PHENOLOGICAL RESPONSE OF CABERNET SAUVIGNON UNDER CLIMATE CHANGE IN TWO SPANISH REGIONS WITH DIFFERENT CLIMATIC CHARACTERISTICS

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Abstract
In this research the phenology of Cabernet Sauvignon was evaluated under present climate and a future climate change scenario. Two regions were compared: Ribera del Duero and Penedès, located respectively in the center and northeast of Spain. In Ribera del Duero, vineyards are cultivated between 700 and more than 1000 m a.s.l, while in the Penedès they are located between sea level and about 800 m. Annual rainfall in both regions ranged between 400-600 mm, with wet winters and dry summers. However, in the Ribera del Duero, the climate is more continental with long, cold winters and sudden temperature changes throughout the year, while the Penedès has a mild and temperate climate with high insolation hours. Phenology data referring to budbreak (BB), bloom (BL), veraison (V) and harvest (H) were analyzed for the period 2003-2015 in the Ribera del Duero and for 1996-2012 in the Penedès. Daily temperature and precipitation from each area, recorded respectively at Aranda de Duero and Els Hostalets de Pierola for the same periods were also evaluated. The relationships between the phenological dates and climate variables were analyzed using a multiple stepwise regression. Changes in climate were simulated using the average of 10 models integrated in the Coupled Model Intercomparison Project (CMIP5) and for two Representative Concentration Pathways (RCP) scenarios – RCP4.5 and RCP8.5 by 2050 and 2070. Differences of about 6 days for BL and about 12 days, on average, for V existed between the two areas. The results showed that increasing Tmin and Tmax for the period before BB and between BB and BL have significant effects on advancing all phenological stages in the Ribera del Duero, while in the Penedès region the temperature recorded between BL and V also had influence on phenology. Using the relationships found under present conditions, future advances predicted for for bloom were quiet similar in both regions (5.6 vs. 5.3 days by 2050 and 7.1 vs. 6.1 days by 2070), but higher in the Penedès for veraison (9.0 vs. 4.8 days and 11.7 vs. 6.6 days), and harvest (14.1 vs. 6.9 days and 17.9 vs. 8.8 days), respectively by 2050 and 2070 under the RCP4.5 scenario. For the more extreme scenario (RCR8.5), the respective advance in by 2070 could be up to 11.7 and 8.9 days for bloom, up to 16 and 11 days for veraison, and 22.0 and 12.2 days for harvest, respectively for the Penedès and Ribera del Duero regions.

Keywords: climate change, phenological dates, Penedès, RCP4.5, RCP8.5, Ribera del Duero, temperature.

1 INTRODUCTION
Growing season temperatures define the suitability of a given region to grow specific winegrape varieties. Each variety has its own phenological timing due to its own morphological and physiological characteristics, and growing season temperatures define the suitability of each variety to be grown in a given area (Jones et al., 2006). However, while these relationships vary slightly from year to year under historic conditions, increasing temperatures may have direct in onset phenology and the length of the growing season with further consequences for grape quality. Furthermore, within the present suitable temperature range for a given variety, the question arises of what the effect of climate change will have on the variety being grown in different regions?

The increasing temperatures recorded during the last 50-100 years in different regions worldwide have shown that growing seasons have shortened with an advance of the majority of grapevine phenological stages (Jones and Davis, 2000; Duchêne and Schneider, 2005; Sadras and Soar, 2009; Bock et al, 2011; Urhausen et al., 2011; Webb et al., 2012; Ruml et al., 2015). As a result of the shortening of the ripening period, harvest occurs during the period with higher temperatures, which could have a negative impact on grape and wine quality (Salazar Parra et al., 2010; Duchêne and Schneider 2005; Jones and Davis, 2000) and yield (Mira de Orduña, 2010; Iglesias et al., 2010).

In this research, the phenology of Cabernet Sauvignon, which is typically suitable for average growing season temperatures between 16 and 20°C, was evaluated for present conditions and under future climate change scenarios (Representative Concentration Pathways (RCP) scenarios – RCP4.5 and RCP8.5 by 2050 and 2070) for two regions in Spain, with different climatic characteristics for viticulture and wine production.

