PROJECTED CHANGES IN THE RIOJA DOCA VINES UNDER CLIMATE CHANGE SCENARIOS

María Concepción Ramos[a*], Fernando Martínez de Toda[b]

[a] Department of Environment and Soil Sciences, University of Lleida- Agrotecnio, Alcalde Rovira Roure, 191, 25198 Lleida, Spain

[b] ICVV (Universidad de La Rioja, CSIC, Gobierno de La Rioja), Logroño, Spain, 26.006, Logroño, Spain

∗ e-m@il: cramos@macs.udl.es; fernando.martinezdetoda@unirioja.es

Introduction

The Rioja DOCa is one of the viticulture areas in Spain with a long tradition. Although the present designation of origin Rioja was approved in 1926 and the status of Qualified Denomination of Origin 'Rioja' (DOCa Rioja) was given in 1991, its origin goes back to the Middle Ages. The main cultivated variety is Tempranillo, which covers approximately 85% of the vineyard surface, followed by Grenache, which occupies about 10%. Both varieties are well adapted to the present conditions, as proven by the quality of their wines, known worldwide. However, climate change could affect their suitability in the areas where they are currently cultivated. In different areas worldwide, various studies have pointed out some effects that climate change can produce on both phenological timing in different varieties (Petrie and Sadras, 2008; Bock et al., 2011; Webb et al., 2011; Ruml et al., 2015; Alikadic et al., 2019; among other), and on grape composition (Salazar Parra et al., 2010; Sadras and Moran, 2012; van Leeuwen and Darriet, 2016).

Changes depend on the variety, location and characteristics of each region, and very little information exists about these two varieties. Both originate from Spain, with Tempranillo one of the main varieties cultivated, not only in Rioja DOCa, but in other Spanish viticultural areas as well. Grenache is cultivated in the same areas, making it necessary to analyse the potential effects that warmer conditions may have on both varieties. This research aspires to contribute to this knowledge, focussing the attention on Tempranillo, as the main red variety cultivated in the Rioja DOCa, as well as on Grenache, as the second variety in importance. The research attempts to evaluate the impact of increasing temperatures that can occur under different climate change scenarios, on phenology and on grape composition. The study covered different areas of Rioja (Rioja Alta and Rioja Oriental), and was based on the information collected in plots located at different elevations a.s.l. in both areas. The vine response at present, in its relationship with different climatic variables, was considered to predict the potential changes under climate change.

Material and methods

Study area

The research was based on the analysis of the response of both varieties Tempranillo and Grenache in seven locations distributed throughout Rioja Alta and Rioja Oriental (Fig. 1). The plots were located in the municipalities of Cenicero, Tricio and Alesanco, In Rioja Alta; and in Murillo de Rio Leza, Tudelilla, Aldeanueva de Ebro and Alfaro, in Rioja Oriental. The elevations at which the selected plots were located ranged between 325 and 650 m a.s.l. At each elevation, plots of both varieties were analysed. Soil characteristics of the selected plots were obtained from the European Soil data base (ESDAC). The soils of the selected plots are classified as Calcixerollic Xerochrept (IGN 2006) with loam and silty loam textures, and have clay contents that range between 19.0 and 27.1%; silt contents that range between 33.4 and 48.5% and sand contents that range between 30.2 and 46.2%, while the coarse fraction vary between 8.4 and 15.4%. The organic carbon contents vary between 1.1 and 1.8%.

Vine phenology and grape composition

Vine phenology referred to the phenological stages H (separated flowers) and M (veraison) defined according to Baillod and Bagiollini (1993), were analysed for the period 2008-2018 for the two varieties at each location. In addition, the date for maturity was defined based on the date in which the probable volumetric alcoholic degree (PVAD) = 13º was reached. Grape composition, including pH, total acidity (AcT), malic acid (AcM), total anthocyanins (AntT), total polyphenols index (TPI) and colour intensity (CI) were analysed at maturity in each analysed plot. The information referred, both to phenology and grape composition, was supplied by the Consejo Regulador of Rioja DOCa.

