Preprints.org

Review

Not peer-reviewed version

Effects of Climate Change on Viticulture (*Vitis* spp.)

Arif Atak *

Posted Date: 5 October 2023

doi: 10.20944/preprints202310.0297.v1

Keywords: Climate change; stress factors; Vitis spp.; extreme climate events; sustainable agriculture

Preprints.org is a free multidiscipline platform providing preprint service that is dedicated to making early versions of research outputs permanently available and citable. Preprints posted at Preprints.org appear in Web of Science, Crossref, Google Scholar, Scilit, Europe PMC.

Copyright: This is an open access article distributed under the Creative Commons Attribution License which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 October 2023 doi:10.20944/preprints202310.0297.v1

Disclaimer/Publisher's Note: The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.

Review

Effects of Climate Change on Viticulture (*Vitis* spp.)

Arif Atak *

Department of Horticulture, Agriculture Faculty, Bursa Uludağ University, 16059, Bursa/ TURKIYE; arifatak@uludag.edu.tr; Tel.: (+90 505 4804130).

Abstract: Climate change has many negative effects on the viticulture sector, as it does in all sectors. In recent years, global climate change has also shown its effect in the form of sudden climatic events. There is an urgent need to develop preventive/protective activities against these negative effects for all plant species in order to protect the increasing world population from being adversely affected by this. Grape industry is among the sectors that feel the negative effects of climate change the most, and this effect is increasing every year. Along with global warming, there are also important problems in accessing water. Particularly, there is a need to develop cultivars that are more resistant to drought stress and to make applications that will protect grapevine plants from drought stress. The one of most important issue to be done is to develop new cultivars that can withstand different stress conditions and to use them more in production. In addition, taking into account the increasing environmental and human health awareness, it is of great importance that all these are carried out in accordance with the sustainable agriculture model and the use of environmentally friendly cultivars in production.

Keywords: Climate change; stress factors; *Vitis* spp.; extreme climate events; sustainable agriculture

1. Introduction

The total vineyard area in the world is about 6.7 million hectares and the production from this area is around 73,5 million tons. The countries with the highest vineyard area in the world are Spain (13%), China (12%), France (11%), Italy (9%) and Turkey (6%)(Figure 1). These five countries represent about half of the global vineyard area [1].

Despite the fact that grapes are produced quite a lot in terms of area and quantity, they have been rapidly affected by the changing climatic conditions in recent years and some negative results of this effect have begun to be seen in the vineyard areas. The effects of climate change have become a global threat that has increased in recent years and caused very important problems, and it has many negative effects on the viticulture sector as in all sectors. When the data of 2020 and 2021 are compared, significant decreases are observed in terms of both area and amount. It is reported that this situation is significantly related to the increasing negative effects of climate change [2].

The world population is increasing every year and in order to be protected from the negative effects of climate change, as in all plant species, there is a need to develop preventive/protective activities against these negative effects for viticulture [3].

Among the most important effects of climate change, increasing air temperatures and their significant abiotic stress on plants, resulting in negative effects on plant growth and fruit quality can be shown. Especially the table grape sector is one of the sectors that feel the negative effects of climate change the most, and this effect is increasing every year [4,5]. With global warming, water resources are limited and there are significant problems in accessing water. As a solution, there is a need to develop varieties that are more resistant to drought stress and to make applications that will protect grapevine plants from heat [6].

In recent years, global climate change has also shown its effect in the form of sudden climatic events (excessive precipitation, heavy wind, hail, etc.) [7].

Especially in many countries where grapes are grown, different covering systems have started to be used in more areas to protect the grapevine plants against increasing extreme weather and climatic events/disasters [8].

© 2023 by the author(s). Distributed under a Creative Commons CC BY license.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 October 2023 doi:10.20944/preprints202310.0297.v1

In addition, with the integration of smart agriculture and artificial intelligence applications into these systems, it has become possible to have prior knowledge and preventive measures against many extreme weather events [9]. In addition, with the negative effects of climate change, the scope of diseases in grapevine plants and different Vitis species has diversified and expanded. Unfortunately, pathogens have become more immune to many fungicides used to protect vines against disease agents, and many chemicals used pose great threats to human health [10].

With the increase in population in the world, the demand for agricultural products has increased at the same rate in recent years. Related to this issue, there is a great demand to increase the quality of different agricultural products and the yield per unit area. For this reason, antifungal agents are widely used as an alternative to control many fungal diseases affecting plants [11,12].

