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Viticulture in Portugal: A review of recent trends and climate change projections

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Abstract

Aim: The winemaking sector in Portugal is of major socio-economic relevance, significantly contributing to the national exports and sustaining many wine-related activities, including oenotourism. Portuguese viticultural regions present a wide range of edaphoclimatic conditions with remarkable regional specificities, thus contributing to the individuality of their wines. Owing to the strong influence of climate and weather factors on grapevines, climate change may drive significant impacts on Portuguese viticulture.

Methods and results: Climatic projections for the next decades in Portugal highlight an overall warming and drying trend of the grapevine growing season, potentially resulting in modifications in phenology, growth, development, yields and eventually wine characteristics and typicity. Furthermore, the current viticultural suitability of each region is projected to undergo significant changes, suggesting a reshaping of the optimal conditions for viticulture throughout the country. In order to sustain high quality levels and affordable yield regularity, cost-effective, appropriate and timely adaptation measures must be implemented by the sector.

Conclusion: The most recent scientific studies covering the potential impacts of climate change on Portuguese viticulture are herein presented.

Significance and impact of the study: Possible adaptation measures against these threats are also discussed, foreseeing their integration into decision support systems by stakeholders and decision-makers.

Keywords: *Vitis vinifera*, viticulture, wine regions, Portugal, climate change

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Viticulture and winemaking in Portugal

1. Socio-economic context

In Portugal, winemaking is historically one of the most relevant socio-economic activities. In the context of the overall agricultural sector (e.g. cereals, vegetables), this industry represents roughly 14% of the total planted area and 6% of the total productions (INE, 2016). With an average vineyard area of over 200 thousand hectares and a yearly wine production of about 6 million hectolitres (IVV, 2013), the national production has shown a slight decrease over the past decade (-2%/yr), which can be mostly attributed to the gradual decrease in vineyard area (-1%/yr). Nonetheless, Portugal is currently the 11th wine producer and the 10th exporter in the world (OIV, 2013), which is a remarkable outcome taking into account the size of the country. Approximately half of the total annual wine production is currently being exported. In absolute terms, this contributes to the national exports with over 700 million €/yr, which corresponds to nearly 2% of total national exports. A major factor for this success is the wide recognition of Portuguese wines in foreign markets, just to mention the renowned Port wine.

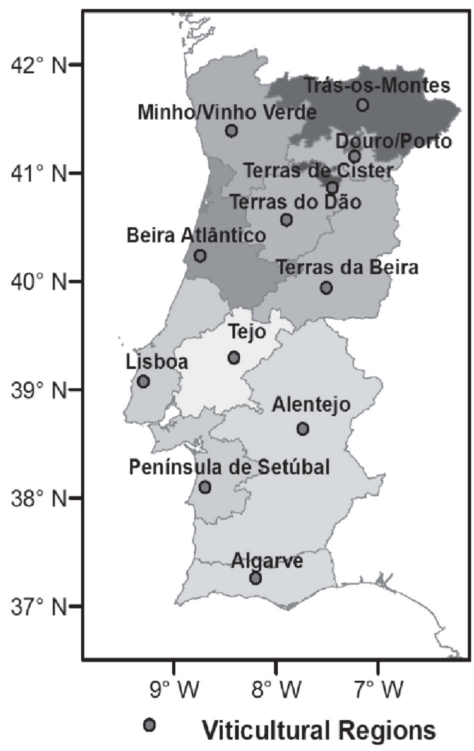

Figure 1. Wine regions in mainland Portugal. The Azores and Madeira archipelagos are not shown.

2. The winemaking regions

Portugal comprises a total of 14 wine regions (mainland Portugal, Azores and Madeira archipelagos) (Figure 1), which include 31 Protected Denominations of Origin. In the north, the Douro Demarcated Region, with almost 1.5 Mhl of total wine production and 45,000 ha of vineyards, is the oldest and one of the most important wine regions of the country. This region, famous for its Port wine, is responsible for one fourth of all wine produced in Portugal (IVV, 2013), and its vineyard landscape is also considered World Heritage by the UNESCO since 2001. In the northwest, the most maritime area of Portugal, the Minho wine region produces mostly white wines, distinguishable for their typical freshness and slightly higher acidity. In the south, the Alentejo wine region, with typical Mediterranean climates, has undergone remarkable growth rates over the recent decades and is currently the leading region in terms of non-fortified wine production. In general, from the sparkling wines of the Beira-Atlântico region to the fortified Madeira wine, many other regions in Portugal present unique wines resulting from their specific *terroirs*. The wines of Portugal are thereby valuable national brands, increasingly recognised worldwide.