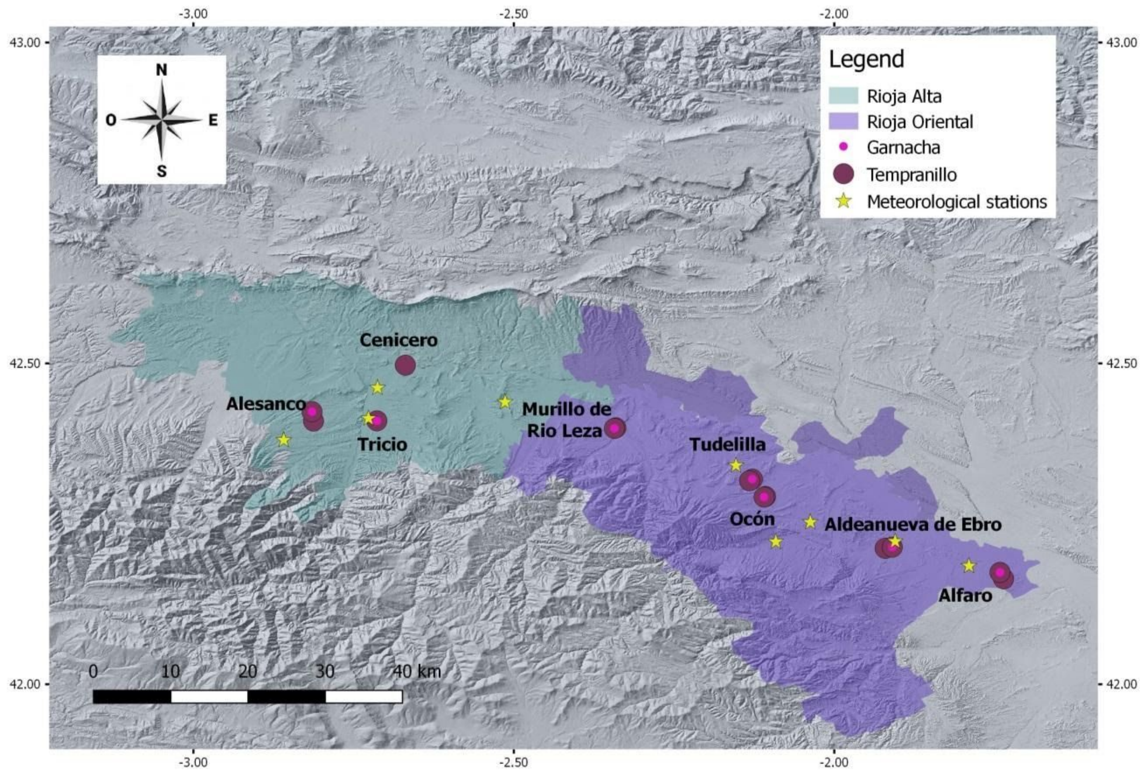


Fig. 1 Location of the plots and meteorological stations used in this analysis

Present and future climate data

The weather conditions during the analysed period (208-2018) were also analysed from data recorded at daily scale in meteorological stations located near the analysed plots (Fig.1). All the meteorological stations used in this research (Logroño, Nájera, Uruñuela, Villar de Torre, Aldeanueva de Ebro, Alfaro, Ausejo and Quel), belong to La Rioja Government.

For the future scenarios, daily maximum and minimum temperature and precipitation, predicted under two emission scenarios (RCP4.5 and RCP8.5) by 2050 and 2070 were analysed. The information used was obtained as the average of the daily information predicted using an ensemble of models (BCC_CSMI_1M; CSIRO_MRk3-6-0; GFDL_ESM2M; GISS_E2H; HADGEM_ES; IPSL_CMJA_MR; MIROC_ESM_CHEM; MIROC5; MRI_CGCM3; NorESMI_M). The data were obtained using the MarkSim™ DSSAT weather file generator, which work with a 30 arc-second climate surface derived from WorldClim (http://gismap.ciat.cgiar.org/ MarkSimGCM/docs/doc.html).