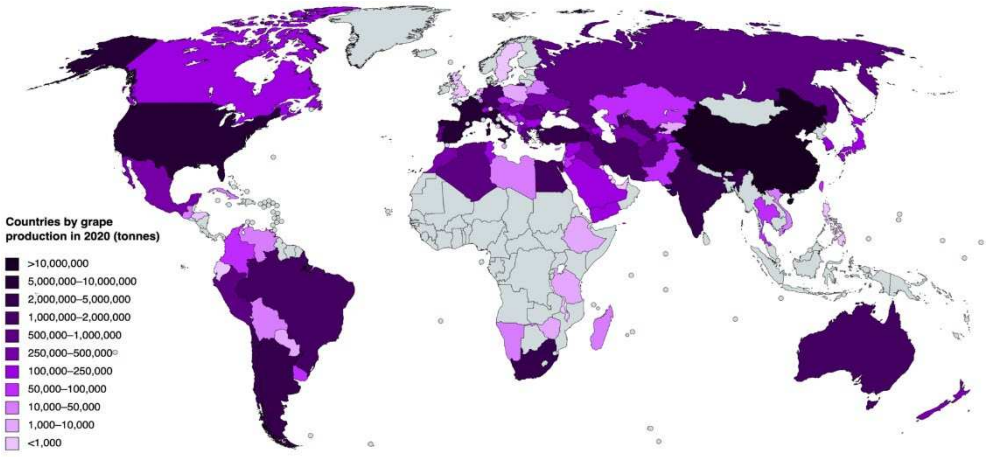

Figure 1. Grape production amounts of countries on the world map.

They cause a significant threat to human and environmental health as a result of excessive application of chemicals used against fungal diseases, sometimes even more than necessary. Some strict laws are needed to prevent the overuse of these fungicides and to prevent them from causing toxic effects. The increasing disease pressure, especially with climate change, increases the need for these regulations [10].

In this case, one of the most important issue to be done is to develop new varieties that can resistance/tolerant different stress conditions or have more tolerance and to use them more in production. It is predicted that these new varieties, especially developed by using the advantages of biotechnology, will constitute a large part of the production in the near future [13,14].

In addition, taking into account the environmental and human health awareness that has increased in recent years, it is of great importance that all these are done in accordance with the sustainable agriculture model and that environmentally friendly species and varieties are used in production.

2. General Effects of Climate Change

Although many people think that human-induced climate change will occur in the very distant future, this is not actually the case. Unfortunately, climate change is still actively ongoing and has been occurring for over a century. It is reported that global temperatures have increased by more than 1°C. In fact, it is understood that climate change is not only limited to the increase in temperature but also causes many adverse conditions [15]. Climate change also refers to sea level rise, changes in weather patterns such as droughts and floods, and much more. Many things that we depend on and value—such as water, energy, transportation, wildlife, agriculture, ecosystems, and human health—are experiencing the effects of a changing climate [16].

Changes in water resources have great effects on our world and plants. As our climate changes, extreme climatic events such as floods have become an increasing problem. Compared to since beginning of the 20th century, many countries experience stronger and more frequent extreme and

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 October 2023 doi:10.20944/preprints202310.0297.v1

heavy rainfalls. Especially with the emergence of increasing climate changes in many countries, the issue of predicting flood events attracts considerable attention [17].

At the same time, drought has become an increasing problem and has increased its impact in many countries. Higher temperatures can cause plants to lose or transcribe more water, which means farmers have to give them more water. Growers and vineyard owners began to use more water, especially for agriculture. This situation, which emerged in places where resources were limited, caused growers to seek different solutions [18].

Snow is one of the most important fresh water resources. However, with decreasing snowfall because of global warming, it poses a serious threat for the amount also continuity of fresh water resources [19].

Our food supply is highly dependent on climate and weather conditions. While farmers and scientists can adapt some farming techniques and technologies or develop new ones, managing some changes really isn't as easy as it seems [20].

Negative effects of climate change for example; increasing temperatures, drought, water stress, diseases and extreme weather conditions, the farmers who produce for us have to cope with many difficulties. Among those who experience these difficulties, there are table and wine grape growers [8,21–23].

2.1. Effects of Climate Change on Table Grapes

Accessing water is one of the important problem after the climate change for the table grapes. We need new varieties/cultivars that are more resistant to drought stress and to make treatments that will protect grapevine plants from heat stress. Due to increased water competition with other related sectors of the economy and climate change, water used for agriculture will become more scarce in the future, leading to more frequent droughts [24]. In recent years, global climate change has also shown its effect in the form of sudden climatic events (excessive precipitation, heavy wind, hail, etc.).

