# GREEK AND CYPRIOT GRAPE VARIETIES AS A SUSTAINABLE SOLUTION TO MITIGATE CLIMATE CHANGE

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## Abstract

**Aim:** The aim of this report is to present evidence on the potential of Greek and Cypriot grape varieties to serve as a sustainable solution to mitigate climate change.

**Methods and Results:** The work provides a review of recent works involving Greek and Cypriot varieties' performance under high temperatures and increased dryness.

**Conclusions:** Climate change could threaten the existing balance between local environmental conditions and vitivinicultural production systems over the majority of wine producing areas. The subsequent decrease in the suitability of the current winemaking regions will require, apart from short-term adjustments in vineyard management, the adaptation of plant material by the use of late-ripening and drought resistant varieties and clones. Greek and Cypriot grape cultivars appear to grow well under dryland conditions, and additionally they mature their crop later than most of the well-established international varieties. However limited evidence exists regarding the direct effects of high daytime temperatures and drought especially on the quality of their grapes. This information would greatly assist grape growers in improving cultivar selection and adjusting management decisions.

**Significance and Impact of the Study**: Indigenous grapevine varieties of the semiarid viticultural regions of Greece and Cyprus have received much less attention compared to other grapes native to Mediterranean areas and therefore deserve to be better studied as a sustainable solution in the context of climate change. However, substituting existing varieties will change the "identity" of (mainly) European wine appellations, therefore the effectiveness of any strategy depends on both the willingness of grape growers and consumers to accept new varieties and also on the flexibility of current legislation.

**Keywords**: Plant material, grapevine, adaptation, temperature, drought

## Introduction

Climate change will create increasingly warm and dry conditions for vineyards and question the viability of the world wine sector. Warming of approximately 1.0-2.0°C has occurred over the last 50-100 years in wine regions globally and estimations by 2040-2060 indicate that this may reach 1.5-2.5°C (Jones *et al.,* 2019). An increase in temperatures has been shown to accelerate grape ripening, shifting harvest earlier and resulting in the production of unbalanced wines with a high alcohol content, decreased acidity and poor aromatic expression due to a loss of synchronization between different levels of grape maturity or to a direct exposure of grapes to extreme day & night-time temperatures which inhibit secondary metabolism in berries (Kliewer, 1973; Gaiotti *et al.,* 2018). Extreme temperatures will also increase drought, because the higher evapotranspiration will result in a faster depletion of soil water reserves, especially in vineyards established on shallow or light-textured soils. Hence, regions characterized by warm and dry summers (e.g. southern Europe, California, South Australia etc.) where grapevines are regularly exposed to periods of heat and drought, may already be at the limit of ideal conditions for high-quality wine production.

Adjustments in vineyard management techniques (e.g. sprawling canopy training systems, delayed pruning, decreases of fruit-to-leaf area ratio by increased bud load/late leaf removal/late shoot trimming, etc), have been a priority objective of viticultural research, as a short-term adaptive solution to mitigate climate change in wine producing areas. However, the vast genetic variability of *Vitis vinifera* species provides a more environmentally and economically sustainable alternative for growers as grapevine varieties greatly differ in their heat requirements and their resilience to drought (Chavez *et al.,* 2007). This variability is linked to grape geographical origin, with cultivars originating from warm semiarid areas appearing to have a longer annual cycle (i.e. higher heat requirements) and to regulate better their water status under extended periods of drought.

The Mediterranean basin is the cradle of a hundreds of local varieties considered adapted to the longer growing seasons (e.g. Mourvedre or Carignan) and drought (Grenache). However, compared to Spanish or Italian regions and varieties, the eastern Mediterranean viticultural regions of Greece and Cyprus, with their numerous indigenous grape varieties, have received much less attention and therefore deserve to be better studied. The aim of this report is to shed some light into one of the oldest grape growing areas in the world where local grapes, until recently unknown to both growers and consumers, have been exposed to heat and drought conditions for centuries, providing a potential genetic pool for future replanting and breeding programs.