Data analysis

For each plot, the phenological dates were related to the accumulated degree days needed to reach each stage. Temperatures were accumulated beginning on 15th March (date at which heat accumulation started).The methodology is described in Ramos et al. (2018), although in this case the base temperature was taken equal cero and the maximum temperature was limited to 22ºC, according to that proposed by Gladstone (1992). The agreement between the observed and predicted dates were analysed using the root mean square error (RMSE) calculated as indicated in Eq.1. Then, the average values were considered to project the changes in phenology under climate change scenarios.

$$RMSE = \sqrt{\frac{\sum_{1}^{n}(DOYs - DOYo)^2}{n}} \qquad (1)$$

$$d = 1 - \frac{\sum_{1}^{n}(DOYs - DOYo)^2}{\sum_{1}^{n}[(DOYs - \overline{DOYo}) + (DOYo - \overline{DOYo})]^2}$$

On the other hand, the grape composition was related to climate variables using a stepwise linear multiple regression analysis (forward selection). The significant relationships for both varieties were considered to predict the potential changes under climate change scenarios.

Results

Climatic characteristics

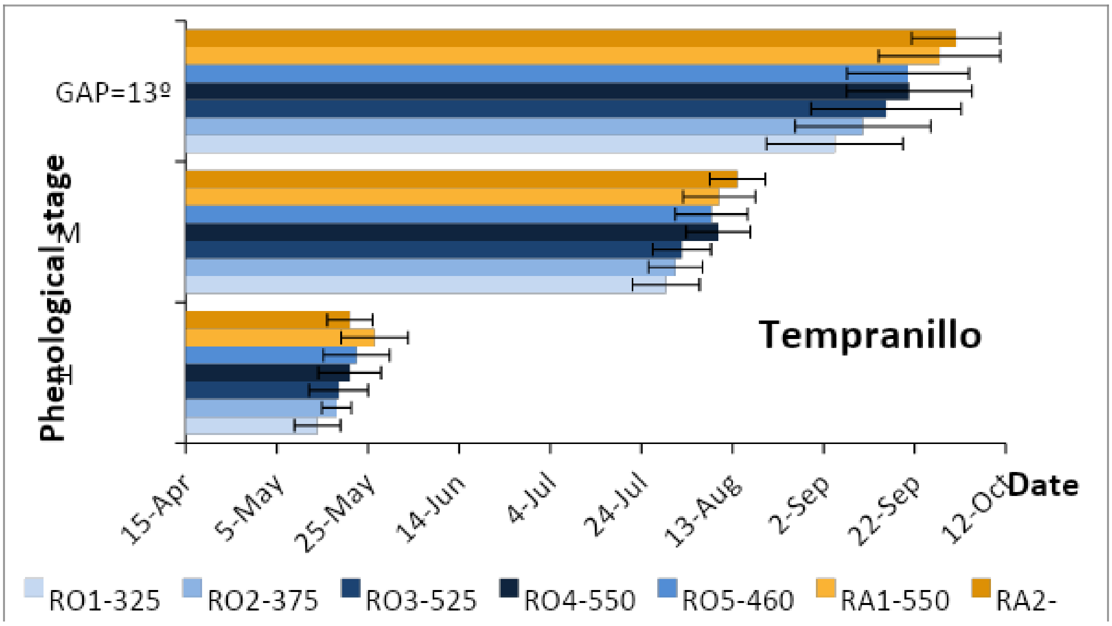
Table 1 summarizes the average climatic characteristics for the analysed period, at different locations and different elevations within the Rioja DOCa. Among the stations located at the highest and the lowest elevation, differences near 3 ºC existed both in the maximum and in the minimum growing season temperature. Regarding precipitation, the variations between zones are hidden by the high variability from year to year.

Table 1: Average maximum (TmaxGS), minimum (TminGS) and mean (TmGS) temperature and precipitation (PGS) corresponding to the growing season (15th April-15th October), and Winkler Index (WI) referred to the period 2008-2018.

