

Viticulture in Santorini Island: current trends and challenges

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Abstract

The Santorini vineyard is a unique and extreme vineyard on a global scale with economic, historical and wine value. It also constitutes the second largest activity after tourism although linked to it. The special soil-climatic conditions and the specificity of viticulture on the island make it uniquely distinct and therefore a field of interdisciplinary study and research at a local and global level. However, the aging of the vineyard, the reduction of its cultivation area, its non-optimal management and finally the looming effects of climate change form a set of factors that should be weighed and assessed by those involved in the sector. At the same time, the rapid changes taking place at the global level (e.g. technological innovations) create opportunities, but at the same time the context in which the brand name "Santorini" is undoubtedly part of becomes more competitive, while also entailing risks from unforeseen developments. Only with collective action and a strategic approach will it be possible to ensure a sustainable future for the vineyard of Santorini. It is up, the stakeholders of the island to take the adequate initiatives.

Keywords: adaptational measures; sustainability; climate change; Santorini; viticulture

Introduction

Since ancient times viticulture and wine-making on this land (Figure 1) has been anchored to myths, trade routes, art, traditions and culture. The recent years, this activity continues to create significant economic value, benefiting from significant progress in quality, a remarkable variety and a recognition all over the world. It is well known that by establishing colonies-historically-Greeks spread viticulture all around the Mediterranean and Black Sea basins where grape growers cultivated predominantly grape varieties from the so called 'greek world' (which today number over 200 species) (Koufos *et al.*, 2020). Despite its ancient heritage and global acclaim, Greece's viticulture is not without its challenges. Characterized predominantly by small, traditional, family-run plots, Greek vineyards nowadays are distinguished by their diverse topography and climatic conditions, ranging from rugged mountainous terrains to arid landscapes. The unique environmental conditions, coupled with modern pressures such as climate change, tourism development, and market dynamics, present both obstacles and opportunities. Exploring the interplay of these factors reveals the resilience of vineyards and the innovative approaches that could shape the future of its wine-making tradition.

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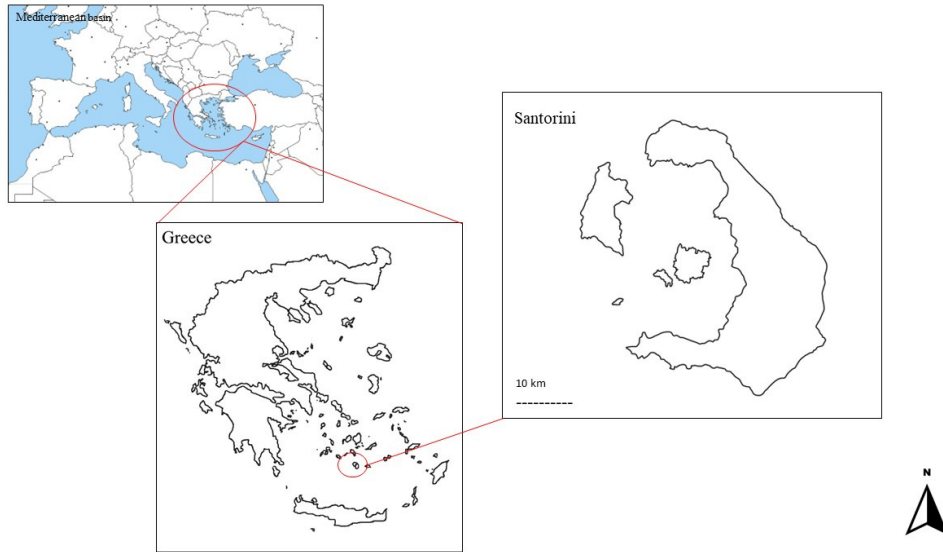