### *Greek and Cypriot Varieties*

Grapevine is cultivated in Greece since antiquity. Today, viticulture occupies an area of about 100,000 ha of which 60,000 ha are planted with winegrapes. The combination of the mountainous mainland, the extended coastline and the multitude of islands creates a diversity of soil and climate conditions where a range of local varieties (estimated between 200 and 300, covering 90% of the total area compared to foreign ones) have been adapted for centuries with minimum inputs. In a recent study where 91 Greek autochthonous grapevine varieties were genotyped at 10 loci (Merkouropoulos *et al.*, 2015), Observed Heterozygosity (defined as the number of individuals heterozygous per locus) ranged from 72.3 % to 90.9 % indicating high genetic variability, although some inbreeding cannot be excluded. Cyprus used to be one of the most densely planted areas in the vitivinicultural world, today counting about 7.000 ha, with more than 10 native grape cultivars, of which the white-skinned Xynisteri is dominant. Recent evidence has shown that these varieties have multiple interesting traits and can be considered as a sustainable solution to mitigate climate change.

### *Adaptation to Higher Temperatures*

The projected warming is expected to increase the length of season for grapevine growing over most of the vitivinicultural world and, therefore, late ripening varieties will be favored. Recent studies have shown that Greek native varieties are among the latest ripening (e.g. they have high heat requirements to complete their annual cycle). In the long term “VitAdapt” comparative vineyard experiment by the EGFV group from the Institut des Sciences de la Vigne et du Vin, involving 52 varieties from different geographical origins of the world, the Greek cultivars Xinomavro and Assyrtiko were the latest ripening among the other red and white varieties respectively (van Leeuwen *et al.,* 2019).

In a recent analysis of the heat requirements of 29 winegrape varieties (16 indigenous and 13 international) cultivated all over the Greek territory, based on GDD from 1st of April to harvest date (Koufos *et al.,* under review), consistent maturity clusters of the varieties studied were identified, especially for indigenous Greek varieties (Figure 1). While cluster 1 with the lowest GDD units required for harvest (green color) consisted of only 2 indigenous and 7 international varieties, cluster 3 (red color) comprised 10 late ripening varieties of which 8 are indigenous and only 2 international. Although data were obtained from vineyards greatly varied in their latitude, altitude, and topography (in contrast to the "VitAdapt" project), the international varieties are skewed towards earlier ripening as compared to indigenous Greek varieties with an average harvest date of 2 September compared to 10 September for the Greek varieties (data not shown).

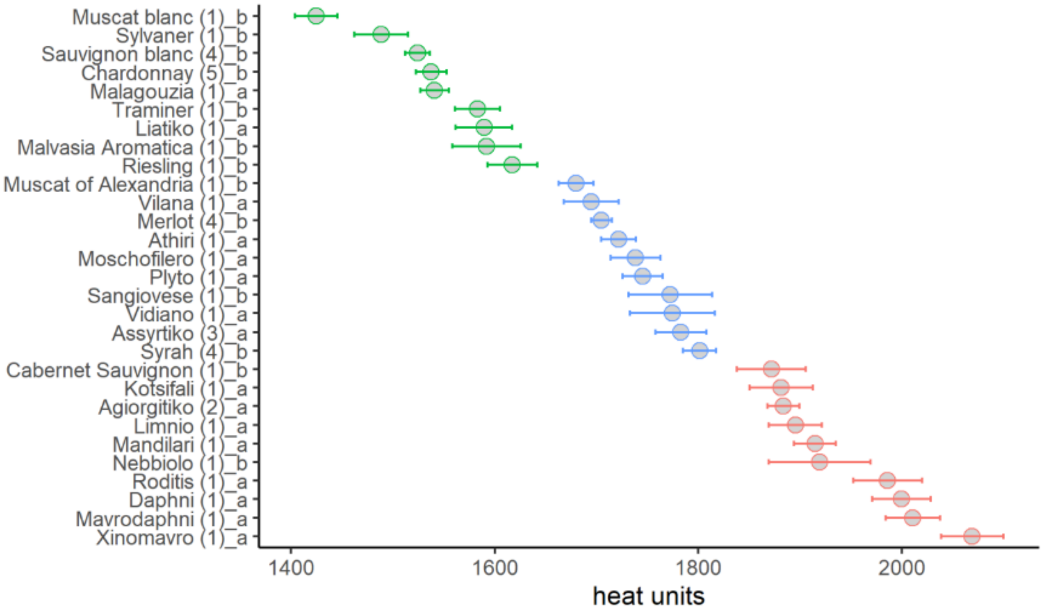


**Figure 1:** Heat requirements for 29 winegrape varieties (16 indigenous and 13 international) cultivated in Greece. Heat units are estimated as mean growing degree-days (GDD) from April 1st to the harvest date. Varieties are grouped according to the K-means cluster analysis [Cluster 1: early ripening varieties (green colour), Cluster 2: mid-ripening varieties (blue colour) and Cluster 3: late ripening varieties (red colour)] (source: Koufos *et al.,* under review).

