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Climate change impacts on thermal growing conditions of Portuguese grapevine varieties

João A. Santos[1], Ricardo Costa[1] and Helder Fraga[1]

[1]Centre for the Research and Technology of Agro-Environmental and Biological Sciences, CITAB, Universidade de Trás-os-Montes e Alto Douro, UTAD, 5000-801 Vila Real, Portugal

Abstract. Heat accumulation conditions of a collection of 44 grapevine cultivars currently grown in Portugal are assessed at very high spatial resolution (~1 km) and for 1981–2015. A Growing Degree Hours – GDH (February–October) index is used for this purpose. Three clusters of grapevine cultivars are identified, assembling varieties with close heat accumulation requirements (early, intermediate and late ripening). These clusters provide more physiologically consistent information when compared to previous studies, as non-linear plant-temperature relationships are herein taken into account. For the future climates in Portugal, ensemble mean projections under two anthropogenic-driven scenarios (RCP4.5 and RCP8.5, 2041–2070), from four EURO-CORDEX simulations, reveal a widespread increase of GDH, but with spatial heterogeneities. The spatial variability throughout Portugal is projected to decrease in GDH, with strongest increases in the coolest regions of the northeast. The typical heat accumulation conditions of each cluster are projected to gradually shift north-eastwards and to higher-elevation areas. An unprecedented level of detail for a large collection of grapevine varieties in Portugal is provided, which may promote a better planning of climate change adaptation measures in Portuguese viticulture.

1 Introduction

Viticulture is strongly subject to environmental factors, as grapevine (*Vitis vinifera* L.) physiological development is significantly influenced by terroirs [1], comprising climate, soils, variety-clone-rootstock combinations, vineyard biodiversity and a wide range of management and cultural practices. Climate is a major terroir element [2, 3], since air temperature largely controls grapevine phenology [4, 5], also influencing yields and quality attributes [6]. Furthermore, precipitation determines soil water balance [7]. Thus, adequate climate conditions are critical for producing balanced table wines. Additionally, climate change drives alterations in vineyard microclimates and, as a result, in regional/local suitability to a specific variety. Therefore, assessing regional climatic suitability for a given grapevine variety, in present and future climates, is critical for a strategic planning of the winemaking sector.

Grapevine thermal requirements play a key role on grapevine varietal distribution [8], as well as on growth, development and yields [9]. Nonetheless, broad differences among grapevine cultivars have also been underlined [4, 10, 11], highlighting the importance of variety-dependent analyses.

Thermal growing conditions can be evaluated by several bioclimatic indices, such as Growing Degree Days, GDD [12] or Growing Degree Hours, GDH [13], though the later provides more accurate assessments by considering an optimum temperature level, as is explained below. Hence, in the present study, heat accumulation conditions of main grapevine cultivars in Portugal are assessed under present and future climates.

2 Data and methods

Gridded daily maximum and minimum 2m air temperatures from the E-OBS dataset [14] were used as input for GDH calculations. The period of 1981–2015 (35 years) was selected. GDH were computed on the original 0.25° latitude × 0.25° longitude grid (~25 km spacing) and were subsequently downscaled to 1 km grid resolution by multivariate linear regression analyses, using latitude, distance to coastline and elevation as exploratory variables. The GTOPO30 digital elevation dataset (https://lta.cr.usgs.gov/GTOPO30) was used for this purpose. Further details about the downscaling methodology can also be found in [15].

For future climates, simulations generated by four Global Climate Model-Regional Climate Model (ESM-RCM) chains were obtained from the EURO-CORDEX project (http://www.euro-cordex.net/, Table 1). These simulations were forced by the representative concentration pathways 4.5 and 8.5 (RCP4.5 and RCP8.5) over the period of 2005–2100 [16]. In RCP4.5, CO2 emissions increase until the mid-21st century and decrease afterwards, whereas in RCP8.5 emissions steadily increase throughout the 21st century [17].

