FUTURE PROJECTIONS FOR CHILLING AND HEAT FORCING FOR EUROPEAN VINEYARDS

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Abstract

Aims: The aims of this study were: (1) to compute recent-past thermal conditions over European vineyards, using state-of-the art bioclimatic indices: chilling portions and growing degree hours; (2) to compute future changes of these thermal conditions using a large ensemble of high-resolution climate models.

Methods and Results: To assess grapevine chilling and forcing conditions, chilling portions (CP) and growing degree-hours (GDH) indices were computed for the baseline period (1989–2005) and for the future RCP4.5 and RCP8.5 scenarios (2041–2060), using several regional-global climate model chains. These calculations also considered model uncertainties and biases. These indices were extracted to the current location of vineyards, in Europe and CP-GDH delimitations were assessed. For the baseline period, higher CP values were found in north-central European regions, while lower values tend to occur on opposed sides of Europe (east-west). Regarding forcing, southern European wine regions currently display the highest GDH values. Future projections depict lower CP in southwestern Europe (-45%) and higher CP (+30%) in Eastern Europe. For GDH, most of Europe is projected to have greater values (up to +30%).

Conclusions: These changes may bring limitations to some of the world's most important wine producers, such as Spain, Italy and Portugal. Nevertheless, a timely planning of appropriate adaptation measures may aid mitigating future yield/quality losses and improve the future sustainability of the winemaking sector.

Significance and Impact of the Study: Temperature is a fundamental factor affecting plant growth and development rates. Grapevines have thermal thresholds for adequate growth, physiological development and phenology. Given the future projections for Europe, it is evident that grapevine productivity may be particularly vulnerable to climatic change. As such, it become imperative to study how future temperature conditions will affect vineyards in Europe, namely the chilling and heat forcing conditions.

Keywords: Climate change, chilling, head forcing, viticulture, Europe

Introduction

The viticultural sector in Europe is of key importance. Europe comprises some of the world main producers of grapes, amongst other temperature climate fruits. Grapevines have a strong socio-economic and cultural importance, due to the prosperous winemaking sector. Vineyard area is approximately 3 Mha, with Spain (33%), France (26%), Italy (23%) and Portugal (6%), accounting for the largest areas (OIV, 2017).

Temperature is an important factor affecting plant growth and growth rates. Many plants have thermal thresholds for suitable growth, physiological development and phenology (Schwartz and Hanes, 2010). There are usually two main thermal factors inducing plant development: cold (chilling) and heat (forcing) *(Benmoussa et al.,* 2017; Ruiz *et al.,* 2007). While the start of vegetative development generally occurs following cold requirements, growth and development are determined by heat requirements.

Chilling refers to an accumulation of cold, which allows the plant to leave the dormancy stage. Non-compliance with dormancy necessities slows/stops crop growth (Campoy *et al.,* 2011). After this stage, heat accumulation plays a main role, forcing plant phenological development and growth. The accumulation of warm temperatures is indeed necessary for plants to achieve a suitable ripening. Given the high sensitivity of grapevines to thermal conditions, it becomes clear that global warming may have significant impacts on grapevine quality and productivity (Fraga *et al.,* 2019). Higher winter temperatures may be harmful to many fruit species, as insufficient chilling might cause tardy budding and foliation, resulting in low yields (Petri and Leite, 2004). Moreover, higher temperatures during the growing season may result in unbalanced fruit ripening, which may lead to implications on fruit quality, fruit-set and yields (Fraga *et al.,* 2020; Fraga *et al.,* 2019). However, higher temperatures may have very diverse implications throughout European viticultural regions. Therefore, estimating present and future heat and chill conditions is essential for identifying suitable fruit tree species at a given site, for maintaining economically viable orchards or for ensuring that negative impacts of climate change can be mitigated *(Fraga et al.,* 2019). The present study aims to examine the impacts of climate change on chilling and heat forcing requirements of vineyards in Europe.

Materials and Methods

To assess chilling and heat forcing, two indices were calculated: the CP (Fishman et al., 1987) and the GDH (Anderson *et al.,* 1986). The CP model is based on a temperature curve from –16°C to 24°C, with optimum around 4°C, from October to February. The CP model is dynamical, i.e. higher temperatures may counteract the effect of earlier chilling and are not accumulated. CP has been shown its usefulness, particularly in warm climates (Ruiz *et al.,* 2007) and in climate change studies (Fraga *et al.,* 2019; Santos *et al.,* 2017, 2018). For GDH, the thermal accumulation from February to October is determined between 4°C and 36°C, with an optimum temperature of 26°C. For calculating both GDH and CP, the R® package 'chillR' was used (Luedeling *et al.,* 2013).

For the required climatic data, several sources were used. For the recent-past (1989–2005), daily gridded maximum and minimum (2 m) temperatures were retrieved from the observation-based E-OBS dataset (Haylock *et al.,* 2008). Data were obtained within a European sector (10°W to 35°E, 35 to 60°N) at a 0.25° latitude × 0.25° longitude grid (~25 km resolution) and are directly used as input in the chillR package to compute both GDH and CP. Regarding future projections for CP and GDH, seven regional climate models (RCM see (Fraga *et al.,* 2019)) were retrieved from the EURO-CORDEX project (Jacob *et al.,* 2014) at a 0.125° latitude × 0.125° longitude spatial resolution. The data was collected for RCP8.5 and for 2041-2060.