In the same study, linear regression analysis showed that the indigenous Greek varieties appear better adapted to the current and projected future climate, responding less to warming (e.g. without, or with a smaller shift in harvest timing) as compared to international varieties in the majority of the study cases. Moreover, late ripening varieties often experience an improved sugar/acid ratio at harvest since warming would allow sugars to accumulate to maximum levels (Koufos *et al.,* 2014).

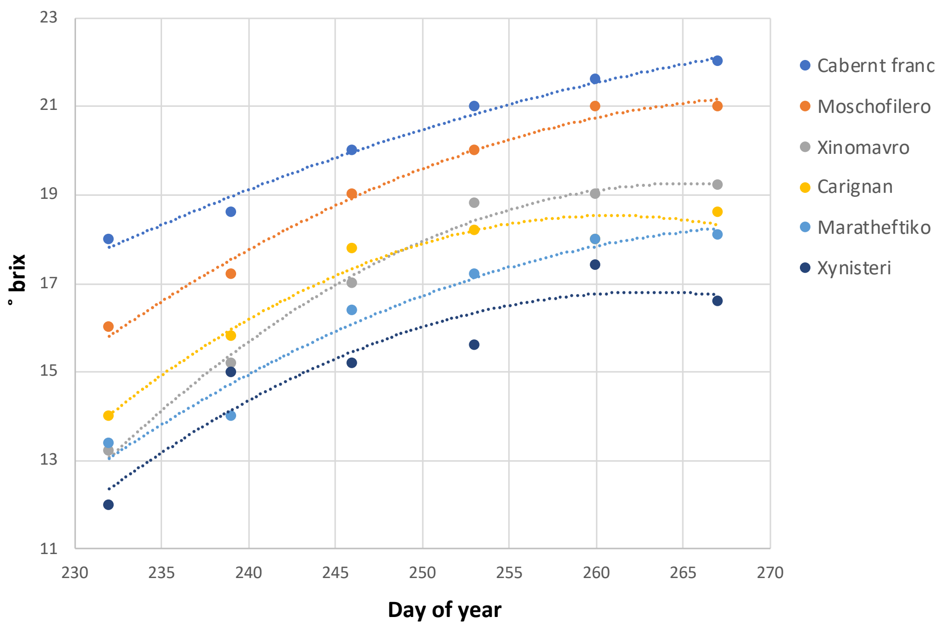


**Figure 2:** Evolution of Xynisteri and Maratheftiko must soluble solids compared to Greek and French varieties (data from AUTh experimental vineyard 2011, Thessaloniki, Greece).

Cypriot varieties Xynisteri (white) and Maratheftiko (red) seem to have even higher heat requirements. According to must sugar monitoring in the ampelographic collection of the Aristotle University experimental Farm, the above-mentioned varieties presented the lowest total soluble solids in the must compared to other late-ripening Greek and French varieties by the end of September, although heat summation (1st April to 30th September) for 2011 was 2181 GDD (Figure 2).

However, the resilience of grape cultivars to global warming should not only be examined on the basis of their heat requirements but also in terms of their resilience to high heat loads, especially on the grapes. In a study involving the two main Cypriot varieties ('Mavro' and 'Xynisteri'), exposure to direct sunlight and high daytime temperatures by fruit-zone leaf removal led to a reduction of soluble solids, titratable acidity, aroma potential and most of the phenolic groups in the musts of both cultivars (Constantinou *et al.,* 2018). There is a lack of knowledge on the response of secondary metabolites (types, concentrations, etc.) in grapes under high temperatures across cultivars. This information would greatly assist grape growers in improving cultivar selection and adjusting vine management to achieve optimum phenolic and aroma expression in their wines, especially if ripening period occurs under hot weather conditions.