In many countries where table grapes are grown, different covering systems to protect the grapevine plants and fruits on them against the increasing extreme weather and climate events/disasters have started to be used more areas [25,26]. In addition, with the integration of smart agriculture and artificial intelligence applications into these systems, it has become possible to have prior knowledge and preventive action against many extreme weather events [27,28]. There is a significant correlation between fungal diseases and climate change. Because increasing temperatures may create more favorable conditions for these diseases [29].

2.2. Adaptation Strategies in Response to Climate Change

The viticulture sector is going through an important process for adaptation to climate change [30].

In viticulture, climate change not only has effects on the yield and quality of grapes, but is also important because of some difficulties brought by the social demand for environmentally friendly farming techniques [31,32]. Viticulture must adapt to these changing conditions in order to guarantee its sustainability. With climate change in the coming years, grape growers will face rising temperatures and changing precipitation patterns. Especially the vine phenology and the water availability in the soil will be among those most affected. Unsuitable conditions in summer, especially (hotter summers) affect both the chemical composition and flavor of the grapes. Higher evapotranspiration rates will be seen due to rising temperatures and vines will grow in more water stress conditions as a result of changing precipitation ratio. It is strongly expected that these changing conditions will have significant effects on grape yield as well as quality. In the light of these expectations, species and cultivars that can more easily adapt to forcings in grapevine phenology and limited water availability in the soil will come to the fore [33,34].

Climate change will create major problems for all sectors of viticulture in the coming years. In recent years, in most viticulture regions, both fruit and wine quality have improved, while yields have decreased due to rising temperatures and lack of water. This situation may negatively affect the quality in the near future. Growers need new and sustainable strategies for quality production at

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 October 2023 doi:10.20944/preprints202310.0297.v1

economically acceptable yields in a warmer, drier climate. Especially for this purpose, varieties developed from different breeding programs seem to be one of the best solution proposals due to their environmentally friendly and more cost-effective production advantages [32,35].

2.3. Medium-Long-Term Adaptive Strategies

In order to ensure sustainability in the production of Vitis species, measures must be taken to adapt to climate change. Adaptation strategies must be evaluated meticulously and the results must be analyzed well. After all factors are evaluated for the region together with these results, effective applications must be taken together with all decision makers for a sustainable viticulture model. This situation must be taken into account sufficiently when determining the real effects and adaptation mechanisms of climate change. In response to the negative effects of climate change on viticulture, medium-long-term adaptive strategies should be developed urgently. Many studies have been conducted on the adaptation mechanisms of climate change in viticulture. Looking at the contents of these studies; It has been reported that adaptation studies are carried out in 3 different ways (experimental, modeling and expert judgement) on irrigation, plant material, vineyard design, canopy management, management of soil, site/location selection, farm strategy, and harvest management (Figure 2) [36].

There is a need to develop biotechnology for varieties, clones and rootstocks that are more resistant to abiotic stress such as water scarcity, thermal and radiation excess. It is also important for local varieties to better understand and develop knowledge of the mechanisms of adaptation to changing radiation, temperature, lack of vapor pressure and water availability.

Some cultural practices can be partially combated against climate change factors that significantly affect the quality of wine grapes. First of all, different applications can be selected by re-evaluating the criteria for the selection of growing systems and vine spacing. However, while doing this, too many changes should not be made in traditional methods that may adversely affect the quality. For example, a later maturation can be achieved with a simple application such as postponing the winter pruning. In addition, grain sugar accumulation and fruit alcohol content can be limited by using methods such as natural antitranspirant and new canopy management techniques [37,38].

2.4. Damage of High Temperatures on Grapevine Plants

Rising temperatures caused by global warming have become a major threat in many areas of agricultural production, as increased temperatures may inhibit both development and plant growth also cause their complete death in extreme conditions [39,40]. As a result of extensive research conducted in recent years, it has been explained that chloroplasts are highly sensitive to heat stress, which affects various photosynthetic processes such as chlorophyll biosynthesis, CO2 assimilation, photochemical reactions and electron transport. In order to protect these photosynthetic organelles, heat stress response mechanisms have been defined by plant cells (Figure 3). In addition, in recent years, it has been reported that chloroplasts have important roles in inducing the expression of some nuclear heat response genes during the response to heat stress [41].