	Elev. (m)	TminGS (°C)	TmaxGS (°C)	TmGS (°C)	WI GDD	PGS (mm)
Aldeanueva de Ebro	343	12.9±1.3	25.8±1.0	18.9±0.8	1842±136	227.4±99.2
Ausejo	563	12.3±0.4	23.8±1.2	17.4±0.9	1558±164	242.5±70.4
Uruñuela	450	10.5±0.5	24.4±1.2	16.9±0.8	1436±138	242.3±93.9
Villar de Torre	735	10.1±0.5	22.4±0.8	15.7±0.5	1224± 75	261.2±74.5

Phenology and grape composition

The variability observed in the climatic conditions within the area, gave rise to differences in the timing of all analysed stages, both in Rioja Alta and in Rioja Oriental (Fig. 2). There were not significant differences between the varieties. For Grenache, differences in the average flowering dates of more than 7 days were recorded between the plots located at lowest and higher elevation in Rioja Oriental (between 15 May and 22 May) and up to 10 days before than in Rioja Alta (May 25th). For veraison, the differences were up to 15 days (from Aug 4th to Aug 19th) in Rioja Oriental and up to 20 days earlier than in Rioja Alta (Aug 25th). Similarly, the differences of the date in which maturity was reached differed more than 15 days between the lowest and highest elevation in Rioja Oriental (between Sep 4th, and 21st) and up to 25 days earlier than in Rioja Alta (Oct 1st). For Tempranillo, the phenology was advanced some days in relation to Grenache but the differences between zones were of the same order of magnitude.



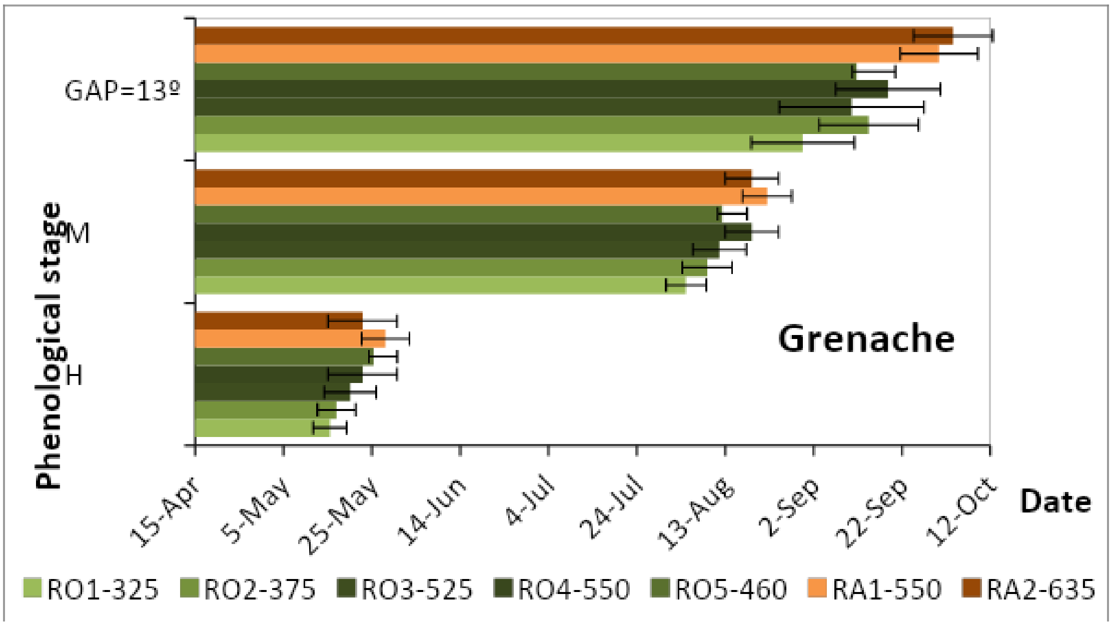


Figure 2. Average phenological dates for Grenache and Tempranillo recorded during the analysed period in the plots located at different elevation (RA1, RA2: plots located in Rioja Alta; RO1 - RO5: plots located in Rioja Oriental).