Figure 1. Maps of Greece and Santorini Island

The vines of Santorini Island have been cultivated traditionally for thousands of years, facing through times various challenges. Nowadays, the challenges include: spatial particularities (terraces, small parcels) (Figure 2, A), traditional mode of cultivation (dry farming, manual cultivation and harvesting, low use of agrochemicals, traditional training systems (e.g. ‘kouloura’, ‘kladefitiko’) (Figure 2, B) and techniques (e.g. digging, ploughing) (Figure 2, C) and the poor soil fertility (sandy-rocky soil with low organic matter) (Figure 2, D) (Xyrafis *et al.*, 2021). To the above, it needs to be added the extreme weather phenomena that are no strange to the island of Santorini but more and more frequent and intense. Heat, drought, gale force winds, and hail plague the island’s viticulture almost every year (Figure 2, E). In the context of climate change, extreme events (heat waves, drought) tend to increase in frequency and intensity (MedECC 2020).

Santorini has specificities and particularities; the island’s unique vineyard landscapes, the centuries-old own-rooted vines and local varieties, its volcanic soil and centuries of viticultural heritage have contributed to the production of distinguished high-quality PDO wines.

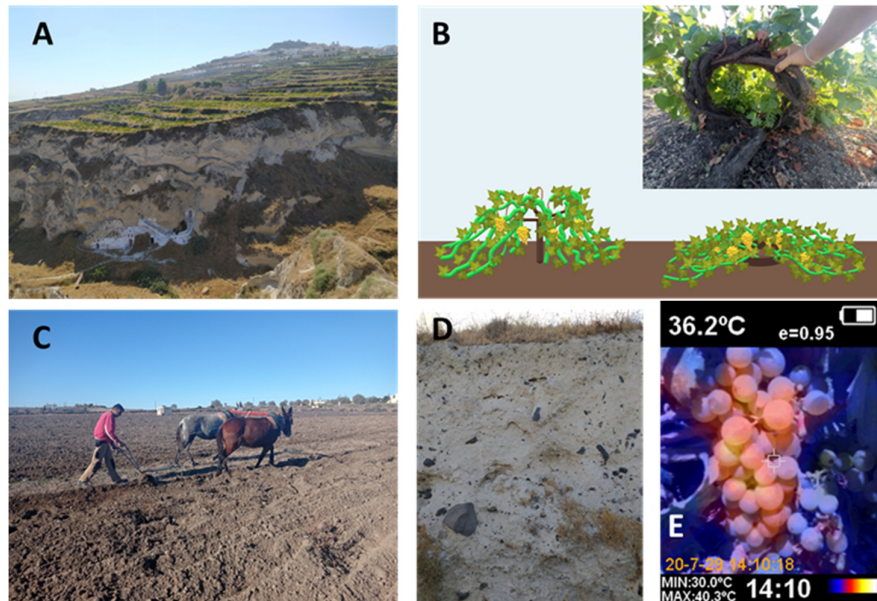


Figure 2. Santorini's vineyard terraces (A), traditional training systems (B) and techniques (C), volcanic soil profile (D) and grape's temperature during a heatwave (E)

Currently new threats are affecting the future of viticulture on the island: a) urbanization pressures due to the impact of mass tourism, b) decreasing cultivated area linked to social-economic factors and c) climate change.

The aim of this study was to analyze the current situation and the overview of Santorini's viticulture in the context of climate change reviewing latest references.

Perspectives and challenges

Santorini, since the 60s, gradually became a top world travel destination. The booming tourism sector has led to urbanization and overpopulation causing social and environmental pressures. Over-building and over-tourism impart threats for the rural landscape and the natural resources of the island. After the 1960s, most small landed properties mainly consisting of vineyards were gradually turned into construction plots (mostly tourism infrastructure) (Sarantakou and Terkenli, 2021). Hence, one of the main challenges faced by viticulture in Santorini (Figure 2) is the shrinking vineyard area. In fact, over the years the total vineyard area in Santorini has decreased from 2.500 hectares in the 1960s to 900 hectares at present. Vineyards are being abandoned, while viticulturists are steadily decreasing. This trend is continuing and poses a serious threat to the existence of viticulture on the island. On the other hand, viticulture has contributed significantly to Santorini's brand name, together with local gastronomy.