In some studies conducted in recent years, it has been reported that many growth and development stages in the grapevine begin at an earlier period, considering that it is highly related to temperature increases. As a result of increasing global temperatures, the duration of many phenological stages has been shortened, and the composition and quality of grapes and their products have been negatively affected. As a result of all these changes, in order to keep the quality of the final product at the desired level, vineyard areas are transferred to more northern regions or high altitude regions where the average temperature is slightly lower [42,43].

High temperatures can cause serious irreversible damage to grapevine plants in the period close to harvest. Against this situation, studies conducted in recent years on the identification of key genes in the molecular regulatory network of grapevines against heat stress and subsequent breeding of new high temperature resistant varieties containing these genes attract attention [44].

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 October 2023 doi:10.20944/preprints202310.0297.v1

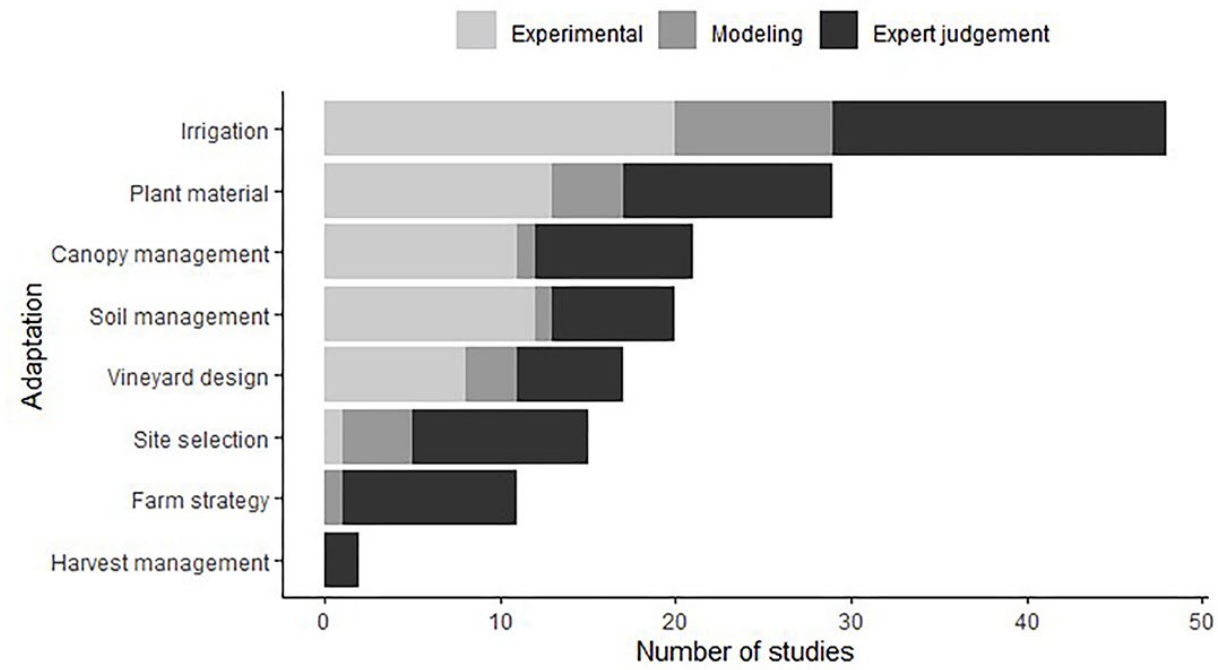

Figure 2. The type, number and content of publications on the adaptation mechanisms of climate change in viticulture [36].

2.5. High Temperatures Stress in Grape Berry Metabolism

Changes in air temperature, and especially increases, affect vine phenology, fruit metabolism and composition very significantly. Global warming poses a serious threat to both grape and wine production in many viticulture regions around the world [45,46]. Above the optimum [40]. Heat stress disrupts cellular homeostasis, leading to significant retardation in growth and development, and sometimes even death. While increasing temperatures in the vine encourage vegetative growth, it disrupts the carbon balance of the plant, negatively affects flower formation and young fruit development [47].

Increasing temperatures also affect the primary and secondary metabolism of fruit, disrupt the harmony of sugar and organic acid metabolism, and delay the accumulation of sugar and polyphenols during ripening. As a result, it can significantly affect the organoleptic properties of wine and cause deterioration in its quality [45,48]. High temperatures greatly disrupt carbohydrate and energy metabolism, and it has been reported that these effects depend on the stage of development and duration of treatment. Also, transcript amounts were weakly correlated with protein expression levels in fruits of high temperature, highlighting the value of proteomic studies in the context of heat stress (Figure 4). It has been reported that high temperatures alter essential proteins that enable fruit development and ripening. Potential markers and proteins for the development or selection of grape varieties that can adapt to warmer climates have been found by researchers [49,50].