Results and Discussion

The patterns of both GDH and CP under current conditions (1989–2005) are shown in Figure 1. Chilling (Figure 1) is higher in central and northwestern Europe, which are not typical viticultural regions. The highest CP values (>100) are found in the British Isles, northern Iberia, northern France, Belgium and Netherlands. The lowest values (CP<60) are located in the opposed sides of Europe, such as southwestern Iberia and northeastern Europe. Regarding heat forcing, despite some exceptions (mainly at high elevations), this index shows a robust latitudinal gradient, with highest (lowest) values in the southern (northern) regions. The highest GDH (GDH>70×10^3) is located in southern European regions (Iberia, Italy, southern France), which are some of the world's top producers of grapes. Regions above 52°N show GDH values <50×10^3 GDH.

For the future (2041-2060, RCP8.5), for CP (Figure 3), opposite climate change signals can be found for southwestern and northeastern European regions. While a decrease is projected for the former, an increase is projected for the latter, a trend that will gradually enhance towards the end of the century. Regarding GDH (Figure 4), future projections point to higher values throughout Europe, also increasing in time and being more distinct in the northern regions. These decreases are certainly associated to extremely high temperature values (>36°C, above the upper threshold).

These outcomes may bring implications to the suitability of a given region to grow a specific grapevine variety. Future grapevine production might be particularly vulnerable in southern Europe, which currently has some of the largest temperate fruit-producing countries worldwide. For the vineyards in southern Europe, enhanced warming may bring additionally challenges, especially during summertime.

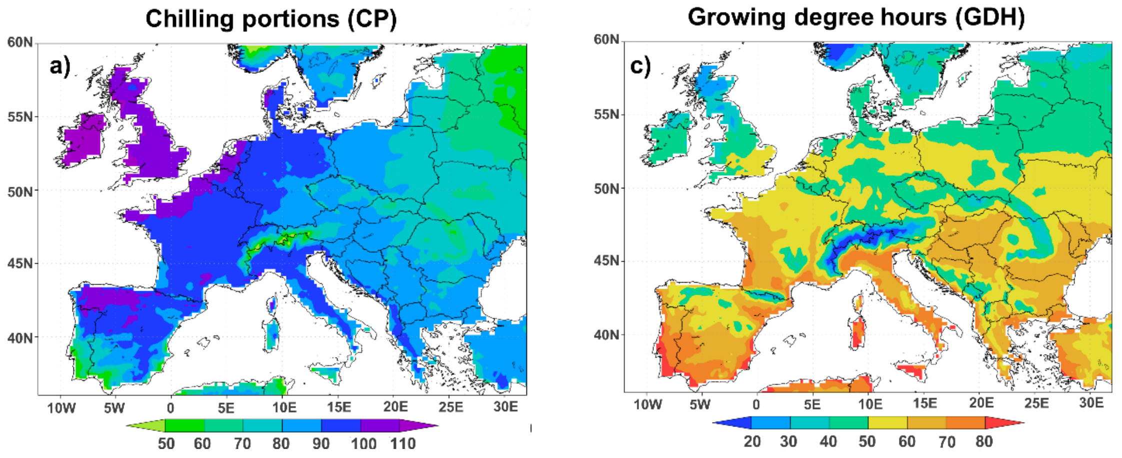

Figure 1: a) Chilling portions (CP) over Europe for 1989-2005. **b)** Growing degree hours (GDH) over Europe for 1989-2005.

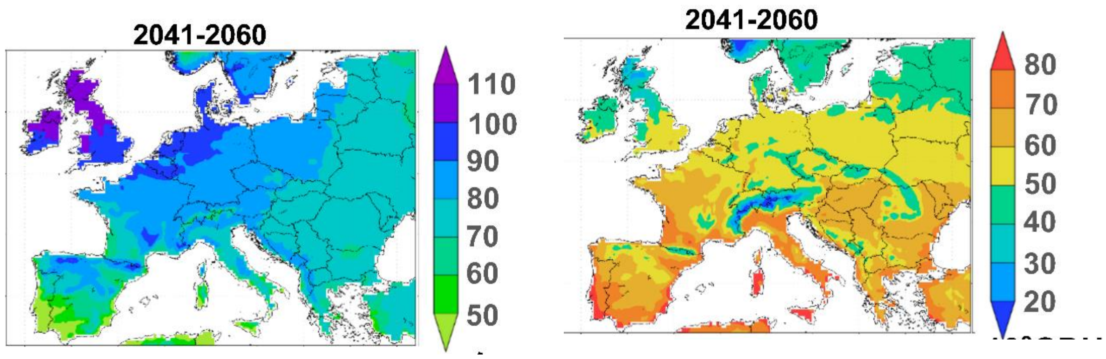

Figure 2: a) Chilling portions (CP) over Europe for 2041-2060. **b)** Growing degree hours (GDH) over Europe for 2041-2060.

The present study outcomes suggest the loss of suitable viticultural areas owing to lower chilling during autumn-winter and warming during spring-summer, particularly in southern Europe. However, a timely planning of suitable adaptation measures may help mitigate future yield/quality losses and warrant the future sustainability of this sector.

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