The accumulated degree days needed to reach each phenological stage were evaluated for each location. The average GDD values for stage H were 889±102 and 925±39 for Tempranillo, and 960±105 and 934±47 for Grenache, respectively in RA and in RO; the GDD needed to reach the stage M were 2404±62 and 2444±75 for Tempranillo and 2624±74 and 2595±74 for Grenache, respectively in RA and in RO. Finally, the GDD accumulated to reach the PVAD = 13° were 3302±105 and 3256±80 for Tempranillo and 3359±136 and 3183±146 for Grenache, respectively in RA and in RO. The validity of using these average values to predict the phenology was confirmed by the root mean square error (RMSE), which were 7.81, 8.55 and 6.75 for Tempranillo and 8.21, 5.88 and 9.6 for Grenache, respectively, for the stages H, M and maturity.

Regarding grape composition, some differences between plots could be also observed. The average values of variables related to acidity, anthocyanins and polyphenols at maturity for both varieties are presented in Table 2. It was observed that, for both varieties, total acidity was higher in the plots located at higher elevation, both within Rioja Alta and in Rioja Oriental (higher values in RO-T3 and RO-T4 than in the RO plots located at lower elevation; and higher acidity in RA-T2 than in RAT1). A similar trend was observed in Grenache (higher acidity in RA-G3 and RO-G4 than in the other RO´G1 and ROG2 and higher in RA-G2 than in RA-G1).

Table 2: Average values of the total acidity (AcT), malic acid (AcM), anthocyanins (AntT), polyphenols and colour index for the plots located a different elevation referred to the period 2008-2018.

	Elev. (m)	pH	AcT (g/L)	AcM (g/L)	AntT (mg/L)	TPI	CI
Tempranillo							
RO_T1	325	4.0±0.3	5.1±0.5	3.1±0.5	479±113	39.2±5.9	10.4±3.8
RO_T2	375	3.8±0.1	5.0±0.5	2.1±0.6	494± 83	39.3±6.6	11.7±2.5
RO_T3	525	3.7±0.1	5.9±1.1	3.4±1.5	467±135	41.4±8.9	12.0±4.3
RO_T4	550	3.7±0.1	5.8±0.8	2.8±1.4	458 ± 74	42.7±8.9	9.8±3.6
RO_T5	460	3.7±0.1	5.2±0.5	2.4±0.8	512± 86	39.4±6.6	13.01±2.6
RA_T1	520	3.7±0.1	5.2±0.7	2.6±0.7	459 ± 60	33.7±4.3	8.6±1.6
RA_T2	635	3.7±0.1	6.2±0.8	4.2±0.9	477 ± 68	33.0±4.7	11.4±2.3
Mean		**3.7±0.1**	**5.5±0.5**	**2.9±0.6**	**478±20**	**38.3±3.9**	**11±1.5**
Grenache							
RO_G1	325	3.5±0.1	6.0±0.6	1.8±0.6	217±37	38.1±6.8	5.9±0.9
RO_G2	375	3.5±0.1	5.5±0.5	1.0±0.3	213±58	29.4±4.7	5.2±1.2
RO_G3	525	3.4±0.1	7.0±0.7	2.6±1.1	214±37	37.6±6.0	6.4±1.2
RO_G4	550	3.4±0.1	6.6±0.9	2.1±0.9	286±74	38.6±5.6	8.1±2.1
RO_G5	460	3.6±0.6	6.1±0.9	2.3±1.0	248±73	36.5±3.7	6.9±1.9
RA_G1	530	3.4±0.1	6.6±0.9	2.9±1.0	224±72	29.1±2.8	6.4±2.0
RA_G2	635	3.4±0.1	6.9±1.0	2.6±1.1	279±109	39.7±6.9	7.9±3.5
Mean		**3.5±0.1**	**6.4±0.6**	**2.2±0.6**	**240±31**	**35.6±4.4**	**6.7±1.0**

The highest values for anthocyanins in Grenache were recorded in the plots located at higher elevation, while Tempranillo showed an opposite trend but without such clear differences. In all cases there was a correspondence between the values and the colour intensity.