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 October 2023 doi:10.20944/preprints202310.0297.v1

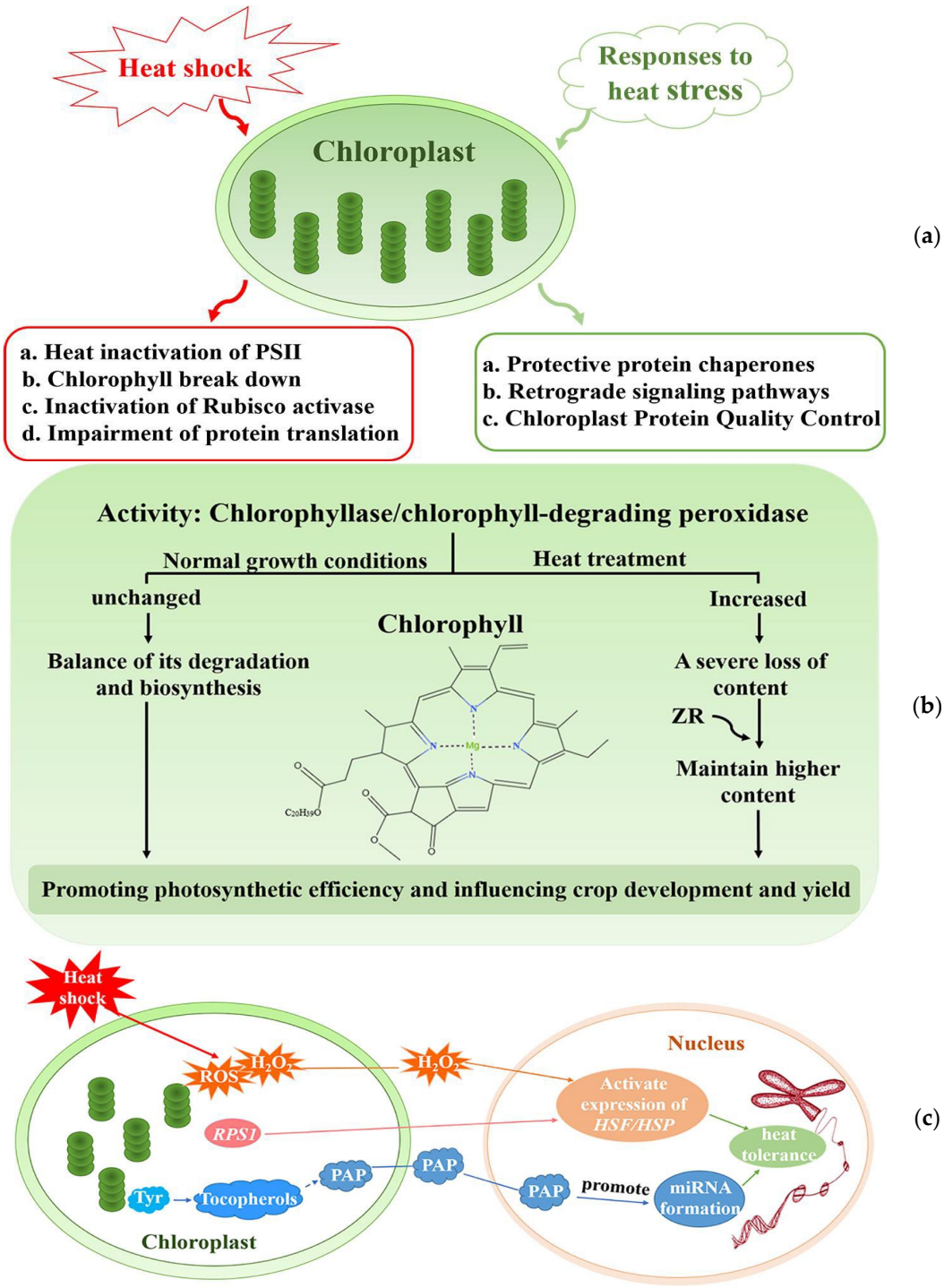

Figure 3. Sensitivities and responses of chloroplasts under high temperature stress. The main effects of heat stress on chloroplasts include heat inactivation of PSII, degradation of Chl, inactivation of Rubisco and disruption of protein translation**(a)**. Chlorophylase and Chl-degrading peroxidase activity is seen in heat stress condition. Under normal conditions, the biosynthesis and degradation of Chl are at constant rates, while under heat stress, the activity of chlorophylase and chlorophyll-degrading peroxidase increases, resulting in a severe decrease in Chl content. In the case of exogenous application of ZR, a higher Chl content is observed **(b).** Illustration of retrograde signaling pathways in chloroplasts under heat stress(c) [41].

