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VARIABILITY OF TEMPRANILLO PHENOLOGY WITHIN THE TORO DO (SPAIN) AND ITS RELATIONSHIP TO CLIMATIC CHARACTERISTICS

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Abstract

Aims: The objective of this research was to analyse the spatial and temporal variability of vine phenology of the Tempranillo variety in the Toro Designation of Origen (DO) related to climatic conditions at present and under future climate change scenarios.

Methods and Results: Seven plots planted with Tempranillo, distributed throughout the DO, and located at elevations between 630 and 790 m a.s.l were considered in this analysis. Phenological dates referred to bud break, bloom, veraison and maturity recorded in each plot for the period 2005-2019 were analysed. The information was supplied by the Consejo Regulador of Toro Designation of Origin (Toro DO). The weather conditions recorded during the period under study were analysed using data recorded in Toro. The thermal requirements to reach each phenological stage were evaluated and expressed as the GDD accumulated from DOY=90, which were considered to predict the changes under future climatic conditions. For future climatic conditions, temperature and precipitation predicted by 2050 and 2070 under two Representative Concentration Pathway (RCP) scenarios –RCP4.5 and RCP8.5-, based on an ensemble of models, were used to predict the changes in phenology.
During the analysed period, the dates at which the different phenological stages were reached presented high variability, with bud break between April 5th and May 7th; bloom between May 3rd and July 14th, veraison between July 20th and August 21st and maturity between September 1st and October 2nd. The earliest dates were observed in the hottest year (e.g. 2017), while the latest dates were recorded in the coolest and wettest years (eg. 2008, 2013 or 2018). Water deficits also gave rise to advances in phenological timing (e.g. 2009, 2015), which affect more the later than the earlier phenological states. Water deficit in the BL-V period had a significant effect on veraison, while in general the maturity was also affected by water existing in the BB-BL period. Some spatial variability was observed in the phenological dates, although the trend was not uniform for all the stages or for all years. Taking into account the thermal requirements to reach each stage and the predictions under future climate scenarios, advances in all phenological dates were projected, higher for the later than for the earlier stages, which may be of up 6 and 8 days for bud break, 7-10 days for bloom, 8 to 11 days for veraison, and 12 to 19 days for maturity by 2050, respectively under RCP4.5 and RCP8.5 emission scenarios.

Conclusion: Based on the climate change projections, the Tempranillo variety cultivated in Toro DO may suffer an advance of all phenological stages, having harvest earlier and under warmer conditions, which could also affect grape composition.

Significance and Impact of the Study: Tempranillo is the third most cultivated wine variety in the world, being 88% of it cultivated in Spain, and in the Toro DO the main variety (“Tinta de Toro”) covering about 5100 ha. Thus, the knowledge of the vine response under future conditions could be a tool to adopt measurements to mitigate the effects of climate change in the area.

Keywords: Climatic change, phenological dates, spatial and temporal variability, temperature, Toro DO, water deficit

Introduction

In different viticultural areas all over the world, changes in phenological timing are being observed and associated to the increase in temperature and to changes in precipitation recorded during the last decades. An advance of phenology and a shortening of the growing cycle has been predicted (Duchêne and Schneider, 2005; Pieri *et al.,* 2012; Webb *et al.,* 2012; Koufos *et al.,* 2014; Ramos and Jones, 2018). However, the changes may be different for each variety and location. Each cultivar is adapted to a given range of temperatures. However, the variability in the predicted changes in temperatures and precipitation may impact cultivars in different zones in different ways. Temperature is usually shown as the main conditioning factor, but water availability may also have significant effects not only on phenology but al o on grape composition (Salazar Parra *et al.,* 2010; Bonada *et al.,* 2015).

This research focused on the cv Tempranillo, which represents greater than 21% of the vineyard area in Spain, and above 50% of the red varieties cultivated in that country. Within Spain, the research was carried out in the Toro Designation of Origin (Toro DO), in which the Tempranillo variety is the main variety (locally named "Tinta de Toro"), covering about 5,100 ha with an annual grape production of more than 20 million kg (Consejo Regulador of Toro DO, https://www.dotoro.com). This variety has a short growth cycle with an early bud break and early ripening, which may make this variety more sensitive to temperature increase. The aim of this research was to analyse the variability of phenology within the DO and to predict its potential changes under future climate change scenarios.