***Adaptation to Water Limitation***

Grapevine varieties respond to drought by modifying anatomical, morphological or biochemical traits such as root volume (Alsina *et al.,* 2011), xylem vessel hydraulic architecture (Palliotti *et al.,* 2011) and stomatal function (Flexas *et al.,* 2010), among others. These responses to water availability may have a varying importance depending on the cultivar, often related to their geographical origin.

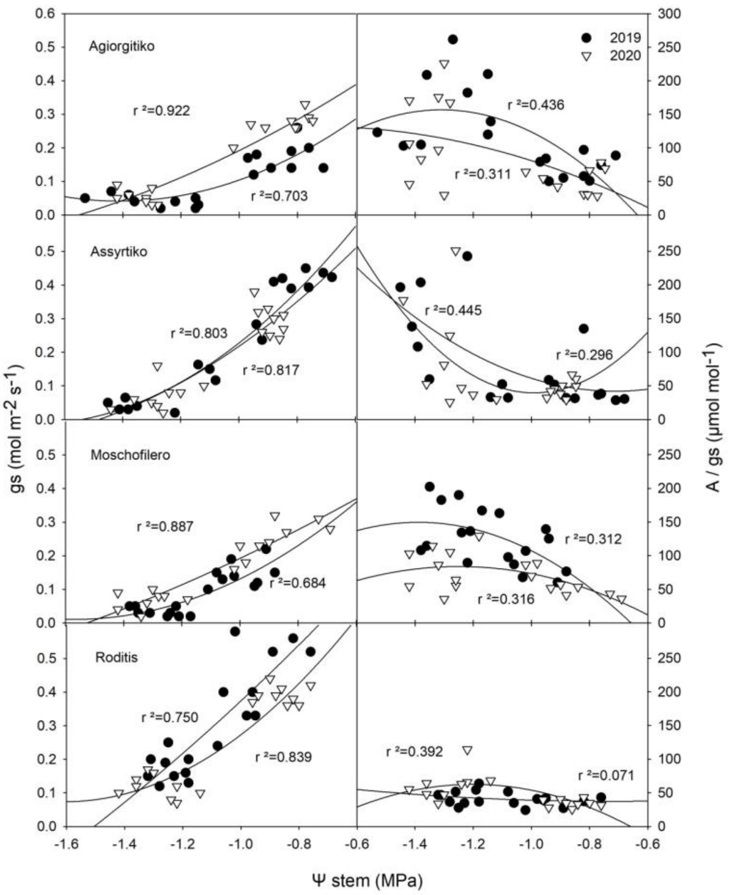


**Figure 3:** Relationship of stomatal conductance (gs) and intrinsic water use efficiency (A/gs) with stem water potential (Ψstem) for four indigenous Greek winegrape varieties. Measurements were taken at midday, on three sampling times in 2019 and 2020. Each point is the mean of 4 leaves per plot.

Stomatal control of transpiration flow is the most commonly studied adaptation to drought in vines. It has been suggested that grapevine genotypes present a varying stomatal sensitivity to limited water availability where some varieties tend to close their stomata earlier than others, thereby increasing water use efficiency (WUE, e.g.

the ratio of net $CO_2$ assimilation rate to stomatal conductance). WUE presents a high interspecific variability with values ranging from 25 to 100 mmol $mol^{-1}$, in irrigated plants and between 100 to 200 mmol $mol^{-1}$ in non-irrigated plants (Flexas *et al.*, 2010).

In a study investigating the physiological and molecular basis of the responses to drought of Greek indigenous cultivars, Roditis showed the highest stomatal conductance (gs) under water stress conditions (between 80 and 230 mmol $m^{-2}$ $s^{-1}$), indicating a decreased sensitivity of its stomatal behavior in response to water conditions, accompanied by a low WUE (Figure 3). On the contrary, in Agiorgitiko, Assyrtiko and Moschofilero, gs changes quickly and falls to low levels (≤100 mmol $m^{-2}$ $s^{-1}$) under increasing drought, thereby increasing WUE values even higher than 200 mmol $mol^{-1}$.

In a comparative study of the two most important red grapes of Greece, Agiorgitiko and Xinomavro with Grenache and Syrah (Theodorou, 2019), planted in a randomized complete block design and submitted to three irrigation regimes, Xinomavro, like Grenache, showed a more sensitive stomatal behavior, less negative midday leaf/stem Ψ and higher WUE (calculated both as A/gs and $\delta^{13}C$) and could be characterized as more drought resistant than Syrah and Agiorgitiko, from a physiological aspect (Table 1). The lower ΔΨ (e.g. $\Psi_{leaf}$-$\Psi_{stem}$) for Xinomavro and Grenache indicate decreased transpiration flow through the leaf, which is typical of isohydric behavior.