For climate change assessments, an intermediate future period (2041–2070) is compared to a baseline period (1981–2005). For all models, the simulated daily maximum and minimum temperatures were bias-corrected using E-OBS as baseline [16]. All indices from model simulations were computed on bias-corrected daily maximum and minimum temperatures for each period, model and future scenario, separately. Ensemble means were then produced to identify the climate change signal of each index.

Table 1. List of the ensemble members used in the present study (ESM-RCM chains), along with the acronyms used herein and the developer institutions.

ESM / RCM	Acronym	Institutions
CNRM-CERFACS / SMHI-RCA4	CNRM	Centre National de Recherches Météorologiques
IPSL-CM5A-MR / SMHI-RCA4	IPSL	Institut Pierre Simon Laplace
MOHC-HadGEM2 / SMHI-RCA4	MOHC	Met Office Hadley Centre
MPI-M-MPI / SMHI-RCA4	MPI	Max Planck Institute

GDH measures thermal accumulation on an hourly timescale, using two cosine functions between a base temperature (4ºC) and an upper limit temperature (36ºC), with an intermediate optimum at 26ºC [18]. Limited growth under excessively high temperatures is thereby taken into account, which is a critical property either for regions with hot summers or for climate change assessments. Although these thermal thresholds for GDH computations were originally developed for temperate climate fruit trees, previous studies suggest similar values for grapevines, namely for the intermediate optimum and upper limit temperatures [19] or for the base temperature of several Portuguese grapevine cultivars [20].

In Portugal, grapevine budburst typically occurs from the beginning to the end of March, though it may occur already by the end of February, namely in the warmest areas of southern Portugal. Under future warmer climates an anticipation of phenological timings is also expected throughout Portugal and budburst are indeed projected to frequently occur in February [21]. Although several previous studies considered the heat accumulation period for grapevines starting in March, the aforementioned future conditions in Portugal justify the anticipation of this period from March to February. GDH is thereby calculated from 1 February to 31 October.

For the vineyard spatial distribution in Portugal, the fifth level of the COS2007 was used. This dataset provides detailed land use and land cover information over Portugal (Source: Direção-Geral do Território, http://www.dgterritorio.pt/). In addition, a digital atlas of 44 grapevine varieties currently grown in Portugal (Table 2) was used following a previous study [11]. Their spatial distributions were overlapped on the GDH maps to extract the corresponding thermal conditions for each variety.

A Ward's linkage hierarchical clustering, based on squared Euclidean distances between the GDH medians for each of the 44 varieties, was applied to identify clusters of grapevine varieties concerning their current thermal growing conditions in Portugal (1981–2015).

Table 2. List of grape varieties used in this study, their synonyms and respective cluster numbers, for current (1981–2015) and future scenarios (RCP4.5 and RCP8.5, 2041–2070).

Grape varieties	Current	RCP4.5	RCP8.5
Alfrocheiro	3	3	3
Alicante-Branco	3	3	3
Alvarinho	3	3	3
Antão-Vaz	3	3	3
Aragonez	3	3	3
Arinto	3	3	3
Avesso	2	3	3
Azal	2	3	3
Baga	3	3	3
Bastardo	1	2	2
Bical	2	3	3
Borraçal	2	3	3
Castelão	3	3	3
Diagalves	2	3	3
Encruzado	2	3	3
Espadeiro	2	3	3
Fernão-Pires	3	3	3
Gouveio	1	2	2
Jaen	2	3	3
Loureiro	2	3	3
Malvasia-Fina	1	2	2
Malvasia-Preta	1	2	2
Malvasia-Rei	2	2	3
Marufo	1	2	2
Moreto	3	3	3
Moscatel-Galego-Branco	1	2	2
Moscatel-Graúdo	3	3	3
Rabigato	1	2	2
Rabo-de-Ovelha	3	3	3
Rufete	1	2	2
Sercial	2	3	3
Síria	2	2	3
Tália	3	3	3
Tinta-Barroca	1	2	2
Tinta-Carvalha	1	2	2
Tinta-Miúda	3	3	3
Tinto-Cão	2	2	3
Touriga-Franca	1	2	2
Touriga-Nacional	3	3	3
Trajadura	2	3	3
Trincadeira	3	3	3
Vinhão	2	3	3
Viosinho	1	2	2
Vital	3	3	3