2 MATERIALS AND METHODS

Study areas

The analysis included information collected in two viticultural areas: Ribera del Duero and Penedès. Both areas have a long tradition in vine cultivation. They represent about 2.4 and 2.3% of the vines cultivated in Spain.

The Ribera del Duero is located in the north central region of Spain (Figure 1), in the large septentrional plateau formed by a large basement filled with Tertiary deposits, and average to lower terraces from the Duero River (Quaternary). The area covers approximately 115 km along the Duero River. Vineyards are cultivated between 700 to more than 1000 m a.s.l., on the river terraces and on hillslopes. About 87% of the vines are planted with red varieties (Tempranillo, Cabernet Sauvignon, Grenache, Malbec and Merlot) and the rest are white varieties (mainly Albillo). The vineyards analyzed in this study were located close to Aranda de Duero, at elevations between 800 and 850 m. The soil types in the plots are classified as *Typic Xerofluvent* and *Calcic Haploxeralf*. The age of the vineyards were 20 years and the training system was vertical trellis. The climate is continental with long and cold winters and dry or temperate summers, with sudden temperature changes throughout the year.

The Penedès area is located in northeastern Spain (Figure 1). This region forms part of the Penedès Tertiary Depression. In this area, the main lithological types are calcilutites (marls), with occasional sandstones and conglomerates. About 82% of cultivated grapes are white varieties, mainly Macabeo, Xarelo, Parellada and Chardonnay, and the rest (about 18%) are red varieties (mainly Tempranillo, Merlot and Cabernet Sauvignon). The climate in the area is predominantly Mediterranean with a maritime influence. It is characterized by warm, wet winters and hot and dry summers and with higher insolation hours. The vineyards included in this study have been planted for 25 years. The soils in the plots of the study were classified as *Typic Xerorthents* and *Fluventic Haploxerepts*, and the training system was vertical trellis.