When the transcriptomic and metabolic reactions of fruits as a result of heat and drought stress in wine grapes were examined, it was reported that heat stress not only alone but also in conjunction with water stress had significant effects on important quality parameters such as organic acid content,

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 October 2023 doi:10.20944/preprints202310.0297.v1

pH and titratable acidity of the fruit. It is also reported that environmental stresses show a distinct organ-specific response, in contrast to previous research for grape leaves and fruits that respond more strongly to water stress. Heat stress has been reported to have a much more significant effect on gene expression in grape fruits than water stress [51].

Researchers have reported that fruits of different species (especially V.labrusca) with a more biochemically rich content under arid conditions can be an excellent genetic resource [52].

Global warming increase sugar and decrease in anthocyanins and acidity in grapes. Climate adaptation strategies are essential to face global warming in viticulture. Certain viticultural techniques may delay grapevine ripening close to 15 days. Forcing bud regrowth delay ripening two months being essential in very-warm areas [42].

2.6. Soil Management Practices

As a result of the effects of climate change on grapevine plants, especially the issue of soil management has gained importance in this process. When we look at the studies carried out to protect from the negative effects of the climate in the vineyards produced for different purposes, we see that the issues of soil cultivation, weed control and optimum utilization of the decreasing water resources come to the fore. It has been reported that the yield in the grapevines with irrigation and tillage is generally increased by almost two times compared to the tillage system without irrigation. The lack of tillage can reduce the negative impact of the no-irrigation system on yield. Decreases in leaf stomatal conductivity were observed in vines that were not irrigated during the verasion period, regardless of whether or not tillage was done. In addition, at veraison, tillage in non-irrigated vines can significantly increase the phenolic substance ratio compared to the no-tillage system. The grapevines can accumulate more N, P and K and less Mg during the flowering stage compared to the verasion. During the verasion period, reductions in K content in vines with irrigation and tillage, and in Mg content in vines without tillage were noted. The total amount of soluble dry matter and anthocyanins of the berries increased in irrigation and no-tillage systems. It was observed that there was an increase in total phenolics with tillage in plants grown both irrigated and non-irrigated [**53**]. Soil management practices in grapevine plants are used to better manage water resources and also to prevent soil erosion. In Europe, demands for environmental precautions are increasing after increasing environmental awareness, and in recent years, alternative suggestions against the use of herbicides and new soil cultivation tools have started to be used more frequently. It is possible to reduce summer drought problems with less evaporation as a result of more superficial cultivation of the soil. The use of grass cover increases the soil's bearing capacity of the soil, especially during rainy periods, and can further limit the vigour of the grapevine [54].

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 October 2023 doi:10.20944/preprints202310.0297.v1