For each location, it was observed that both acidity and phenolic compounds were significantly affected by temperature. A negative relationship was found between total acidity and malic acid and the average maximum temperature recorded during the growing season. Similarly, it was also confirmed a decrease of anthocyanin concentration with an increase in the maximum growing season temperature.

Expected changes in temperature and precipitation

According to the predictions made with the different models, the mean temperature of the present growing season period could increase between 2.3 and 2.4 ºC by 2050 and up to 3.3 ºC by 2070 under the RCP4,5 and between 3.3 and 3.6 ºC by 2050 and up to 3.7 ºC by 2070 under the RCP8.5 emission scenario. Regarding precipitation, a decrease is predicted, which could be between 10 and 20% under the RCP4.5 and between 20 and 30% under the RCP8.5 scenario. This may produce significant changes in the phenological timing and also in grape composition.

Projected changes in phenology

Based on the accumulated degree days required to reach each phenological stage and taking into account the projected temperatures under the analysed emission scenarios, a projection of change in the phenological timing was done by 2050 and 2070. All phenological stages will be advanced, with higher advance for veraison and maturity than for flowering. The projected advances for different areas (at different elevations) in Rioja Alta and in Rioja Oriental are shown in Table 3.

By 2050, the stage H could be advanced about 5 days and between 8 and 10 days, respectively under the RCP4.5 and the RCP8.5 scenario, with similar values for both varieties. Veraison could be advanced between 8 and 10 days, and between 12 and 15 days, respectively under the RCP4.5 and RCP8.5 scenarios. Maturity could be advanced up to 14 days and 19 days, respectively under both scenarios, with the highest advance under the most unfavourable scenario. The predicted changes agree with the observed variation between the hottest and the coolest years recorded during the analysed period (e.g. years 2012 and 2017 vs. 2008, 2013 or 2018 and they are also in agreement with results predicted in other viticultural areas (Pieri et al. 2012; Ruml et al. 2015; Hall et al. 2016).

Although the predicted advance may be higher in Rioja Alta and in the zones of higher elevation of Rioja Oriental than in the zones located at lower elevation in that area, the phenological dates at present are significantly earlier in this last zone. This means that, under the warmer predicted scenarios, the areas located at lower elevation could have maturation not only earlier but in addition under warmer conditions (during the first half August), which could have negative impacts on the maturation process and on grape composition.

Table 3: Average advance (in days) of flowering (stage H: flowers separated), veraison (stage M) and maturity (Mat= related to PVAD=13) in Rioja Alta (RA) and in Rioja Oriental (RO) at different elevations, projected by 2050 and 2070 under the RCP4.5 and RCP8.5 emission scenarios.

RC	Elev a.s.l	2050	2070

P4.5	(m)	T	H	M	Mat	H	M	Mat
	RO 325-275	Tempranillo	5	8	9	9	11	12
	RO 525-550		6	10	14	8	12	16
	RA 550-635		5	8	14	7	10	15
RCP8.5	RO 325-275		8	12	14	12	17	22
	RO 525-550		10	14	19	15	20	26
	RA 550-635		8	12	17	12	17	23
				2050			**2070**	
			H	**M**	**Mat**	**H**	**M**	**Mat**
RCP4.5	RO 325-275	Grenache	6	7	10	12	17	22
	RO 525-550		6	10	13	15	20	26
	RA 550-635		5	7	12	12	17	23
RCP8.5	RO 325-275		10	12	15	13	17	22
	RO 525-550		9	15	18	14	20	24
	RA 550-635		8	12	16	12	18	22

The predicted changes in temperature can also give rise to changes in grape composition. Table 4 summarises the predicted changes in acidity and in anthocyanin concentrations for areas located at different elevation in Rioja Oriental and in Rioja Alta. The predicted changes in total acidity could imply a decrease between 1 and 1.5 g/L depending on the location and scenario, which could represent up to 25% decrease. A decrease in total acidity has been already found in other areas, which has been attributed to an increase in temperature (van Leeuwen and Darriet, 2016) and in the same direction, Barnuud et al. (2014) in Australia projected changes in total acidity of about 15% and 12% for Shiraz and Cabernet Sauvignon, respectively, by 2070 under warmer conditions.