**Table 1:** Influence of genotype on water relations and leaf gas exchange parameters [$\Psi_{leaf}$: midday leaf water potential (MPa), $\Psi_{stem}$: midday water potential (MPa), $\Delta\Psi=\Psi_{leaf}-\Psi_{stem}$, gs: midday stomatal conductance (mol $m^{-2}$ $s^{-1}$), A: midday net assimilation rate (μmol $m^{-2}s^{-1}$), A/gs: intrinsic water use efficiency (mmol $mol^{-1}$), $\delta^{13}C$ of winter canes] of Xinomavro, Agiorgitiko, Syrah και Grenache noir (means averaged over three seasons: 2012, 2013 & 2014), n=27.

| | $\Psi_{leaf}$ | $\Psi_{stem}$ | ΔΨ | gs | A | A/gs | $\delta^{13}C$ |
|---|---|---|---|---|---|---|---|
| Xinomavro | -1.38 b | -1.05 b | 0.33 d | 0.23 c | 13.4 c | 58.2 b | -27.2 b |
| Grenache noir | -1.35 a | -1.00 a | 0.36 c | 0.22 c | 12.7 d | 64.0 a | -27.0 a |
| Syrah | -1.62 d | -1.11 d | 0.51 a | 0.30 a | 15.1 a | 50.3 c | -27.8 c |
| Agiorgitiko | -1.52 c | -1.08 c | 0.45 b | 0.26 b | 14.2 b | 54.6 c | -27.8 c |
| *year x variety* | 0.001 | 0.160 | 0.008 | 0.278 | 0.001 | 0.107 | 0.001 |

Significant differences among varieties are indicated by different letters (Tukey's test, $p < 0.05$)

Apart from stomatal conductance, of water flow can be also modified by adaptations of anatomical and morphological traits, such as the size and distribution of the xylem vessels or the size and density of stomata, in order to avoid water loss without great reductions in gs (Palliotti *et al.,* 2011). Indeed, in the same experiment, Agiorgitiko and Syrah that lack a fast stomatal regulation of transpiration flow, showed lower xylem vessel sizes compared to Grenache and Xinomavro, especially in the upper shoot internodes (Table 2 & Figure 4B). Moreover (Figure 5), non-irrigated Agiorgitiko and Syrah had more vessels in the smallest vessel diameter range (20–80 μm) and had no or few larger diameter vessels (>160 μm) considered as more susceptible to cavitate at low Ψ. This different response of the varieties Agiorgitiko and Syrah was confirmed by the lower density of stomata and the smaller stomatal pore, especially under non-irrigated conditions (Figure 4A). In Savatiano (another Greek cultivar admitted as one of the most resistant to drought), the maintenance of cell turgor under drought was reportedly achieved by osmotic adjustment at the mesophyll cells by active Ca and K accumulation, as shown by Patakas *et al.* (2002).

Regarding Cypriot varieties, in a potted trial with three irrigation regimes, Xynisteri showed higher leaf water potential, stomatal conductance and chlorophyll content when compared to Sauvignon blanc, and produced greater root, trunk and shoot biomass (Copper *et al.,* under review). Yield and vigor were also higher in Xinomavro and Grenache compared with Agiorgitiko and Syrah (Table 2) but their shoot growth was more responsive to progressive water deficit, possibly because of the higher proportion of large vessels at the internodes below the shoot tip (Schultz and Matthews, 1988).