3. Results

Vineyards are spread over most of Portugal, though particularly high densities can be found in the Douro and Lisboa Wine Regions. Mainland Portugal is characterized by very complex topography in its northern half, with several mountain ranges, deep valleys and steep slopes, contrasting with southern Portugal, where flat terrain widely prevails. As a result, northern Portugal has a strong spatial climate variability, while relatively homogeneous climatic conditions are found in the south

[22]. Portuguese vineyards are thus currently growing under a wide range of thermal conditions.

The pattern of GDH (Fig. 1a) for current climate conditions over Portugal reveal important spatial variability, with a clear signature of both elevation and latitudinal thermal gradient. Highly contrasting conditions between the inner high-elevation areas of northern/central Portugal and the low-elevation areas in the south are particularly noteworthy (Fig. 1b).

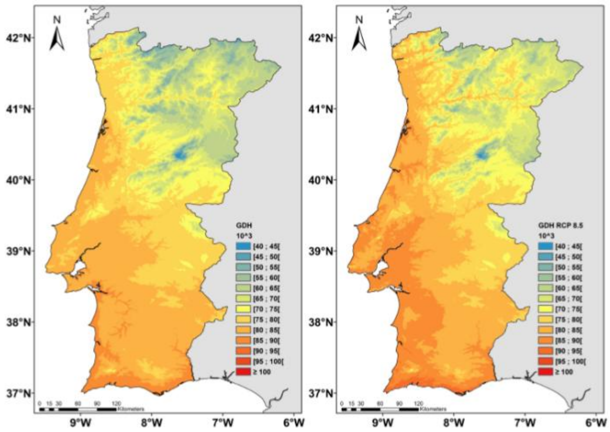

Figure 1. a) Growing degree hours (GDH) for present and b) future period (2041–2070) under RCP8.5.

The values of GDH for each grapevine variety were extracted for their current locations and their corresponding medians were then calculated. The varieties are subsequently ranked as a function of their respective GDH medians (Fig. 2). For current conditions, grapevine varieties are found between ~67,000 and ~83,000 GDH medians. Varieties such as Bastardo, Viosinho, Gouveio, Malvasia-Preta and Marufo are manifestly growing in areas with lower values of GDH (lower heat accumulation). Conversely, Tinta-Miúda, Castelão, Moscatel-Graúdo and Antão-Vaz are preferably located in areas with high values of GDH (higher heat accumulation).

In order to systematize the results, the 44 selected grapevine varieties were clustered according to their GDH medians (Fig. 2). Cluster 1 (C1) comprises 12 varieties (Bastardo, Viosinho, Gouveio, Malvasia-Preta, Marufo, Rabigato, Moscatel-Galego-Branco, Tinta-Barroca, Touriga-Franca, Tinta-Carvalha, Malvasia-Fina and Rufete), cluster 2 (C2) 15 varieties (Jean, Malvasia-Rei, Bical, Tinto-Cão, Encruzado, Avesso, Azal, Sercial, Síria, Vinhão, Diagalves, Espadeiro, Trajadura, Borraçal, Loureiro) and cluster 3 (C3) 17 varieties (Alvarinho, Tália, Alfrocheiro, Arinto, Baga, Touriga-Nacional, Rabo-de-Ovelha, Moreto, Aragonez, Vital, Fernão-Pires, Alicante-Branco, Trincadeira, Antão-Vaz, Moscatel-Graúdo, Castelão and Tinta-Miúda). The centroids of each cluster (averages over all cluster elements) are of approximately: 68,000 GDH, 74,000 GDH and 80,000 GDH for C1, C2 and C3, respectively (Fig. 2).