3. The climate and the soils

Overall, the wine regions in mainland Portugal present Mediterranean-like climatic conditions, with warm dry summers and mild wet autumns-winters. In the northern/coastal areas (i.e. Minho and Beira-Atlântico), the Atlantic influence is strong, resulting in relatively high precipitation totals (>1,000 mm). In general, temperatures are higher in the south (e.g. Alentejo) and lower in the north (e.g. Minho and Trás-os-Montes). In the inner areas, however, summertime low water availability critically limits grapevine development (inner Alentejo and Douro). Winter temperatures tend to be milder in the southern regions, such as in Lisboa and Algarve (January mean temperature of 10–12ºC), though late spring frost is common in some northern regions (e.g. Terras do Dão), which may lead to important damages in vineyards.

Growing degree-day (GDD (Winkler, 1974); April–October, 1950–2000) climatologies over Portugal (Figure 2a) indicate that the northern regions typically show temperate climates, with cool areas at higher elevations and warm/temperate-warm areas at lower elevations, especially in the Douro region. Almost all of the southern part of the country shows a warm climate, but with some inner areas already in the very-warm class. Regarding dryness conditions (Dryness Index (Tonietto and Carbonneau, 2004); April–September, 1950–2000), the Atlantic influence is noticeable in the northern coastal areas, with sub-humid or even humid climates (Figure 2b), whereas the rest of the country depicts moderate dryness.

There are two main soil types in Portugal: cambisols in the centre-north and lithosols/luvisols in the south (FAO, 2006). The most important exceptions are the Douro region in the north, with lithosols, and the Peninsula-de-Setubal and Tejo regions, with podsols. Loam is the predominant soil texture in Portugal, while sand and clay are less frequent (Fraga *et al.*, 2014a). With respect to physiography, the most mountainous areas are located in inner northern and central areas, northwards of the Tagus River, while flatlands prevail in coastal and southern areas.

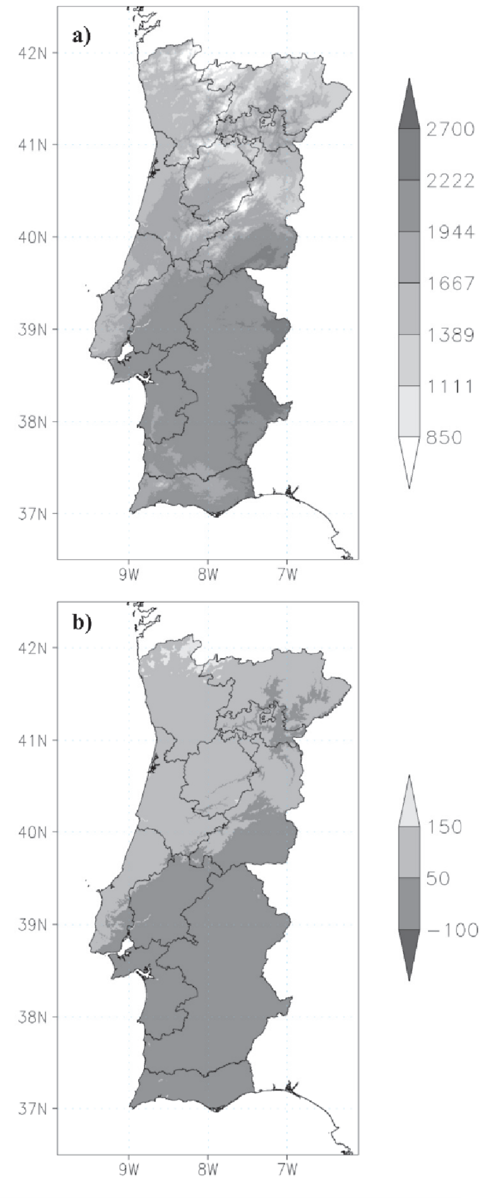

Figure 2. a) Growing degree-days and b) Dryness Index calculated for the growing season (April–September, 1950-2000) over Portugal.