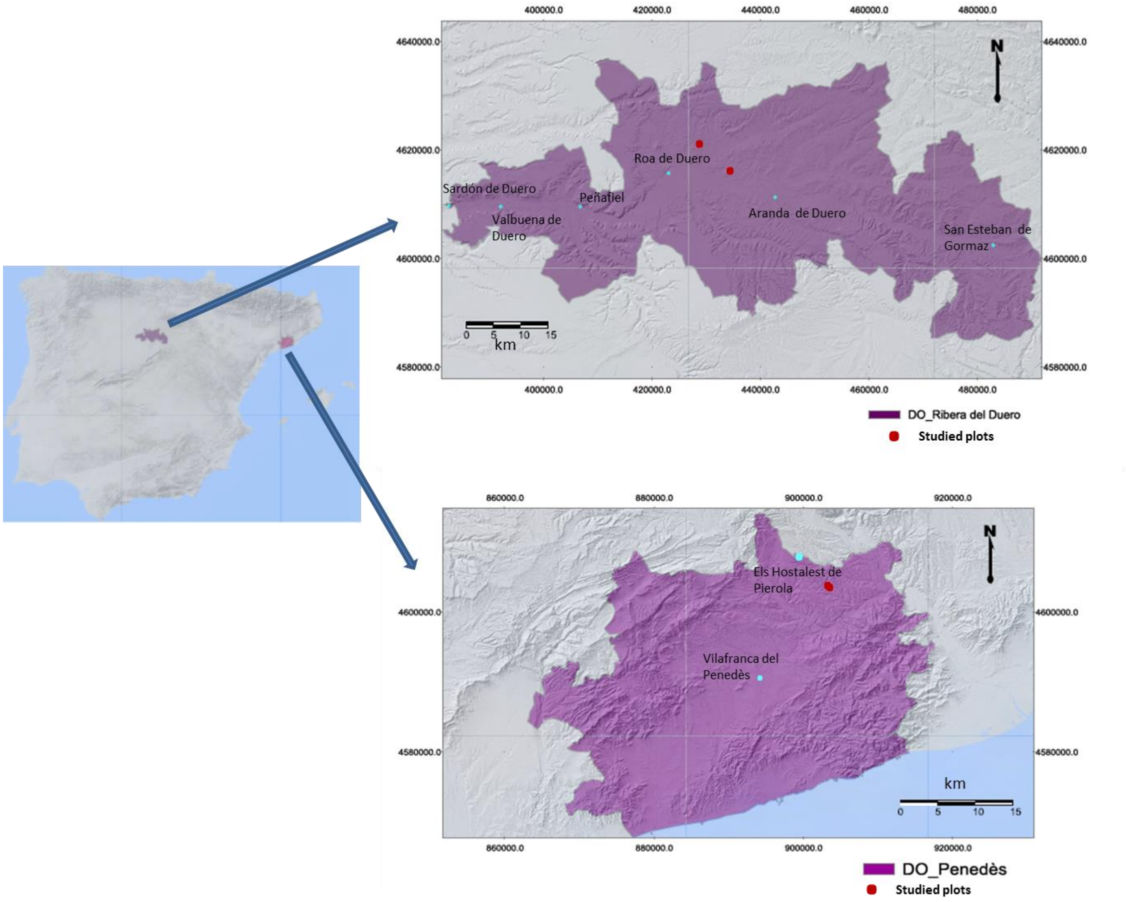

Figure 1: Location of the study areas, meteorological stations and plots used in the analysis.

Data and analysis

Climate data: Daily climatic data [maximum and minimum temperature (Tmax, Tmin) and precipitation (P)], recorded respectively at Aranda de Duero (Ribera del Duero) and Els Hostalets de Pierola (Penedès) for the period 1996-2015 were evaluated. These meteorological stations were the closest ones to the studied vineyards with available data. The data were averaged for each year and for the periods between phenological dates. Additionally, commonly used bioclimatic indices such as the Winkler index (WI) and the HI index (HI) were calculated.

Phenology data: Phenological dates referred to budbreak (BB), bloom (BL), veraison (V) and harvest (H) were collected in both areas, for the period 2004 to 2015 in the Ribera del Duero and for 1996 to 2012 in the Penedès. The data from Ribera del Duero were supplied by the Consejo Regulador of Ribera del Duero. For the Penedès, the data were supplied by the growers in the region. Data from two plots located relatively close one to each other were analyzed in each area.

Climate change scenarios: Changes in climate were simulated using 10 models integrated in the Coupled Model Intercomparison Project (CMIP5) [MOROC5; ACCESS1.0; CNRM_M5; INMCM4; MPI-ESM_MR; HadGEM2-CC; CMCC-CM; BCC-CSM1-1; MSI_CGCM1; BNU-ESM] and for two Representative Concentration Pathways (RCP) scenarios – RCP4.5 and RCP8.5 by 2050 and 2070. Data were downloaded at daily time scale for 2006-2100 and compared with the period (1970-2000). The predicted values for maximum (Tmax) and minimum (Tmin) temperatures were calibrated for the growing season and then also analyzed for different periods between phenological dates (period before BB, BB to BL, BL to V and V to H). The degree of accuracy was estimated using two statistics (PBIAS and NSE). The average values estimated using the EMSEMBLE of models were considered in the final analysis.

Climate-phenology relationships and prediction: Different variables related to Tmax and Tmin for different periods between phenological dates were defined based on the observed dates corresponding to the different phenological stages in each viticultural area. The relationships between the phenological dates and climate variables were analyzed using a multiple stepwise regression. Predicted changes in phenology for both areas, based on the relationships between phenological dates and climate variables and the predicted changes in temperature, were evaluated and compared.

3 RESULTS AND DISCUSSION

Climatic characteristics of the study areas

Within the period analyzed, the average Tmin in Ribera del Duero ranged between 7.2 and 9.8°C, while in the Penedès it ranged between 11.8 and 17.0°C. The differences in Tmax were smaller: they ranged between 23.9 and 27.0 ºC in Ribera del Duero and between 23.3 and 28.0 in the Penedès. Differences in the WI were similar, ranging between 1098 and 1584 GDD in Ribera del Duero and between 1788 and 2530 GDD in the Penedès. Annual rainfall varied between 244 and 550 mm in the Ribera del Duero and between 398 and 903 mm in the Penedès, where the variability from year to year was also higher. The wetter years were not always the same in the two areas, and they were not the years which recorded higher rainfall during the growing season. During the growing season, precipitation varied between 75 and 454 mm in the Penedès and between 160 and 305 mm in Ribera del Duero. The highest differences were observed in the period between veraison and harvest.