Regarding the anthocyanin concentrations, the reduction could be higher for Tempranillo in Rioja Oriental than in Rioja Alta, while for Grenache the changes could be opposite, higher in Rioja Alta than in Rioja Oriental. However, due to the fact that the highest values of anthocyanins in Rioja Alta were higher than in Rioja Oriental for Grenache, the change in both areas present more or less the same percentage (up to 25% under the most unfavourable scenario). Barnuud et al. (2014), in this respect, projected a reduction of anthocyanin accumulation of up to 33% by 2070 in some areas in Australia under similar climate change scenarios.

Table 4. Predicted changes in acidity and anthocyanins in Rioja Alta (RA) and in Rioja Oriental (RO) at different elevations by 2050 and 2070 under two emission scenarios (RCP4.5 and RCP8.5) (AcT: total acidity; AcM: malic acid; AntT: total anthocyanins).

RCP	Elev a.s.l (m)		2050			2070		
			AcT (g/L)	AcM (g/L)	AntT (mg/L)	AcT (g/L)	AcM (g/L)	AntT (mg/L)
RCP4.5	RO 325-275	Tempranillo	-0.9	-0.7	-87	-1.1	-0.8	-102
	RO 525-550		-1.3	-1.6	-43	-1.5	-1.9	-50
	RA 550-635		-0.9	-1.2	-63	-1.0	-1.3	-70
RCP8.5	RO 325-275		-1.2	-0.9	-111	-1.7	-1.2	-134
	RO 525-550		-1.7	-2.0	-54	-2.4	-2.8	-77
	RA 550-635		-1.4	-1.5	-70	-2.0	-1,9	-98
	RO 325-275	[illegible]	-0.9	-1.0	-55	-1.1	-1.2	-64
	RO 525-550		-1.2	-0.9	-76	-1.3	-1.0	-89
	RA 550-635		-1.0	-1.0	-77	-1.1	-1.1	-86
RCP8.5	RO 325-275		-1.1	-1.3	-70	-1.3	-1.8	-99
	RO 525-550		-1.5	-1.1	-97	-2.1	-1.5	-138
	RA 550-635		-1.5	-1.2	-99	-1.9	-1.5	-145

Conclusions

The temperature changes predicted under different emission scenarios project an advance of all phenological stages, being greater for veraison and maturation than for flowering. The projected changes may be similar for the two varieties and follow similar trends, although the advance could be one or two days greater for Tempranillo than for Grenache. Nevertheless, differences between areas located at different heights and with different temperatures are predicted, with higher advance in the cooler areas located at higher elevation. The increase in temperature will lead to a decrease in the acidity (both total acidity and malic acid) and in the anthocyanins, and may affect the sugar/ anthocyanins balance when harvesting takes place in warmer conditions.

References

Alikadic, A.; Pertot, I.; Eccel, E.; Dolci, C.; Zarbo, C.; Caffarra, A.; De Filippi, R.; Furlanello, C.; 2019: The impact of climate change on grapevine phenology and the influence of altitude: A regional study. Agric. For. Meteorol. 271, 73–82. ttps://doi.org/10.1016/j.agrformet.2019.02.030

Baillod, M.; Baggiolini, M.; 1993. Les stades repères de la vigne. Revue Suisse de Viticulture Arboriculture 324 Horticulture 25: 10-12.

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. Int. J. Biometeorol. 58, 1279–93. https://doi.org/10.1007/s00484-013-0724-1

Bock, A.; Sparks, T.; Estrella, N.; Menzel, A.; 2011: Changes in the phenology and composition of wine from Franconia, Germany. Clim. Res. 50, 69–81. https://doi.org/10.3354/cr01048

Gladstones, J.S.; 2011: Wine, terroir and climate change. Wakefield Press. Kent Town. South Australia. 273 pp.