Material and Methods

Phenological dates referred to budbreak, bloom, veraison (stages C, I and M according to Baggiolini classification) (Baillod and Baggiolini, 1993) and maturity (based on the date at which the probable alcoholic degree =13° was reached) for the period 2005-2019 were analysed. The information was recorded for seven plots planted with Tempranillo, distributed throughout the DO (Figure 1) and was supplied by the Consejo Regulador of Toro DO. The vineyards were located at elevations between 630 and 790 m a.s.l, and all of them were cultivated under rainfed conditions. The weather conditions (temperature and precipitation), recorded during the period under study, were analysed using data recorded by the Toro weather station (51º 21'3.53" W; 41º 30' 36.14"N), which belongs to the network managed by the Instituto Tecnológico Agrario, Junta de Castilla y León (ITACYL).

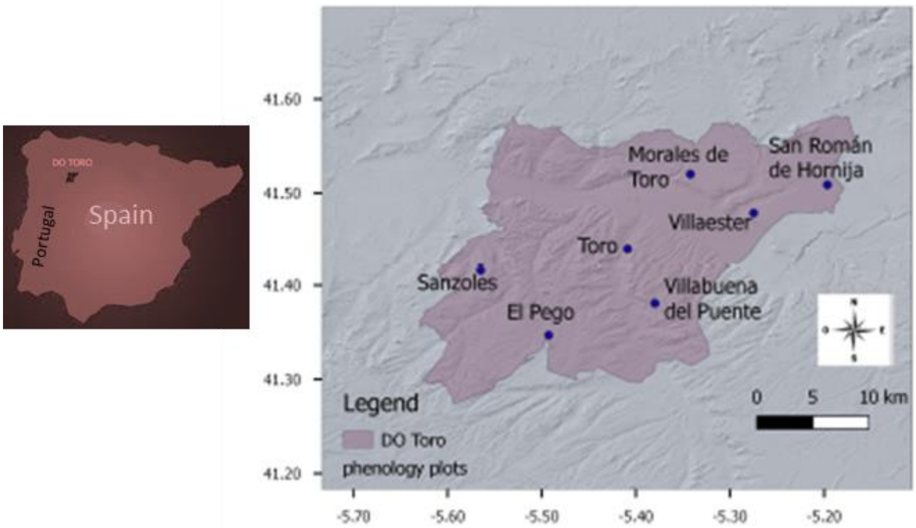

Figure 1: Location of the study area.

The thermal requirements to reach each phenological stage were evaluated and expressed as the GDD accumulated from the date at which the chill phase full filed and determining the optimal base temperature for each period, following the methodology described in Ramos (2017). The obtained GDD were used to predict the changes under future climatic conditions. For future climatic conditions, temperature and precipitation predicted by 2050 and 2070 under two Representative Concentration Pathway (RCP) scenarios –RCP4.5 and RCP8.5-, were analysed. The information was generated with the MarkSim weather file generator using an ensemble of models

(Jones and Thornton, 2013). The influence of climate variables on phenology was analysed by partial regression analysis.

Results and Discussion

Temporal and Spatial Variability of Phenology in the Toro DO

The dates at which the different phenological stages were reached during the period analysed presented high variability, with bud break between 10th April and 7th May; bloom in June (between 2nd and 30th), veraison between 25th July and 21st Aug. and maturity between 1st Sept. and 1st.Oct. There were no differences between the seven analysed locations for a given year. However, differences of up to one month were observed between years (Figure 2).