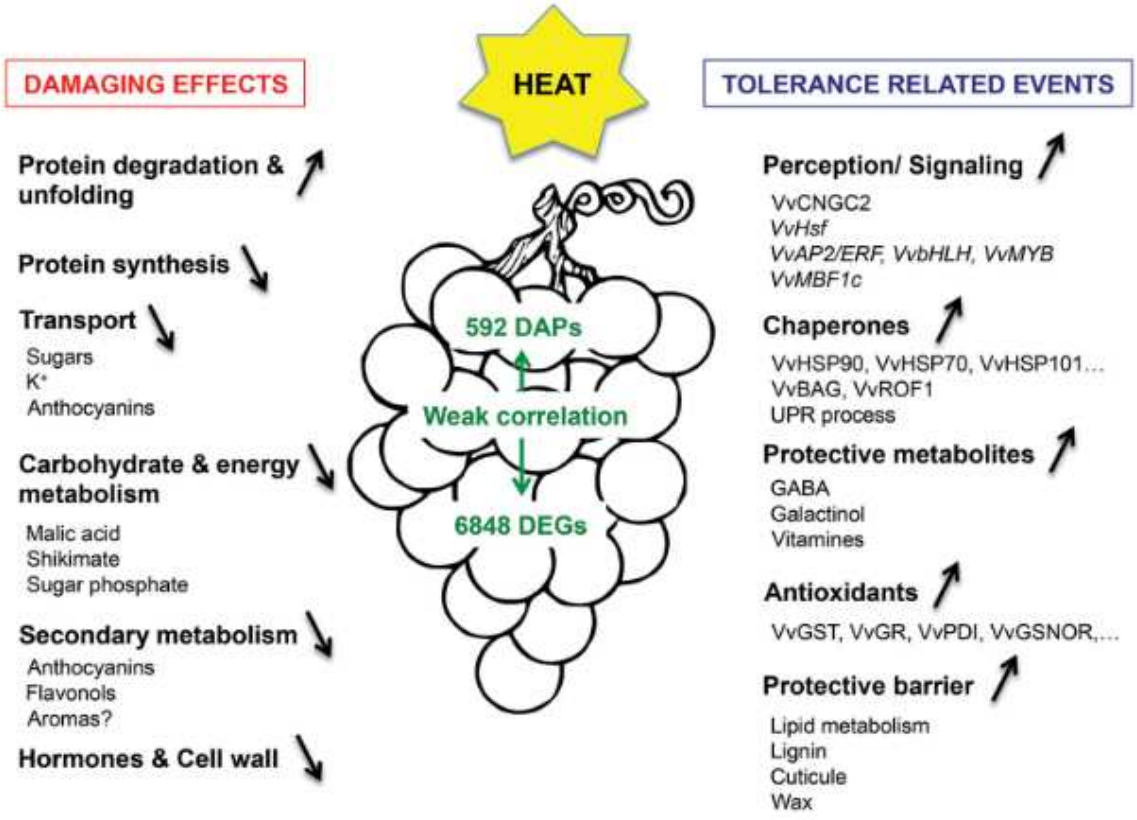

Figure 4. Diagram showing the effects of heat stress on fruits of Cabernet Sauvignon. (The up and down arrows reflect the accumulation levels of the corresponding transcripts, proteins or metabolites in the heated fruit).

The adaptation of the roots, which is the hidden and often overlooked part of the grapevine in the soil, to different soil types has a significant effect on the adaptation of grapevine plants to climate change. Due to the complexity of soil-root interactions, it is necessary to determine strategies to improve the adaptation of viticulture to the existing and possible threats to be encountered in the future, with a comprehensive approach that will combine different disciplines such as physiology, genetics and pathology. Rootstocks have played an important role in viticulture since the introduction of phylloxera into Europe at the end of the 19th century. In order to adapt to climate change, new rootstocks with different soil types and resistant to stress conditions need to be developed for both wine and table grapes. To cope with the effects of climate change and emerging soil-borne pests and pathogens, rootstocks need to be addressed with soil management [55,56].

2.7. Site and Cultivar/Variety Selection

Choosing the right place in viticulture is a very important issue and climate change has increased the importance of this issue even more. Establishing a connection to a wrong place at the beginning of the such an investment will both affect the efficiency and quality and increase the production costs significantly. For a sustainable viticulture, it is necessary to examine the place where the vineyard will be established for both wine and table grape cultivation in terms of many characteristics, including mainly climate and soil data [57]. With climate change, it is expected that there will be changes in the determination of suitable areas for viticulture. While determining new vineyard areas, bioclimatic indexes are used and these indexes provide important information for suitable areas. It is predicted that new areas suitable for viticulture will emerge with the increasing temperatures, especially in the north of Europe [58–61].

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 October 2023 doi:10.20944/preprints202310.0297.v1

New areas to be selected for viticulture; they will be areas with higher altitudes, higher annual precipitation, and less impact on vines from higher temperatures. However, as different plant species are already grown in these new areas, the grapevine may have to compete with them [62].

In order to be protected from the negative effects of climate change in viticulture, particular attention should be paid to the selection of location, direction and variety. Local differences are very important to reduce the negative effects of climate change on viticulture [63].

It is possible for grape growers to benefit from local conditions such as topography, slope and direction to adapt to climate change. Temperatures in the higher elevations differ from those in the lower elevations by several degrees. Grape growers can adapt their vineyard areas to changing temperatures by taking advantage of these local differences. With climate change, the risk of sudden frost events in many vineyard regions has started to increase in recent years [64]. There is a close relationship between the local conditions of the vineyard areas and the damaging effects of low temperatures, so both active and passive protection measures must be taken carefully. Although the most effective method for active protection from frost events is the operation of suspended sprinkler systems during frost events, wind machines and different heating applications are also widely preferred [65]. The most effective passive methods against late spring frosts include choosing a suitable location and choosing the appropriate grapevine cultivars. Grape growers may be advised not to plant vineyards in regions where frost events occur frequently or to plant cultivars that bud burst late [66].