One other significant socio-economic factor affecting the future of viticulture on the island is the human factor (Figure 3). Few independent viticulturists remain active while the trend is towards the concentration of wineries into larger conglomerates. Most local, self-employed viticulturists, who often own small vineyard parcels and work in this field part-time or alongside tourism, are of advanced age. This poses challenges for renewing and investing in the vineyards. For the majority of these particular cases the succession of the exploitations is limited as demand for land is high and high prices make this alternative very attractive for subsequent generations.

Over the past two years, there has been a significant decline in yields per hectare, reaching historic lows of 1.5 and 1 ton per hectare in 2023 and 2024, respectively. During the decade from 2005 to 2015, the average

yield per hectare was 2.8 ± 0.2 tons, whereas from 2016 to 2024, the average yield dropped to 2.3 ± 0.8 tons (data sourced from: <https://minagric.gr>).

Hence., the decline in grape production, combined with rising production costs and increasing competition, is putting significant pressure on the viability of the sector. This sector is primarily composed of small-scale growers who are not full-time viticulturists, leading many to abandon their vineyards or, alternatively, seek tenants to manage them. The burden of high rental prices further exacerbates production costs, particularly when proposed lease agreements are short-term (3-4 years).

Despite these challenges, the selling price of grapes remains high, which can be attributed to the elasticity of the demand for Santorini's high-quality wine. This strong demand underscores the unique value of Santorini's wine in both domestic and international markets.

Extreme weather conditions are a permanent challenge for Santorini. The island's viticulture faces annual threats from high temperatures, droughts, intense winds, and hailstorms.

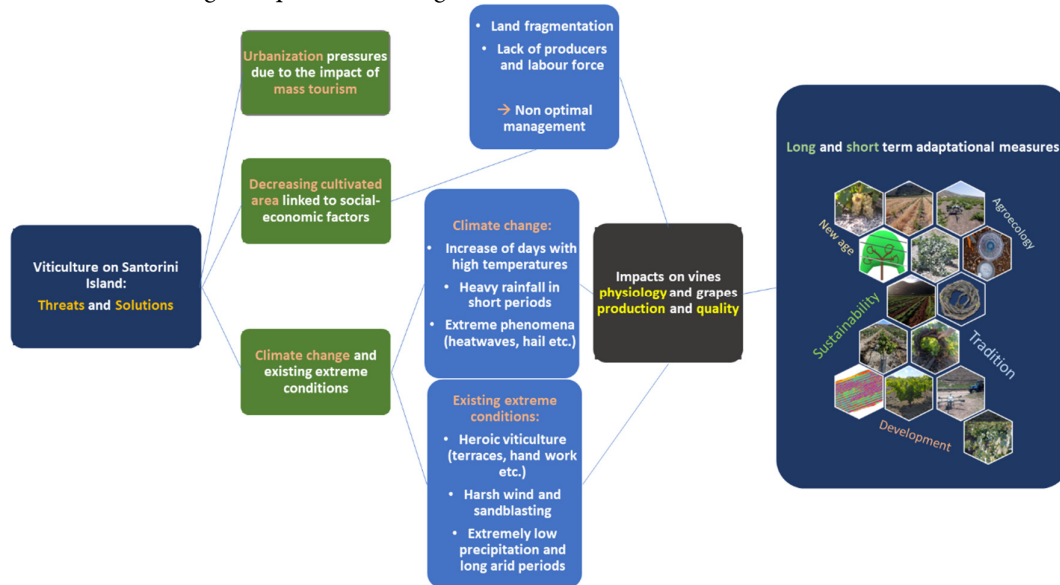


Figure 3. Viticulture on Santorini Island: threats and solutions

Some meteorological data¹ from the extreme and rare events that took place from 2020 to 2023 compared to the average of the previous 45 years (Figure 4). In the four years under study, the following were observed:

Consecutive years with low rainfall during the winter period. For the period 1974 to 2019 the annual average rainfall was 316 ± 40 mm while in the period 2020 to 2023 the annual average rainfall was 235 ± 90 mm (Figure 4, A). High temperatures for the winter period that led to premature and irregular budburst (Figure 4, D-ii). As shown in Figure 4B, in the period 2020-2023 the winter was warmer than in the period 1974-2019. The highest temperature differences between the two periods under study were presented in the months of November and December with the difference being 0.8 °C and 1.3 °C respectively. Unprecedented high rainfall in August 2022 causing crop protection issues (downy mildew). The amount of precipitation in August 2022 reached 26.8 mm, while on average for the period 1974-2019 did not exceed 2 mm (Figure 4, A). Hailstorm in the south-western region of the island took place in April 2023 causing significant damages to the production and vines (Figure 4, D-iii). In 2021 there was a prolonged heatwave with consecutive days with temperatures >35 °C and soil temperatures >40 °C (Figure 4, C). The heat affected the quality and production of the grapes causing sunburns and berry shriveling (Figure 4, D-i).

¹ Climate data for Santorini were obtained from the Hellenic National Meteorological Service and the National Meteorological Society

Like many viticultural regions in the Mediterranean, Santorini is being affected by climate change (Xyrafis *et al.*, 2022). In Santorini Xyrafis *et al.* (2022) have analyzed chronological climate data, evaluated the trends in the change of climate parameters and bioclimatic indices and correlated them with viticultural indices for Santorini Island. In brief, they found that average annual temperature has increased in the last 45 years by almost 3 °C together with a significant increase in the frequency of days with extreme high temperatures. Bioclimatic indicators correspond to warmer climates with warmer nights and longer periods of drought. Finally, it appears that the high temperatures occurring during the critical stages of the development of the vine are driving earlier harvest dates and higher sugar content and seem to affect production in the following growing season(s).

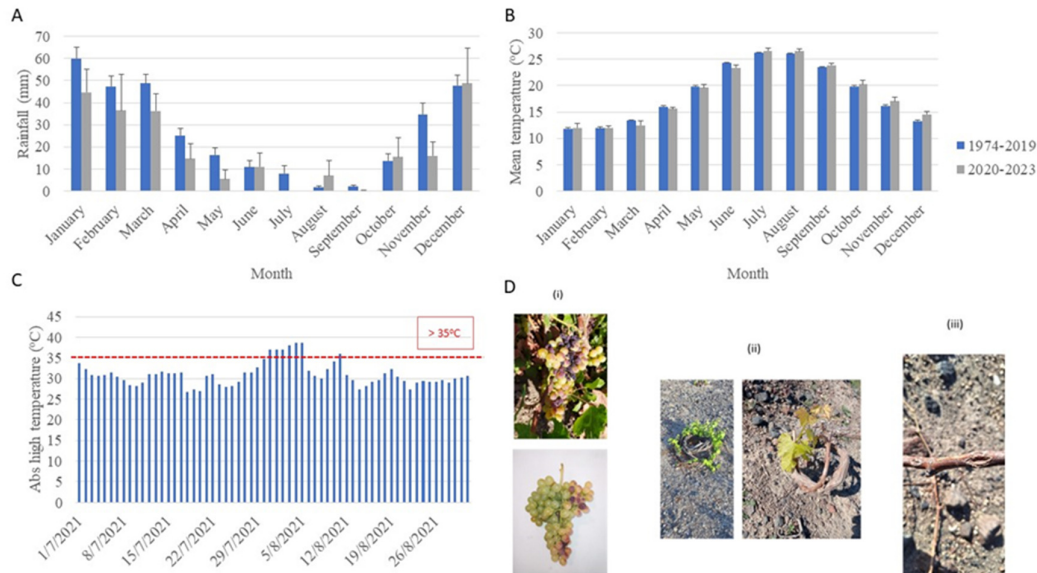


Figure 4. Monthly rainfall (A) and mean temperature (B) for two chronological series 1974-2019 and 2020-2023, daily absolute high temperature during July and August of 2021 (C) and images of sunburn grapes in 2021 (i), winter inflorescence in 2022 (ii) and hail damage on canes during hailstorm of April 2023 (iii) (D)