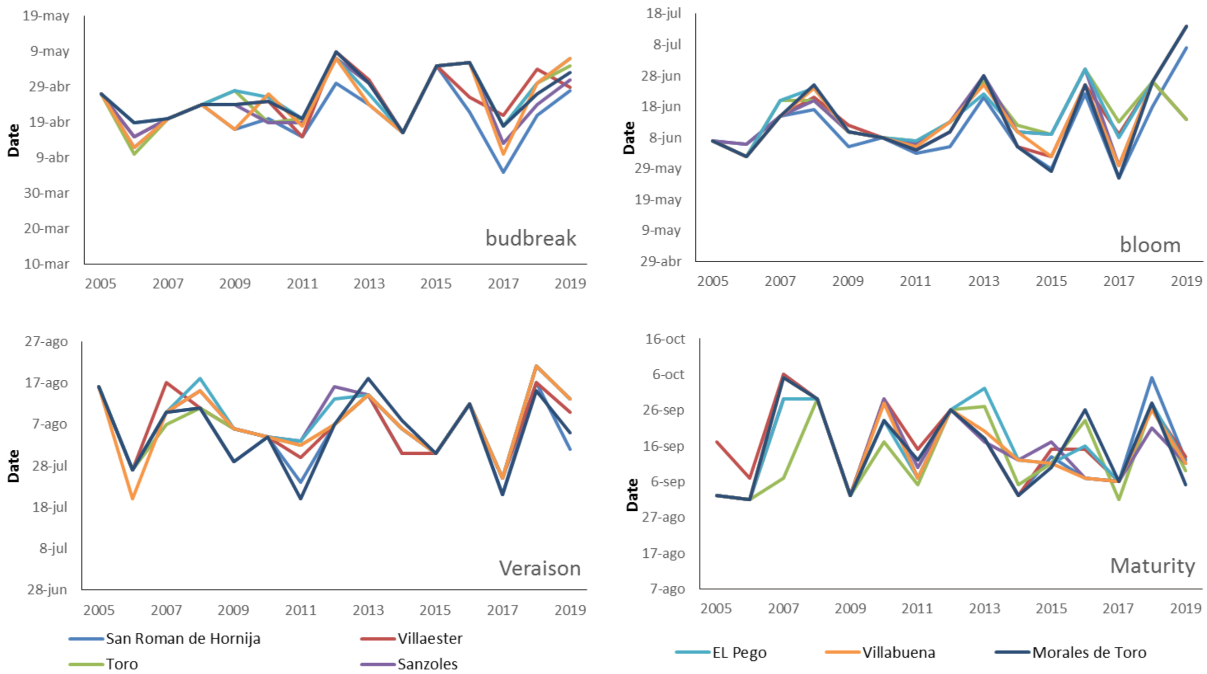

Figure 2: Variability of phenology (bud break, bloom, veraison and maturity) during the period 2005-2019.

Influence of Climate Variables on Phenology

The earliest dates were observed in the driest (e.g. 2006) and hottest years (e.g. 2017). On the other hand, the latest dates occurred in the wettest and cooler years of the analysed series (e.g. 2007, 2008, 2013 or 2018).

The analysis of the chill and heat units and the relationship between bud break dates and chill units indicated that the heat accumulation started on DOY (day of year) = 90. Accumulating temperatures from that date it was found that the base temperature to reach bud break was 6.6°C. Then the base temperature for the following stages were estimated considering the accumulated temperatures from the previous stage, with 0, 7.5 and 7°C, respectively for bud break to bloom, bloom to veraison and veraison to maturity periods, respectively. The thermal requirements, expressed in GDD, needed to reach the respective analysed stages, using these base temperatures were 109±83, 782±109, 1148±142 and 696±197 GDD, respectively. These values were used to make projections of the phenology under climate change.

The influence of climatic variables was quantified with the regression analysis and the results are shown in Table 1. The variables that gave rise to better fits include accumulated temperatures (GDD) and available water (accumulated precipitation –evapotranspiration), recorded in different periods between phenological events.

Table 1: Coefficients of the Partial least squares regression (PLS regression) analysis between phenological dates [budbreak(BB); bloom (BL), veraison(V) and maturity (Mat)] and climatic variables (number of frost days until budbreak (NdT<0), accumulated temperature (GDD) and precipitation- crop evapotranspiration (P-ETc) for different periods between phenological events [BB: period from DOY=91 to budbreak; BB-BL: period budbreak to bloom; BL-V: period bloom to veraison; V-Mat: period veraison to maturity].

	Variables	Coefficients	% Variance	Loadings/Variance	
				Comp1	Comp 2
Budbreak			**87.02%**	**82.56%**	**5.72%**
	P BB	0.2954		0.001	**0.8194**
	GDD BB	**0.8324**		**0.8932**	0.2446
	NdT<0	0.2954		**0.4493**	-0.3316
Bloom			**47.55%**	**47.55%**	
	NdT<0	0.1319		0.1028	
	GDD_BB	**0.6129**		**0.7215**	
	GDD BB-BL	**0.6145**		**0.6634**	
	P-ETc BB-BL	0.0575		-0.1695	
Veraison			**72.19%**	**67.64%**	**5.80%**
	GDD BB	0.3003		0.3515	0.2605
	GDD BB-BL	**0.6263**		0.3659	**0.8913**
	GDD BL-V	0.176		0.3450	-0.2359
	P-ETc BB-BL	0.0481		0.0639	0.2812
	P-ETc BL-V	**-0.6083**		**-0.7870**	0.0054
Maturity			**73.69%**	**54.59%**	**19.10%**
	GDD BB	0.3253		0.1520	0.2610
	GDD BB-BL	0.1926		0.3525	0.0006
	GDD BL-V	-0.01226		-0.3148	0.033
	GDD V-Mat	**0.5152**		**0.6229**	0.3639
	P-ETC BB-BL	**0.4304**		**0.5764**	0.2432
	P-ETc BL-V	**-0.3850**		-0.1298	**-0.6604**
	P-ETC V-Mat	-0.0385		-0.1211	0.0560

The variables that represented a higher percentage of the variance were the variables related to temperature, in particular during the first stages. The variance explained by the variables related to temperature were 82.5 and 47.6% respectively for bud break and bloom. However, veraison seemed to be mainly driven by water availability during the previous period (period bloom to veraison), representing this factor up to 67% of the variance, and it has also a significant effect on the maturation date (representing about 19% of the variance).