Phenology dates recorded in the study areas

The average dates for each phenological stage were; April 13th (BB), May 24th (BL), Aug 9th (V) and September 21st (H) in the Penedès area, April 30th (BB), May 30th (BL), Aug 21st (V) and October 4th (H) in Ribera del Duero. Differences of more than 15 days in BB, and approximately 6 days for BL and about 12 days for V, on average, were observed between the two areas with earlier timing in Penedès than in Ribera del Duero. These differences were mainly driven by differences in temperature, and in particularly in Tmin. Based on these observed dates different periods were established for each area, which were then used to analyze the influence of climate on phenology and examine future climate scenarios. The periods established in each area were: for Penedès March1st to April 15th (period before BB); April15th to May 31st (BB to BL); Jun 1st to Aug 10th (BL to V) and April 15th to Sep 30th (V to H); for Ribera de Duero March 1st to April 30th (period before BB); May 1st to May 31st (BB to BL); June 1st to Aug 31st (BL to V) and April 15th to Sep 30th (V to H).

Relationship between phenological dates and climatic variables

The dates of each phenological stage were related to maximum and minimum temperature although the variables that better fitted were different in the two areas. In the Ribera del Duero, BB was related to Tmin observed during the dormant period, and the rest of stages were related to Tmin recorded between BB and BL. In the Penedès, BB dates were related to Tmin during the dormant period; BL exhibited significant correlation with Tmax for the period between BB and BL; V dates were related to Tmin during BL to V, and H dates were related to Tmin recorded between BB and BL. The results showed that increasing temperature, and in particular an increase in Tmin, could give rise to and advance of almost all pheological events in both areas, although the timing of the events were related to different periods. Increasing Tmin during the dormant period just before BB and between BB and BL have significant effects on advancing all phenological stages in Ribera del Duero, while in the Penedès region temperatures recorded between BL and V had also influence on phenological timing.

Predicted changes in phenology associated with different climate change scenarios.
Figure 2 shows the predicted trends of growing season maximum and minimum temperatures under the scenarios RCP4.5 and RCP8.5 after calibration. According to Moriasi et al., (2007) the degree of accuracy was satisfactory for two statistics used, with PBIAS <10% and NSE values> 0.9. The fit was better for Tmax than for Tmin. Similar values for the statistics were found when the different periods corresponding to BB-BL, BL-V and V-H were considered. However, the temperature for the dormant period exhibited the worst fit. The predicted changes in Tmin for the period before BB in the Penedès, for the years 2050 and 2070, were estimated in 1.5 and 1.9 ºC under the scenario RCP4.5, and 1.8 and 2.7ºC for the scenario RCP8.5. For the Ribera del Duero, the estimated changes were respectively 0.7 and 1.1ºC under the scenario RCP4.5 and 1.1 and 1.9ºC for the scenario RCP8.5. The changes for Tmin for the period between BB and BL by 2050 and 2070, were respectively 1.7 and 2.5 ºC for the Penedès and 1.0 and 1.2 ºC for the Ribera del Duero, under the scenario RCP4.5; and 1.8 and 2.7ºC for the Penedès and 1.3 and 2.4 ºC for the Ribera del Duero, under the scenario RCP8.5. For the period between BL and V, the changes in Tmin in the Penedès were estimated to be 2.5 and 3.0ºC under the scenario RCP4.5 and 3.2 and 4.5 ºC under the scenario RCP8.5, respectively by 2050 and 2070.