4. The varieties and practices

Portuguese vineyards preserve a large number of autochthonous and international varieties, with over 300 authorized varieties. Aragonez or Tinta-Roriz (also known as Tempranillo, red) is the most planted variety in Portugal, followed by Touriga-Franca (red), Castelão (red), Fernão-Pires (white) and Touriga-Nacional (red). These varieties are present in nearly all regions. Other varieties are more region-specific, such as Alvarinho (white) in Minho or Baga (red) in Beira-Atlântico. All these varieties present unique agronomic and oenological characteristics that ultimately result in distinctive wines, either mono-varietal or blended, though blended wines are more traditional, including the Port wine. The cordon (unilateral or bilateral) is the most used training system, though pergola (in Minho) and gobelet (e.g. Trás-os-Montes) can also be found. Phenological timings (budburst, flowering, veraison and maturation), although varietal-dependent, tend to occur earlier in the southern/warmest part of the country. Budburst occurs from March to April and flowering in May–June, while harvest is typically carried out from late August to early October.

Climate change

1. Climate change projections

Atmospheric conditions are one of the most important controlling factors for the growth and productivity of grapevines (Keller, 2010). In fact, grapevine physiology and berry composition are highly influenced by air temperatures during the growth cycle (Keller, 2010). Furthermore, winter chilling is also very important for bud dormancy (Bates *et al.*, 2002; Field *et al.*, 2009). Consequently, a base temperature of ca. 10ºC is required to break this dormancy period and to onset the growing/vegetative cycle (Amerine and Winkler, 1944; Winkler, 1974). Despite its high adaptability to different climatic conditions and its resilience to moderate water and heat stresses, this crop can be severely affected by stresses derived from extreme weather events. Extremely low negative temperatures in spring may significantly damage grapevine development (Branas, 1974). Grapevines are also very sensitive to frost and hail during their vegetative period (e.g. Spellman, 1999). Heat weaves may also considerably affect physiology and yields (Kliewer, 1977; Mullins *et al.*, 1992).

According to the International Panel on Climate Change, global temperature is expected to rise from 2 to 5ºC by 2100 (IPCC, 2013). For Portugal, temperature projections are in agreement with these changes, while precipitation is expected to decrease, particularly in the south-innermost areas (SIAM2, 2006). The recent climatic trends over Portugal are already in line with these climate projections (Fraga *et al.*, 2012).

For the future, an overall warming and drying of the grapevine growing season is indeed anticipated (Fraga *et al.*, 2012; Fraga *et al.*, 2014b). GDD projections for 2041-2070 under the IPCC A1B scenario suggest large increases in accumulated temperatures (Figure 3a), particularly in the innermost regions, reaching values above 2700 ºC (excessively hot class). In addition to the overall warming, the drying trend will lead to changes in the DI patterns. Severe dryness is likely to occur in the future, particularly in the innermost southern regions (Figure 3b). The expected decrease in rainfall in spring and summer will enhance water requirements and may trigger severe water stress in vineyards. Moreover, updated projections following the IPCC RCP scenarios are in close agreement with these outcomes (Fraga *et al.*, 2016a). Given the key role played by atmospheric factors on viticulture, climate change is expected to bring new challenges to this crop.

2. Impacts on phenology

Grapevines will be particularly affected by the projected higher temperatures during the growing season. As temperatures are a major driver of the grapevine development stages (Parker *et al.*, 2013), significant warmings are expected to lead to earlier onsets (Bock *et al.*, 2011; Chuine *et al.*, 2004; Dalla Marta *et al.*, 2010; Daux *et al.*, 2011; Jones *et al.*, 2005a; Molitor *et al.*, 2014; Sadras and Petrie, 2011; Webb *et al.*, 2011). Recent studies for Portugal isolated future projections for the phenological stages of 16 native varieties under RCP4.5 and 8.5 (Fraga *et al.*, 2015; Fraga *et al.*, 2016c; Malheiro *et al.*, 2013). The results hint at earlier onsets of 2–5 days for budburst and flowering, and of 7–15 days for veraison until 2070, depending on the selected future scenario and variety.

Earlier phenological timings will bring heterogeneous outcomes. Earlier budburst and flowering may result in substantial increases in the risks of frost damages. Given the projected increase of grapevine-related pests/diseases (Francesca *et al.*, 2006; Valero *et al.*, 2003; Van Niekerk *et al.*, 2011), this may also entail increased risks and cause a strong impact on management practices. Extreme heat during this period may abruptly reduce vine metabolism, affecting the aroma and colour of wines. Still, higher sugar concentrations and lower acidity are expected, which may potentially increase the risk of organoleptic degradation or even spoilage (Orduna, 2010), threatening the production of well-balanced wines.