Hall, A.; Mathews, A.J.; Holzapfel, B.P.; 2016: Potential effect of atmospheric warming on grapevine phenology and post-harvest heat accumulation across a range of climates. Int. J. Biometeorol. 60. https://doi.org/10.1007/s00484-016-1133-z

van Leeuwen, C.; Darriet, P.; 2016: The Impact of Climate Change on Viticulture and Wine Quality. Journal of Wine Economics 11, 150–167. doi:10.1017/jwe.2015.21

Petrie, P.R.; Sadras, V.O.; 2008: Advancement of grapevine maturity in Australia between 1993 and 2006: Putative causes, magnitude of trends and viticultural consequences. Aust. J. Grape Wine Res. 14, 33–45.

Pieri, P.; Lebon, E.; Brisson, N.; 2012: Climate change impact on French vineyards as predicted by models, in: Acta Horticulturae. pp. 29–38.

Ramos, M.C.; Jones, G. V, Yuste, J.; 2018: Phenology of tempranillo and cabernet-sauvignon varieties cultivated in the Ribera Del Duero DO: Observed variability and predictions under climate change scenarios. Oeno One 52, 31–44. https://doi.org/10.20870/oeno-one.2018.52.1.2119

Ruml, M., Korać, N., Vujadinović, M., Vuković, A., Ivanišević, D.; 2015: Response of grapevine phenology to recent temperature change and variability in the wine-producing area of Sremski Karlovci, Serbia. J. Agric. Sci. 1–21. https://doi.org/10.1017/S0021859615000453

Sadras, V.O.; Moran, M.A.; 2012: Elevated temperature decouples anthocyanins and sugars in berries of Shiraz and Cabernet Franc. Aust. J. Grape Wine Res. 18, 115–122. https://doi.org/10.1111/j.1755-0238.2012.00180.x

Salazar Parra, C.; Aguirreolea, J.; Sánchez-Díaz, M.; Irigoyen, J.J.; Morales, F.; 2010: Effects of climate change scenarios on Tempranillo grapevine (Vitis vinifera L.) ripening: response to a combination of elevated CO2 and temperature, and moderate drought. Plant Soil 337, 179–191. https://doi.org/10.1007/s11104-010-0514-z

Webb, L.B.; Whetton, P.H.; Barlow, E.W.R.; 2011: Observed trends in winegrape maturity in Australia. Glob. Chang. Biol. 17, 2707–2719.

Summary

The objective of this research was to analyse the potential impacts of climate change on the vine phenology and on the grape composition of two red varieties cultivated under rainfed conditions in the DOCa Rioja. The analysed varieties were Tempranillo and Grenache, which represent about 85 and 10% of the cultivated surface in the Rioja

DOCa. The analysis included information from 14 vineyards located at different elevations and with differences in the climatic conditions, distributed throughout Rioja Alta and Rioja Oriental. Phenological dates related to separated flowers (stage H), veraison (stage M) and maturity of the two varieties, as well as the grape composition at maturity recorded during the period 2008-2018 were evaluated. For the same period, daily mean, maximum and minimum temperatures and precipitation recorded in meteorological stations located near the analysed vineyards were also analysed. The prediction of future scenarios were based on the predicted temperature and precipitation changes under two Representative Concentration Pathway (RCP) scenarios –RCP4.5 and RCP8.5-, which were simulated with an ensemble of 10 models. An advance of all phenological stages was predicted, higher for veraison and maturity than for the earlier stages, and without big differences between both varieties but with differences among zones located at different elevations. Veraison was predicted to be advanced up to 10 days for 2050 and up to 15 days by 2070 under the RCP4.5 scenario, while under the RCP8.5 scenario, the advance by 2070 could be up to 20 days for both varieties. For maturity, the advance could be up to 26 days for Tempranillo and 24 days for Grenache, with differences between the cooler and the warmer areas. Based on the relationship between grape composition and climate variables, a decrease in acidity as well as a reduction in the total anthocyanin content is expected for both varieties