moutinho-Pereira, J., Carlos, C., Silvestre, J., Eiras-Dias, J., … Malheiro, A. C. (2016). Statistical modelling of grapevine phenology in Portuguese wine regions: Observed trends and climate change projections. *Journal of Agricultural Science*, *154*(5), 795–811. https://doi.org/10.1017/S0021859615000933

García-Escudero, E. (2018). *La Rioja, its vineyards and wine*s. Ed. Gobierno de La Rioja, ISBN: 978-84-8125-688-8. 200 pp.

Greer, D., & Weedon, M. (2014). Temperature-dependent responses of the berry developmental processes of three grapevine (*Vitis vinifera*) cultivars. *New Zealand Journal of Crop and Horticultural Science*, *42*(4), 233–246. https://doi.org/10.1080/01140671.2014.894921

 © 2021 International Viticulture and Enology Society - IVES

Gutiérrez-Gamboa, G., Zheng, W., & Martínez de Toda, F. (2021). Current viticultural techniques to mitigate the effects of global warming on grape and wine quality: A comprehensive review. *Food Research International, 139*. https://doi.org/10.1016/j.foodres.2020.109946

Hochberg, U., Batushansky, A., Degu, A., Rachmilevitch, S., & Fait, A. (2015). Metabolic and physiological responses of shiraz and cabernet sauvignon (*Vitis vinifera* L.) to near optimal temperatures of 25 and 35 °C. *International Journal of Molecular Sciences*, *16*(10), 24276–24294. https://doi.org/10.3390/ijms161024276

Jones, G. V. (2012). Climate, grapes, and wine: Structure and suitability in a changing climate. *Acta Horticulturae*, Vol. 931, pp. 19–28. https://doi.org/10.17660/ActaHortic.2012.931.1

Keller, M. (2015). Managing grapevines to optimize fruit development in a challenging environment: A climate change primer for viticulturists. In: *Environmentally Sustainable Viticulture: Practices and Practicality*. https://doi.org/10.1201/b18226

Levchenko, S., Volynkin, V., Likhovskoi, V., Vasylyk, I., Ostroukhova, E., Vasylyk, A., … Belash, D. (2021). The profile of the phenolic components of grape cultivars of a complex genetic structure. Acta Horticulturae, Vol. 1307, pp. 391–398. https://doi.org/10.17660/ActaHortic.2021.1307.59

Martínez De Toda, F., & Balda, P. (2015). Quantifying the effect of temperature on decoupling anthocyanins and sugars of the grape (*Vitis vinifera* L. 'Maturana Tinta de Navarrete'). *Vitis - Journal of Grapevine Research*, *54*(3), 117–120. https://doi.org/10.5073/vitis.2015.54.117-120

Martínez de Toda, F., & Ramos, M.C. (2019). Variability in grape composition and phenology of 'Tempranillo' in zones located at different elevations and with differences in the climatic conditions. *Vitis - Journal of Grapevine Research,* 58 (4), 131-139. https://doi.org/10.5073/vitis.2019.58.131-139

Mori, K., Goto-Yamamoto, N., Hashizume, K., & Kitayama, M. (2007). Effect of high temperature on anthocyanin composition and transcription of flavonoid hydroxylase genes in "Pinot noir" grapes (*Vitis vinifera*). *Journal of Horticultural Science and Biotechnology*, *82*(2), 199–206. https://doi.org/10.1080/14620316.2007.11512220

OIV (2004). Organisation Internationale de la Vigne et du Vin, 2004. *Recueil des Méthodes Internationales d'Analyse des vins et des moûts*. Ed. Office International de la Vigne et du Vin, Paris, France.

OIV (2017). Focus OIV 2017. *Distribution of the world's grapevine varieties.* OIV. Paris. 54pp

Ovadia, R., Oren-Shamir, M., Kaplunov, T., Zutahy, Y., Lichter, A., & Lurie, S. (2013). Effects of plant growth regulators and high temperature on colour development in "Crimson Seedless" grapes. *Journal of Horticultural Science and Biotechnology*, *88*(4), 387–392. https://doi.org/10.1080/14620316.2013.11512980

Pastore, C., Allegro, G., Valentini, G., Muzzi, E., & Filippetti, I. (2017). Anthocyanin and flavonol composition response to veraison leaf removal on Cabernet Sauvignon, Nero d'Avola, Raboso Piave and Sangiovese *Vitis vinifera* L. cultivars. *Scientia Horticulturae*, *218*, 147–155. https://doi.org/10.1016/j.scienta.2017.01.048

Pérez-Álvarez, E. P., Intrigliolo Molina, D. S., Vivaldi, G. A., García-Esparza, M. J., Lizama, V., & Álvarez, I. (2021). Effects of the irrigation regimes on grapevine cv. Bobal in a Mediterranean climate: I. Water relations, vine performance and grape composition. *Agricultural Water Management*, *248*. https://doi.org/10.1016/j.agwat.2021.106772

Ramos, M.C., Go, D.T.H.C, & Castro, S. (2021). Spatial and temporal variability of cv. Tempranillo response within the Toro DO (Spain) and projected changes under climate change. *OENO One 55* (1), 349-366. DOI: https://doi.org/10.20870/oeno-one.2021.55.1.4493

Ramos, M. C. & Jones, G. V. (2018). Relationships between Cabernet Sauvignon phenology and climate in two Spanish viticultural regions: Observations and predicted future changes. *Journal of Agricultural Science, 156*(9), 1079–1089. https://doi.org/10.1017/S0021859618001119