3. Impacts on yield

Under future climates, the potential impacts on grapevine yield can be very diverse. The interaction between negative (higher heat and water stresses) and positive (enhanced CO_2 effect on plant physiology) climate change effects on yields are expected to lead to different outcomes (Bindi *et al.*, 1996; Fraga *et al.*, 2014c). Basically, the overall effect on production will depend on CO_2 concentrations, temperature, solar radiation, precipitation and many other factors. As an example, for the Douro region, several studies suggest higher grapevine yields and wine productions in future climates (Gouveia *et al.*, 2011; Santos *et al.*, 2011; Santos *et al.*, 2013). Nonetheless, these studies were conducted considering the more humid part of the region (Baixo-Corgo), while projections for the driest areas hint at yield decreases (Cima-Corgo and Douro-Superior). Furthermore, yield decreases are also projected to occur in the Alentejo region (Coelho *et al.*, 2013), which shows a much warmer and drier climate. Although projections for yield are largely heterogeneous and site-specific, most studies agree regarding the projections for the annual yield irregularity. The expected increase in the frequency and intensity of weather extremes (Andrade *et al.*, 2014) will lead to higher inter-annual yield variability, which may affect the whole winemaking sector (Jones *et al.*, 2005a; Schultz, 2000).

4. Impacts on wine quality

Under future warmer climates, extremely high temperatures may inhibit the formation of anthocyanins (Buttrose *et al.*, 1971), impacting berry colour and aroma (Bureau *et al.*, 2000; Downey *et al.*, 2006). Higher sugar concentrations and lower acidity are also expected under future warming. For regions already presenting warm climates (e.g. Alentejo, Douro), climate change may thus endanger the balanced ripening of grapes and the sustainability of the existing varieties and wine styles (Fraga *et al.*, 2016b; Jones and Alves, 2012). However, future warming in the cooler climate regions (e.g. Minho, Beira-Atlântico) may improve suitability for the production of high quality wines. As such, although a modification of the currently established wine types may occur, the socio-economic impacts of climate change on wine quality can be quite diverse.

Adaptation measures

As a protection strategy against the unwanted impacts of climate change, adaptation measures should be considered, focusing on specific problems. Adequate and timely planning of these measures needs to be adopted by the winemaking sector. The readiness to define and implement adaptation strategies to climate change will result in lower detrimental impacts to the sector (Barbeau *et al.*, 2014; Battaglini *et al.*, 2009; Olesen *et al.*, 2011). These strategies may include short-term measures, such as changes in viticultural management practices, grown varieties or even oenological practices (Neethling *et al.*, 2016). Additionally, long-term adaptation measures should also be considered, as some regions may become excessively warm and dry. These different types of adaptation measures are discussed in the following subsections.

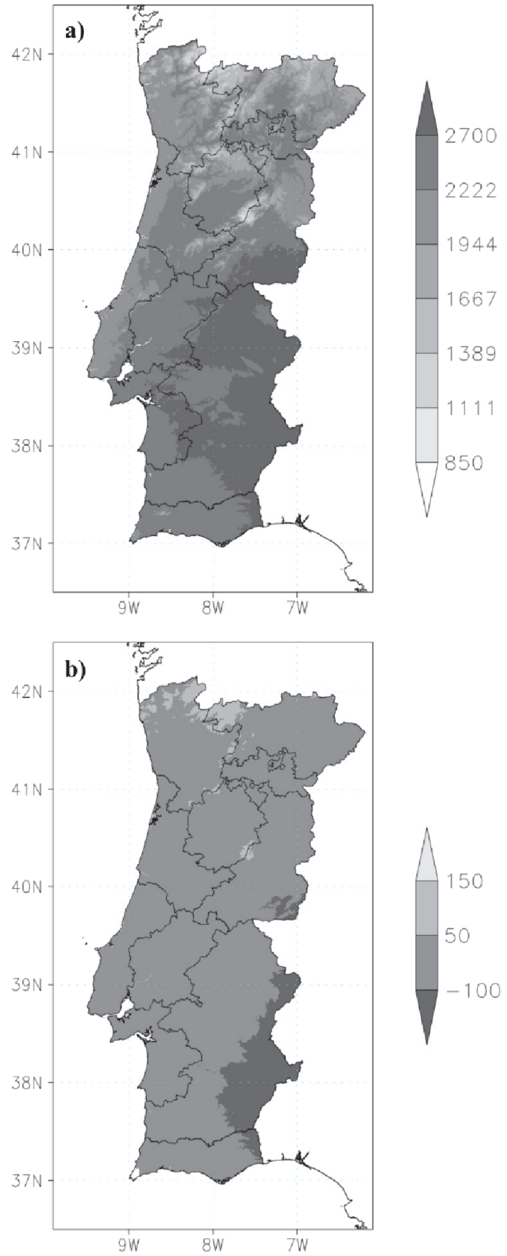

Figure 3. a) Growing degree-days and b) Dryness Index calculated for the growing season (April–September) over Portugal for 2041-2070 and the A1B scenario.