**Table 2:** Influence of genotype on anatomical traits [SD: stomatal density (No $mm^{-2}$), SPD: stomatal polar diameter (μm), VF vessel frequency (No $mm^{-2}$), VD: vessel diameter (mm)] and growth parameters [LA: total vine leaf area ($mm^{-2}$), PW: vine pruning weight (kg) and vine yield (kg)] of Xinomavro, Agiorgitiko, Syrah και Grenache noir (means averaged over three seasons: 2012, 2013 & 2014), n=27.

| | SD | SPD | VF | VD | LA | PW | Yield |
|---|---|---|---|---|---|---|---|
| Xinomavro | 239 a | 417 b | 62 b | 93 b | 3.8 a | 1.8 a | 4.9 b |
| Grenache noir | 225 b | 463 a | 59 c | 96 a | 3.3 b | 1.8 a | 7.6 a |
| Syrah | 228 c | 347 d | 59 c | 83 c | 2.9 c | 1.1 c | 5.4 b |
| Agiorgitiko | 229 b | 365 c | 64 a | 84 c | 2.9 c | 1.3 b | 4.0 c |
| *year x variety* | 0.001 | 0.001 | 0.123 | 0.800 | 0.570 | 0.003 | 0.206 |

Significant differences among varieties are indicated by different letters (Tukey's test, $p < 0.05$)

Selecting varieties for their resilience to drought is a more challenging task than selecting late-ripening varieties; moreover, apart from physiological, anatomical and morphological adjustments, qualitative traits should also be considered. Molecular genetic studies have shown that anthocyanin formation in the grapes of vines subjected to water deficit is stimulated by an earlier expression of genes of the flavonoid biosynthetic pathway in Cabernet-Sauvignon berries (Castellarin *et al.,* 2007). Moreover, according to Kyraleou *et al.* (2016), water deficits would be expected to lead to less astringent tannins, in Syrah wines. However, previous work in Agiorgitiko (Koundouras *et al.,* 2013) showed that its phenolic composition is maximized under mild water deficit, a result which is further supported by preliminary analysis of the expression of the genes of the phenylpropanoid and terpenoid pathways (unpublished data). Similarly, although Xynisteri and Maratheftiko are both late-ripening and vigorous varieties, Maratheftiko appears as more sensitive to drought (personal communication).

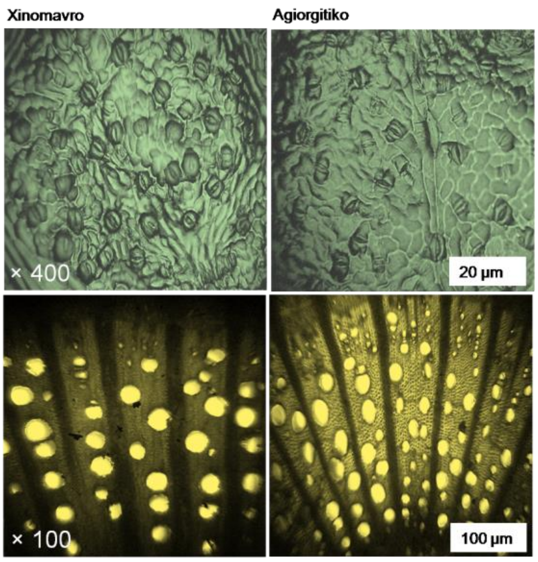


**Figure 4:** (A) Stomatal morphology and distribution of lower leaf epidermis viewed in a nail varnish impression at 400x magnification (upper images) and (B) tangential cross-sectional area of canes (9th internode from the base) showing xylem vessel size and distribution at 100x magnification (lower images) of non-irrigated Xinomavro and Agiorgitiko vines, in 2014.

**Conclusions**

Indigenous varieties of Greece and Cyprus seem to be less impacted by recent and projected temperature and drought increases indicating that the introduction to other regions of the world and/or further improvement (clonal selection or breeding programs) could provide a sustainable means of adaptation to climate change for grape growers and wine makers.

Fine wine is an agricultural product that has characteristics that make it an especially interesting topic for analyses against the background of a changing climate mainly because it is usually produced in delineated geographical areas, where production parameters (variety mainly) are controlled by legislation and are tight to historical traditions; substituting Chardonnay by Assyrtiko or Xynisteri will change the "identity" of (mainly) European wine appellations, therefore the effectiveness of any strategy of introducing Greek/Cypriot varieties depends on both the willingness of grape growers and consumers to try new varieties and also on the flexibility of current regulations. For that reason, studies of consumers' response to these varieties are already undertaken to investigate whether these grape varieties can be introduced successfully (Copper *et al.,* 2019).