Ramos, M. C., Jones, G. V., & Yuste, J. (2015). Spatial and temporal variability of cv. Tempranillo phenology and grape quality within the Ribera del Duero DO (Spain) and relationships with climate. *International Journal of Biometeorology*, *59*(12), 1849–1860. https://doi.org/10.1007/s00484-015-0992-z

Ramos, M. C., & Martínez de Toda, F. (2019). Variability of Tempranillo grape composition in the Rioja DOCa (Spain) related to soil and climatic characteristics. *Journal of the Science of Food and Agriculture*, *99*(3). https://doi.org/10.1002/jsfa.9283

Ramos, M. C., & Martínez de Toda, F. (2020). Variability in the potential effects of climate change on phenology and on grape composition of Tempranillo in three zones of the Rioja DOCa (Spain). *European Journal of Agronomy*, *115*, 126014. https://doi.org/10.1016/j.eja.2020.126014

Ruml, M., Korac, N., Vujadinovic, M., Vukovic, A., & Ivaniševic, D. (2016). Response of grapevine phenology to recent temperature change and variability in the wine-producing area of Sremski Karlovci, Serbia. *Journal of Agricultural Science*, *154*(2), 186–206. https://doi.org/10.1017/S0021859615000453

Sadras, V. O., Petrie, P. R., & Moran, M. A. (2013). Effects of elevated temperature in grapevine. II juice pH, titratable acidity and wine sensory attributes. *Australian Journal of Grape and Wine Research*, *19*(1). https://doi.org/10.1111/ajgw.12001

Sadras, V. O., Soar, C. J., & Petrie, P. R. (2007). Quantification of time trends in vintage scores and their variability for major wine regions of Australia. *Australian Journal of Grape and Wine Research*, *13*(2), 117–123. https://doi.org/10.1111/j.1755-0238.2007.tb00242.x

© 2021 International Viticulture and Enology Society - IVES

Shinomiya, R., Fujishima, H., Muramoto, K., & Shiraishi, M. (2015). Impact of temperature and sunlight on the skin coloration of the "Kyoho" table grape. *Scientia Horticulturae*, *193*, 77–83. https://doi.org/10.1016/j.scienta.2015.06.042

Sridhar, K., & Charles, A. L. (2018). Application of multivariate statistical techniques to assess the phenolic compounds and the in vitro antioxidant activity of commercial grape cultivars. *Journal of Chemometrics, 32*(12). https://doi.org/10.1002/cem.3073

Sugiura, T., Sato, A., Shiraishi, M., Amamiya, H., Ohno, H., Takayama, N., … Konno, S. (2020). Prediction of acid concentration in wine and table grape berries from air temperature. *Horticulture Journal*, *89*(3), 208–215. https://doi.org/10.2503/hortj.UTD-141

Tarara, J. M., Lee, J., Spayd, S. E., & Scagel, C. F. (2008). Berry temperature and solar radiation alter acylation, proportion, and concentration of anthocyanin in Merlot grapes. *American Journal of Enology and Viticulture*, *59*(3), 235–247.

Tramontini, S., van Leeuwen, C., Domec, J.-C., Destrac-Irvine, A., Basteau, C., Vitali, M., … & Lovisolo, C. (2013). Impact of soil texture and water availability on the hydraulic control of plant and grape-berry development. *Plant and Soil*, 1–16. https://doi.org/10.1007/s11104-012-1507-x

van Leeuwen, C., & Darriet, P. (2016). The impact of climate change on viticulture and wine quality. *J. Wine Econ.*, *11*(1), 150–167. https://doi.org/10.1017/jwe.2015.21

van Leeuwen, C., Destrac-Irvine, A., Dubernet, M., Duchêne, E., Gowdy, M., Marguerit, E., … & Ollat, N. (2019). An update on the impact of climate change in viticulture and potential adaptations. *Agronomy, 9*(9). https://doi.org/10.3390/agronomy9090514

Vršič, S., Šuštar, V., Pulko, B., & Šumenjak, T. (2014). Trends in climate parameters affecting winegrape ripening in northeastern Slovenia. *Climate Research*, *58*(3), 257–266. https://doi.org/10.3354/cr01197

Webb, L. B., Whetton, P. H., Bhend, J., Darbyshire, R., Briggs, P. R., & Barlow, E. W. R. (2012). Earlier wine-grape ripening driven by climatic warming and drying and management practices. *Nature Climate Change*, *2*(4), 259–264. https://doi.org/10.1038/nclimate1417

Volschenk, H., van Vuuren, H.J.J., & Viljoen-Bloom, M. (2006). Malic Acid in Wine: Origin, Function and Metabolism during Vinification. *South African Journal Enology and Viticulture, 27* (2), 123-136. https://doi.org/10.21548/27-2-1613

Zheng, W., del Galdo, V., García, J., Balda, P., & Martínez de Toda, F. (2017). Use of minimal pruning to delay fruit maturity and improve berry composition under climate change. *American Journal of Enology and Viticulture, 68*(1), 136–140. https://doi.org/10.5344/ajev.2016.16038

This article is published under the **Creative Commons licence** (CC BY 4.0).
Use of all or part of the content of this article must mention the authors, the year of publication, the title, the name of the journal, the volume, the pages and the DOI in compliance with the information given above.