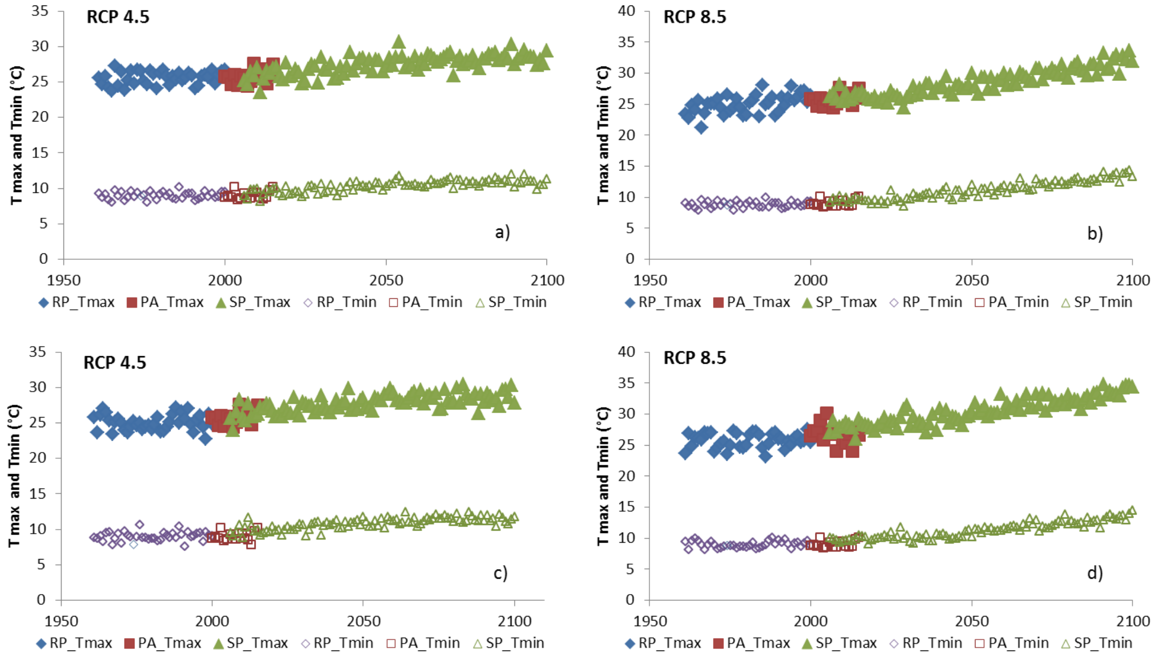

Figure 2. Predicted maximum and minimum growing season temperature trends under the scenario RCP4.5 and RCP 8.5 for both studied areas

Based on the observed relationships between phenology and the climate variables and the predicted changes of temperature for the specific periods, the expected changes in the phenological stages under the different scenarios were estimated. The results for both areas are shown in Figure 3.

The advance in the phenological dates, for the same variety, is projected to be higher in the Penedès than in Ribera del Duero. Under the scenario RCP4.5, budbreak in the Penedès may experience an advance of 6 days or more by 2050 and 8 days or more by 2070, while in Ribera del Duero the advance is estimated at 2.3 and 3.8 days, respectively by 2050 and 2070. For bloom, lower differences between the two areas were simulated, which ranged between 5.3 and 5.6 days by 2050 and between 6.6 and 7.1 days by 2070 under the scenario RCP4.5, while under the scenario RCP8.5, the changes are projected to be 8.9 and 11 days by 2070, respectively in Ribera del Duero and Penedès areas.

For veraison and harvest the advance is projected to be much higher in the Penedès than in Ribera del Duero: For veraison: 9.0 vs. 4.8 days by 2050 and 11.7 vs. 6.6 days by 2070 under the scenario RCP 4.5 and 10.1 vs. 6.1 days and 16.1 vs. 11.9 days by 2070 under the scenario RCP8.5. For harvest the advance is projected to be 14.1

vs.6.9 days by 2050 and 17.9 vs. 7.4 days by 2070 under the scenario RCP4.5, and the advance is projected to be nearly doubled under the scenario RCP8.5

The advance for bloom and veraison were of higher magnitude that those of budbreak, which is in agreement with that found by Fraga et al (2015) and Malehiro et al. (2013). These researchers indicated an advance of bloom between 2 and 6 days and between 6 and 14 days for veraison. The predicted advance for bloom and veraison was higher in the warmer rergion, located at lower elevation a.s.l., which is in agreement with the higher increase in Tmax observed in the area. A shortening of the time between phenological periods was also observed in agreement with those documented by other researchers (Moriondo and Bindi, 2007; Ferrise et al, 2014). Advancing phenology of this magnitude will bring ripening into summer under higher temperatures than at present, and harvest may occur both earlier in the year and in a warmer conditions, which may affect grape quality attributes. In particular, high temperatures during ripening may give rise to smaller berries and therefore lower yield (Kliever, 1977), and inhibition of color and polyphenols development (Kliewer and Torres, 1972; Mori et al., 2007; Deis et al., 2012; Sadras and Moran, 2012) and disjointed or off flavors (Mullins et al, 1992).