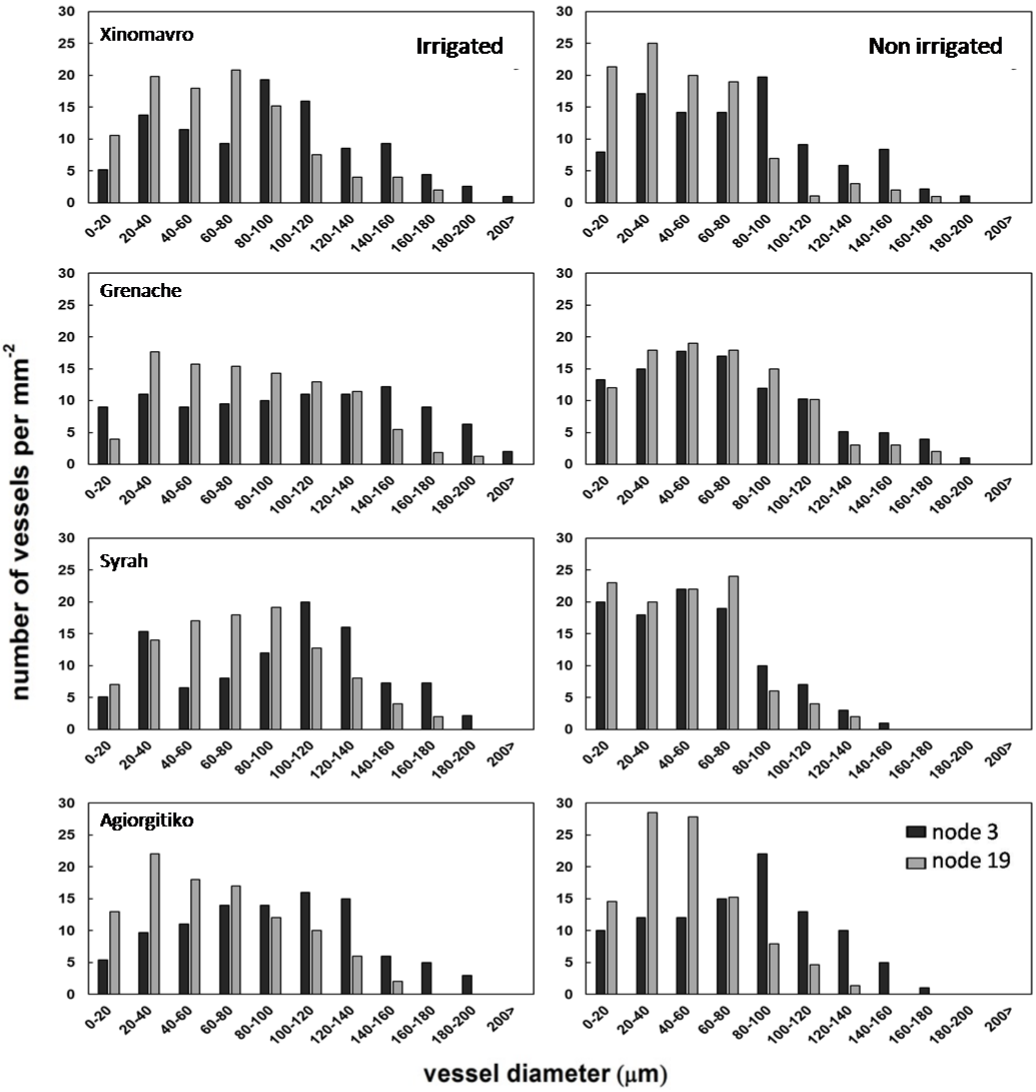


**Figure 5:** Vessel diameter distribution per mm$^2$ of cross-sectional area of xylem tissue of Xinomavro, Agiorgitiko, Syrah και Grenache noir in 2012, 2013 και 2014 canes (9$^{th}$ internode) subjected to different irrigation (irrigated at 100% of ETc and non-irrigated).

## References

**Alsina, MM., Smart, DR., Bauerle, T., de Herralde, F., Biel, C., Stockert, C., Negron, C., Save, R., 2010.** Seasonal changes of whole root system conductance by a drought-tolerant grape root system. Journal of Experimental Botany, 62: 99-109.

**Castellarin, SD., Matthews, MA., Di Gaspero, G., Gambetta, GA., 2007.** Water deficits accelerate ripening and induce changes in gene expression regulating flavonoid biosynthesis in grape berries. Planta, 227: 101-112.