Despite these challenges, Santorini’s viticulture has the potential to adapt and thrive if appropriate measures are taken. Promoting sustainable agricultural practices, incentivizing the younger generation to remain in viticulture, and investing in climate-resilient vine varieties could play a crucial role in safeguarding this vital element of the island’s heritage. Recognizing the value of viticulture as not only an economic activity but also a cultural and environmental asset is essential for ensuring its survival in the face of evolving pressures.

Short and long term adaptational measures

These changing climatic conditions pose challenges to adapt the island’s traditional viticulture practices to the new climatic conditions resulting from climate change, which will intensify in the future (Droulia and Charalampopoulos, 2021). Stakeholders in Santorini need to find sustainable short- and long-term solutions and balance to assure sustainability and development while protecting the tradition and the island’s landscape (Santos *et al.*, 2020; Droulia and Charalampopoulos, 2021). The special soil-climatic conditions and the specificity of viticulture on the island make it uniquely distinct and therefore a subject of interdisciplinary study and research at a local and global level.

As shown in Table 1, a blend of short-term and long-term strategic measures is proposed to combat the effects of climate change in Santorini. This blend includes long-term measures concerning the restructuring-redistribution (Moriondo *et al.*, 2013) and the mechanization of the vineyard, the study of heat and drought tolerant traditional grape varieties (Gambetta *et al.*, 2020; Xyrafis *et al.*, 2021; Santos *et al.*, 2018; Wolkovich *et al.*, 2018), and highlighting the modification of traditional training systems and planting density (Morales-Henrique *et al.*, 2022; Deloire *et al.*, 2022; Xyrafis *et al.*, 2023). But also short-term measures such as late pruning (Allegro *et al.*, 2019; Gatti *et al.*, 2016), the foliar use of inert materials such as kaolin, zeolite and CaCO₃ (Dinis *et al.*, 2016; Teker, 2023; Valentini *et al.*, 2021; Petoumenou, 2023), the use of biostimulants (Cataldo *et al.*, 2022), hydrogels (Uysal *et al.*, 2023), cover crops (Neethling *et al.*, 2016; Santos *et al.*, 2020), as well as the use of precision viticulture technologies (drones, robots, sensors) (Santesteban, 2019; Tardaquilla *et al.*, 2021).

Table 1. A selection of long and short term adaptational measures for Santorini’s viticulture

Long-term measures	References	Short-term measures	References
Gradually replanting and restructuring Santorini’s vineyard	Moriondo <i>et al.</i> (2013)	Precision and Smart irrigation	Koech and Langat (2018); Santos <i>et al.</i> (2020); Bellvert <i>et al.</i> (2021)
Adaptations and modifications of the traditional training systems and vine density	Morales-Henriquez <i>et al.</i> (2022); Deloire <i>et al.</i> (2022); Xyrafis <i>et al.</i> (2023)	Micro-cooling and overhead irrigation	Carravia <i>et al.</i> (2017); Wilson <i>et al.</i> (2024)
Heat and drought tolerant local varieties, rootstocks and clones	Xyrafis <i>et al.</i> (2021); Santos <i>et al.</i> (2018); Wolkovich <i>et al.</i> (2018)	Sunscreen application	Dinis <i>et al.</i> (2016); Teker (2023); Valentini <i>et al.</i> (2021); Petoumenou (2023)
		Hydrogel application	Uysal <i>et al.</i> (2023)
		Use of biostimulants	Cataldo <i>et al.</i> (2020)
		Cover crops-mulching	Neethling <i>et al.</i> (2016); Santos <i>et al.</i> (2020); Xyrafis <i>et al.</i> (2023)
		Leaf management and late pruning	Molitor <i>et al.</i> (2011); Allegro <i>et al.</i> (2019); Gatti <i>et al.</i> (2016)
		New technologies (drones, robot-tractors, sensors etc)	Santesteban (2019); Tardaquilla <i>et al.</i> (2021)