1. Short-term adaptation measures

Taking into account the warming trend projected for the future, selecting varieties with higher thermal requirements and higher stress resistance may strengthen the overall resilience of the Portuguese viticulture under future climates (Fraga *et al.*, 2016b). Therefore, preserving the existing biodiversity is critical, as some varieties may thrive in the future and may thereby be part of the solution. Furthermore, oenological practices may also play a key role in maintaining regional wine typicity and quality.

Regions under severe dryness, such as Alentejo and Douro, should promote higher water use efficiencies (Flexas *et al.*, 2010) by adopting training systems that promote shorter trunks and lower total leaf areas, such as gobelet. The selection of more drought tolerant rootstocks must also be regarded as a possible adaptation measure (Harbertson and Keller, 2012; Keller *et al.*, 2011). Changes in tillage systems and soil management should also be considered (Bahar and Yasasin, 2010; Kvaternjak *et al.*, 2008). One of the most controversial (in Portugal) measures is the application of water by irrigation, but smart irrigation strategies can promote a balanced compromise solution between environment, economy and plant water requirements (Chaves *et al.*, 2007; Chaves *et al.*, 2010; dos Santos *et al.*, 2003; Ferreira *et al.*, 2012).

Excessive solar radiation can also be damaging for grapevines, already under water and heat stresses. Shading materials, either natural (e.g. olive trees) or artificial, can help overcome this shortcoming (Greer *et al.*, 2011; Shahak *et al.*, 2008). Furthermore, the use of chemical sunscreens for leaf protection against sunburns may also represent an important alternative (Dinis *et al.*, 2016). Another option to consider is the adjustment of the implemented training system (Pieri and Gaudillere, 2003). Changing canopy geometry or orientation can also significantly influence light interception (Grifoni *et al.*, 2008; Intrieri *et al.*, 1998).

2. Long-term adaptation measures

Long-term adaptation measures should also be considered, although their extent and application may bring significant socio-economic implications. These measures include changing vineyard location, as some regions may become excessively warm and dry (Fraga *et al.*, 2016b; Moriondo *et al.*, 2013). Relocations of vineyards to cooler sites, such as higher elevations, coastal zones or simply areas with lower solar exposures, are possible measures.

Conclusions

Although climate change is expected to drive significant changes on Portuguese viticulture, large uncertainties still remain regarding the true extent of its impacts. The expected warming and drying trends throughout Portugal may bring some additional challenges for grapevine production (Santos *et al.*, 2011). Increases in the growing-season mean temperatures are indeed expected not only in all of the Portuguese winemaking regions, but also in other regions worldwide (Duchene and Schneider, 2005; Jones *et al.*, 2005b; Neumann and Matzarakis, 2011). This will lead to earlier phenological timings, with potential detrimental impacts (Bock *et al.*, 2011; Chuine *et al.*, 2004; Dalla Marta *et al.*, 2010; Webb *et al.*, 2008). Some southern regions are projected to become excessively dry to grapevine production using the currently established viticultural practices and varieties. Additionally, enhanced risks of pests and diseases in vineyards can be an additional threat (Francesca *et al.*, 2006; Valero *et al.*, 2003; Van Niekerk *et al.*, 2011).

The implementation of adaptation measures is urging, as scientific confidence for significant climate change in the upcoming decades is growing. Appropriate measures need to be addressed by the wine industry to face climate change impacts, mainly by developing suitable strategies at regional scales (Metzger *et al.*, 2008). Winegrape growers are becoming progressively more aware of this problem (Battaglini *et al.*, 2009), since timely strategic planning will provide competitive advantages. Nevertheless, in order to effectively cope with the projected changes, continuous research is needed as climate change is progressing. As such, it is up to the decision-makers and stakeholders from the winemaking sector to implement actions against climate change. These actions will critically contribute to the future economic and environmental sustainability of the Portuguese viticulture.

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