Projected Changes in Phenology under Climate Change Scenarios

The ensemble models used in this research predicted an increase in temperature for the period corresponding to the present average growing season of about 2.1 and 2.9°C for Tmin and 2.5°C and 3.4°C for Tmax, respectively by 2050 and 2070 under the RCP4.5 emission scenario. Under the RCP8.5 scenario, by 2070, the increase for the minimum and maximum temperatures could be up to 4 and 5.3°C, respectively. Regarding precipitation, a decrease of up to 40% could be recorded during the growing season, which is already lower than vine water needs, which imply an increase in water deficits.

Based on the thermal requirements to reach each stage and the above predicted changes in climate variables, advances in all phenological dates are expected, which could be higher for the later than for the earlier stages. Bud break might be advanced up to 6 and 8 days by 2050, respectively under RCP4.5 and RCP8.5 emission scenarios. For the same period and scenarios, advances of up to 7 to 10 days, 8 to 11 days and 12 to 19 days, are projected respectively for bloom, veraison and maturity. Under the RCP8.5 scenario, the advance may imply harvesting near one month earlier than at present by 2070. The projected changes are shown in Fig. 3. The predictions are in agreement with the observed differences between years with different weather conditions recorded during the period under study, and in line with that indicated by other authors in other European regions (Jones *et al.,* 2005; Bock *et al.,* 2011; Koufos *et al.,* 2014), which has been linked to changes in the maximum and minimum temperatures. The projected advance is a little bit greater than expected for the same variety cultivated in Rioja (Ramos and Martínez de Toda, 2020), and little smaller than in Ribera de Duero (Ramos *et al.,* 2018). The comparison of projections for areas located at different elevations indicated higher advance in the cooler areas. However, the final effects could be worst for the warmer areas, where at present harvesting already occur significantly earlier.

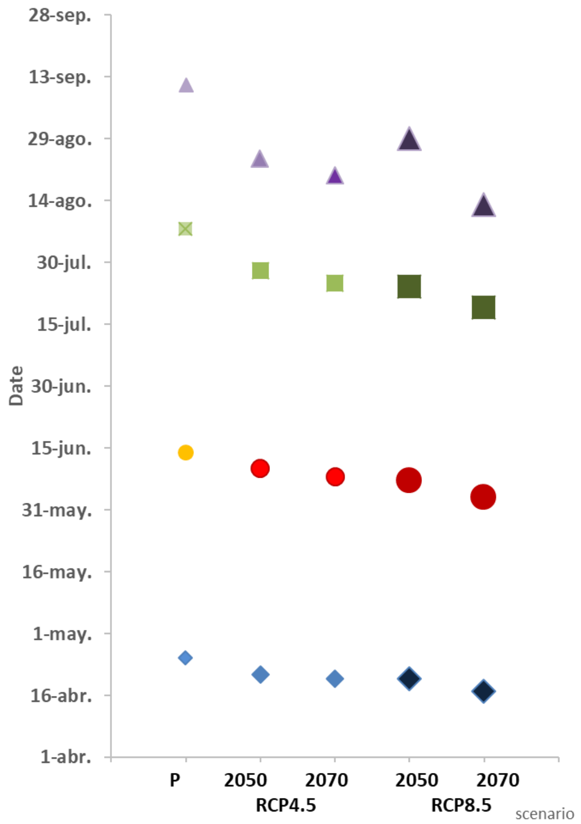

Figure 3: Projected changes in phenological timing of Tempranillo in Toro DO under RCP4.5 and RCP8.5 climate change scenarios, by 2050 and 2070.

Conclusion

The results confirmed the variability in phenology from year to year within the Toro DO, mainly driven by the variability of temperature and water availability during the growing season. The results confirmed the effect of temperature and available water on phenology, being the period between bloom and veraison, the one that have higher effect on veraison and maturity. The observed trends in temperature and precipitation and the predicted changes, using an ensemble of models, demonstrates significant advances in all phenological phases, which may be greater for the later than for the earlier phases. The advance in phenology will give rise to ripening occurring under warmer conditions, which could affect also grape quality.

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