Last but not least, the use of irrigation is becoming increasingly important for the island’s viticulture viability. According to Chartzoulakis and Bertaki (2015), sustainable water management in agriculture seeks to balance water availability and demand in terms of both quantity and quality, across different locations and time periods, while maintaining reasonable costs and minimizing environmental impact. Its implementation requires addressing technological challenges, adapting the social behavior of rural communities, overcoming economic limitations, and considering the legal, institutional, and agricultural practice frameworks.

In this context, precision irrigation using smart, deficit irrigation strategies are recommended in arid areas (Bellvert *et al.*, 2021; Koech and Langat, 2018; Chaves *et al.*, 2007; Santos *et al.*, 2020). Drip (Peacock, 1977), subsurface (Miras *et al.*, 2017), micro cooling (Carravia *et al.*, 2017) and overhead (Wilson *et al.*, 2024) irrigation are some of the systems available to winegrowers.

To effectively address the irrigation needs of Santorini's vineyards amidst emerging climate challenges, several key factors must be optimized: the quantity of water applied, the frequency and timing of irrigation, the type of irrigation system employed, and the development of essential infrastructure, such as desalination facilities, wastewater recycling, rainwater harvesting, and efficient water distribution networks (Chartzoulakis and Bertaki, 2015). These elements are critical for ensuring sustainable water management and resource conservation while maintaining the high-quality grape production for which Santorini is renowned.

Achieving this balance demands systematic and applied field research tailored to the unique conditions of the island. Such studies would help refine irrigation practices, ensuring they are both efficient and environmentally sustainable. The ultimate goal is not to convert Santorini's vineyards into heavily irrigated systems but rather to use irrigation as a strategic tool—a buffer during years with exceptionally low winter and early spring rainfall, which are traditionally the main rainy seasons on the island.

This approach aligns with preserving Santorini's distinctive viticulture traditions while addressing modern challenges. By using irrigation selectively and judiciously, it can mitigate the adverse effects of climate change, such as heatwaves and prolonged droughts, which pose increasing threats to the vineyards. Irrigation, in this sense, becomes a protective measure, reducing the risk of damage and ensuring the long-term resilience of the vineyards.

The focus is on precision and adaptability. Irrigation should complement the island's traditional dry-farming methods rather than replace them, providing support during extreme weather conditions without disrupting the ecological and cultural heritage of Santorini's vineyards. With strategic planning and ongoing research, irrigation can serve as a vital ally in safeguarding both the sustainability and productivity of these iconic vineyards.

Conclusions

The Santorini vineyard is a unique and extreme vineyard on a global scale with economic, historical and wine value. It also constitutes the second largest activity after tourism although linked to it.

The Island's soil, its climatic conditions and the specificity of viticulture on the island make Santorini uniquely distinct and therefore a field of interdisciplinary study and research at a local and global level.

Like many viticultural regions in the Mediterranean, Santorini is being affected by climate change. These changing climatic conditions pose challenges to adapt the island's traditional viticulture practices to the new climatic conditions resulting from climate change, which will intensify in the future.

The empirical study of local varieties and traditional training systems have shown that they tend to resist and they are well adapted to the extreme soil-climatic conditions of the island. However, due to the ongoing climate change small- and large-scale interventions incorporating innovation are needed. Stakeholders in Santorini need to explore sustainable short- and long-term solutions and to balance, assuring sustainability for the exploitations, development for the sector while protecting the tradition and the island's physiognomy by giving prominence to its famous brand name.

Authors' Contributions

The author read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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