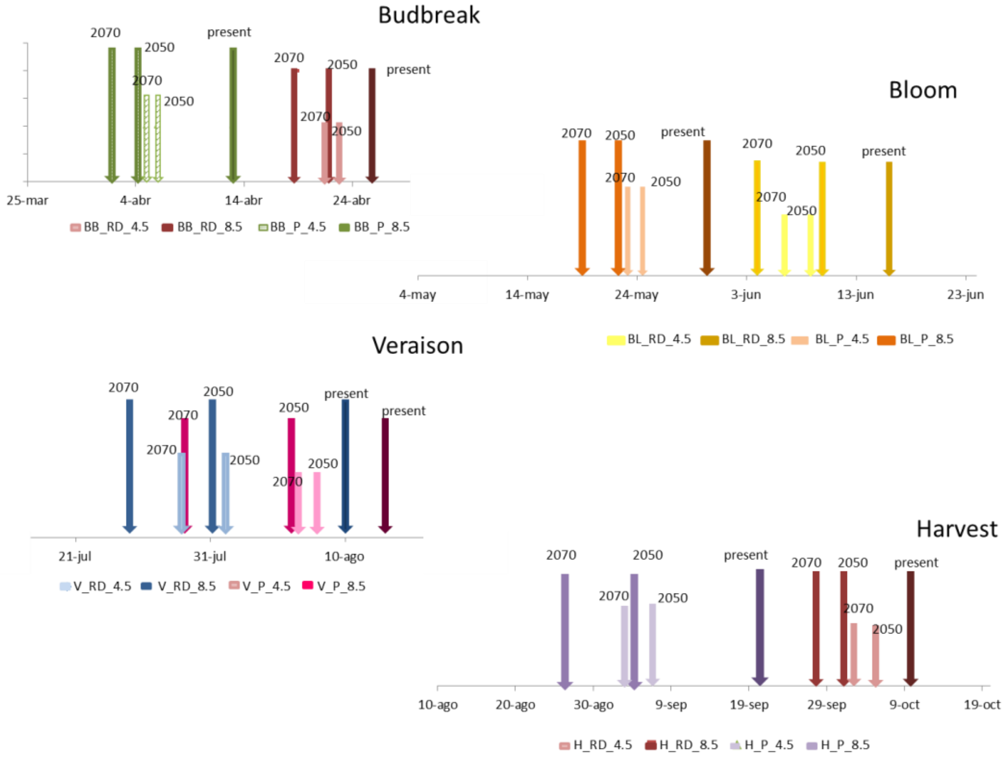

Figure 3. Predicted changes of the phenological dates (budbreak: BB; BL:bloom; V:veraison; H:harvest) under the scenario RCP4.5 and RCP 8.5 by 2050 and 2070 in both studied areas

4 CONCLUSIONS

The projections of the phenological stages under two climate change scenarios, RCP4.5 and RCP8.5, suggest an earlier onset of all phenolgical stages with greater advances for bloom and veraison. The projected advances are shown to be likely higher in the Penedès than in Ribera del Duero, in agreement with greater temperature increases observed in these regions. The differences in the phenological dates that already exist at present (up to 15 days in budbreak and veraison and up to 6 days in bloom and harvest), between the two areas of study, may increase significantly under climate change. The advances of the growing cycle will produce ripening under warmer conditions, which will likely affect grape quality at harvest and potential wine quality. If the observations and future projections are correct, then the effects may be more negative in the Penedès than in Ribera de Duero, which may require new management techniques and the adaptation of new varieties more adapted to the new climatic conditions.

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