**Chaves, M., Santos, T., Souza, C., Ortuño, M., Rodrigues, M., Lopes, C., Maroco, J., Pereira, J., 2007.** Deficit irrigation in grapevine improves water-use efficiency while controlling vigour and production quality. Annals of Applied Biology, 150: 237–252.

**Constantinou, S., Gómez-Caravaca, AM., Goulas, V., Fernandez-Gutierrez, A., Koundouras, A., Manganaris, GA., 2018**. Leaf removal at veraison stage differentially affects qualitative attributes and bioactive composition of fresh and dehydrated grapes of two indigenous Cypriot cultivars. Journal of the Science of Food and Agriculture, 99: 1342-1350.

**Copper, AW., Johnson, TE., Danner, L., Bastian, SE., Collins, C., 2019.** Preliminary sensory and chemical profiling of Cypriot wines made from indigenous grape varieties Xynisteri, Maratheftiko and Giannoudhi and acceptability to Australian consumers. OENO One, 53(2): 229-248.

**Flexas, J., Galmes, J., Galle, A., Gulias, J., Pou, A., Ribas-Carbo, M., Tomas, M., Medrano, H., 2010.** Improving water use efficiency ingrapevines: potential physiological targets for biotechnological improvement. Australian Journal of Grape and Wine Research, 16 : 106–121.

**Gaiotti, F., Pastore, C., Filippetti, I., Lovat, L., Belfiore, N., Tomasi, D., 2018.** Low night temperature at veraison enhances the accumulation of anthocyanins in Corvina grapes (*Vitis Vinifera* L.). Scientific Reports, 8 : 8719.

**Jones, GV., 2019.** The State of Climate. In: Proceedings of the 21st GIESCO International Meeting, June 23-28 2019: Thessaloniki, Greece, pp. 32-43.

**Kliewer, WM., 1973.** Berry composition of *Vitis vinifera* cultivars as influenced by photo-and nycto-temperatures during maturation. Journal of the American Society of Horticultural Science, 2: 71-77.

**Koufos, G., Mavromatis, T., Koundouras, S., Fyllas, NM., Jones, GV., 2014** Viticulture-climate relationships in Greece: The impacts of recent climate trends on harvest date variation. International Journal of Climatology, 34: 1445-1459.

**Koundouras, S., Kanakis, I., Drossou, E., Kallithraka, S., Kotseridis, Y., 2013**. Effects of postveraison water regime on the phenolic composition of grapes and wines of cv. Agiorgitiko (*Vitis vinifera* L.). OENO One, 47: 115-128.

**Kyraleou, M., Kotseridis, Y., Koundouras, S., Chira, C., Teissedre, P-L., Kallithraka, S., 2016.** Effect of irrigation regime on perceived astringency and proanthocyanidin composition of skins and seeds of *Vitis vinifera* L. cv. Syrah grapes under semiarid conditions. Food Chemistry, 203: 292-300.

**Merkouropoulos, G., Michailidou, S., Alifragis, A., Zioziou, E., Koundouras, S., Argyriou, A., Nikolaou, N., 2015.** A combined approach involving ampelographic description, berry oenological traits and molecular analysis to study native grapevine varieties of Greece. Vitis, 54: 99–103.

**Palliotti, A., Poni, S., Silvestroni, O., Tombesi, S., Bernizzoni, F., 2011.** Morpho-structural and physiological performance of Sangiovese and Montepulciano cv. (*Vitis vinifera*) under non-limiting water supply conditions. Functional Plant Biology, 38: 888–898.

**Patakas, A., Nikolaou, N., Ziozioux, E., Radoglou, K., Noitsakis, B., 2002.** The role of organic solute and ion accumulation in osmotic adjustment in drought stressed grapevines. Plant Science, 163: 361-367.

**Schultz, HR., Matthews, MA., 1988.** Resistance to water transport in shoots of *Vitis vinifera* L. Plant Physiology, 88: 718–724.

**Theodorouy, N., 2019.** Study of drought adaptation mechanisms of grape varieties of different geographical origin. PhD of Aristotle University of Thessaloniki, 187 p.

**van Leeuwen, C., Destrac-Irvine, A., Dubernet, M., Duchêne, E., Gowdy, M., Marguerit, E., Pieri, P., Parker, A., de Rességuier, L., Ollat, N., 2019.** An update on the impact of climate change in viticulture and potential adaptations. Agronomy, 9: 514.