The climate change projections for GDH under RCP8.5 hint at an overall warming trend (Fig. 1b), with the previous range of 40,000–85,000 GDH changing to 60,000–95,000 GDH, apart from a few exceptions in high elevation areas. Nevertheless, there are remarkable spatial heterogeneities in the warming trend, with much stronger values over northern Portugal and even slightly negative changes in the inner-south, which is a remarkable outcome. In fact, the changes in the temperature distributions in future climates are expected to have a more effective effect on plants in northern than in southern Portugal, as temperature distributions will be closer to optimum in the north and clearly beyond optimum in the south (excessively warm conditions). As a result, the contrasts between GDH over northern and southern Portugal will be progressively lowered in future warmer climates (i.e. the lower GDH in the cooler areas of the north will gradually converge to the higher GDH in the warmer areas of the south).

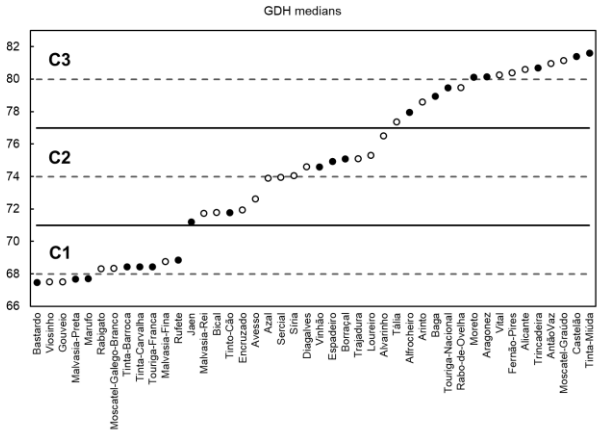

Figure 2. Medians of the growing degree hours (in 10^3 GDH) for the outlined 44 grapevine varieties over the period of 1981–2015. White (red) varieties are plotted as white (black) circles. The varietal clusters C1, C2 and C3 are also shown. Solid black lines correspond to the cluster limits, while dashed grey lines correspond to the centroid values of each cluster.

Lastly, the current and future projected thermal clusters for each variety are shown in Table 2, where shifts in clusters are frequent. For the 44 varieties, there are 24 class shifts (55%) under RCP4.5 and 27 shifts (61%) under RCP8.5. Of these shifts, 12 are from C1 to C2, while the remaining are from C2 to C3 (12 under RCP4.5 and 15 under RCP8.5). It is still worth noting that C1 is totally absent under both future scenarios, while C2 only occurs for 15 or 12 varieties under RCP4.5 and RCP8.5, respectively, thus highlighting the large prevalence of the C3 conditions.

4. Conclusions

The thermal growing conditions of a collection of 44 grapevine cultivars in Portugal are aggregated into three clusters, based on their current heat accumulation conditions (GDH): cluster 1 for varieties growing in the coolest conditions, cluster 2 for intermediate conditions and cluster 3 for the warmest conditions over Portugal. These clusters tend to isolate varieties with similar thermal requirements and provide more detailed information when compared to previous studies based on GDD or not considering a variety-dependent analysis.

Despite the identification of clusters and of their thermal niches, it cannot be strictly stated that grapevine varieties in C1 prefer colder climates, while those in C3 are more adapted to warmer climates. However, many of these varieties are either native or have been empirically selected in each region and are thus already growing in the most adequate climatic conditions to be economically viable and sustainable. Future alterations of the thermal conditions under two anthropogenic-driven scenarios (RCP4.5 and RCP8.5) clearly reflect a general warming over Portugal. As such, the typical conditions associated with these three clusters will undergo a general shift from the south to the northeast and higher-elevation areas.

This variety-dependent information reveals the changes that are expected to occur for each variety under climate change, but considering their current geographical distributions and not taking into account any possible adaptation measures. The successful adaptation of a given wine region to changing climates may be significantly controlled by the resilience of locally-relevant grapevine varieties. These changes may modify grapevine physiological processes, leading to an anticipation of the phenological timings, such as budburst, flowering, veraison and ripeness, or to heat, water and nitrogen stresses, implications on yields and modifications in berry composition, among others [21]. These impacts may affect the wine typicity of a given region and are an important challenge to the winemaking sector. Overall, climate change is a global problem, but adaptation should follow local solutions, as no general solution applies everywhere.

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