In order to be protected from the negative effects of climate change in viticulture, it will be necessary to pay more attention to the selection of varieties. In studies carried out for this purpose, local varieties that may be less affected by high temperature conditions are determined, and new hybrid varieties are developed with breeding programs [67–69].

2.8. Select Suitable Rootstocks

Rootstock selection is important for adaptation to climate change in viticulture. Rootstocks commonly used in viticulture were obtained from crosses of some American species. Rootstocks obtained from different Vitis species and hybrids, especially V.berlandieri, V.riparia and V.rupestris species, are widely used. These American grapevine rootstocks are resistant to phylloxera and have also been reported in many studies to provide resistance or tolerance to various pathogens and biotic/abiotic stress conditions [70,71]. In addition, grape rootstocks can affect the grape berry quality and make the varieties grafted on them more resistant to different abiotic stress conditions [72,73]. Rootstocks can provide resistance or tolerance to a wide variety of abiotic stresses, in addition to their ability to help the scion cope with different biotic stresses. It is known that rootstocks have significant effects on the grapevine's tolerance to abiotic stress factors (especially high salinity, drought, and iron deficiency). These stress factors are among the very important factors that limit the productivity of the grapevine plant and cause serious yield loss [74].

The breeding of new grape varieties and rootstocks that use water more efficiently is a very important strategy against global climate change. According to global climate models, which predict that drought will increase in the future, there will be significant reductions in water resources and this will be among the main limiting factors of vineyard areas. Therefore, rootstocks are expected to play an important role in limiting crop loss by improving water use, plant survival potential, growth capacity, and adaptation of items to different stress conditions. One of the priorities of today's viticulture research is to develop new rootstocks that are more drought resistant. The biggest advantage of adapting the cultivars to increasing drought stress is that these rootstocks are drought resistant, and their biggest advantages are that they make a significant contribution to reducing production costs [75].

Rootstocks and varieties grafted on them differ in their resistance to drought. For example, rootstocks such as 101-14 and Schwarzmann are less drought tolerant, while rootstocks such as Kober 5 BB, 1103 P, Richter 110, and 140 R are more ressitance and can provide higher drought tolerance to grafted scions [76,77]. The ability of rootstocks to tolerate water stress is related to some structural characteristics. Stomata, which have particularly important roles in regulating water loss, are organs

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 October 2023 doi:10.20944/preprints202310.0297.v1

that need to be taken into consideration in managing water stress. Closure of stomata is one of the earliest responses in grapevines during a lack of water. Stomatal closure is guided by many factors, such as phytohormone accumulation. Abscisic acid (ABA) is one of the most studied hormones in grapevine plants, as in many plant species, and is very sensitive to water stress. Therefore, ABA synthesis is among the fastest plant responses under abiotic stress conditions [78,79].

Salt stress is another important abiotic stress factor and negatively affects both the growth and yield of grapevines. High salt levels cause problems in the uptake of micronutrients as well as water uptake of the soil, and as a result, the toxic ion concentration increases and some deteriorations in the soil structure may occur. Salt stress can affect plants in different ways. First of all, this negative effect is seen as affecting photosynthesis in the leaves. Tolerant varieties defend against this negative effect with their own mechanisms and sometimes they can eliminate this effect. It has also been reported that different grape species, varieties and genotypes have significant differences in the main signaling pathways and gene expressions that cause salt stress [80].

In recent years, it has been reported that engineered nanoparticles (NPs) give positive results in combating abiotic stress factors such as salinity in different species, including vine plant [81].

Iron (Fe) chlorosis is among the most important abitotic stressors affecting grapevines grown in calcareous soil. Iron chlorosis caused by iron deficiency is among the main nutritional disorders seen in susceptible grape varieties or genotypes due to high bicarbonate levels in the soil. Fe deficiency causes a decrease in the productivity of the grapevine plant, reducing both its growth and yield [82].

Moreover, as a result of some wrong practices over many years, the negative effects of climate change are becoming more evident in grapevine plants. For example, many acidic fertilizers used excessively can sometimes cause some negative effects on vine leaves and therefore on crop yield. Particularly in high pH and calcareous soils, it is necessary to prevent chlorosis by creating very careful plant fertilization programs for the uptake of microelements and iron [83].

Non-vinifera rootstocks have higher tolerance or resistance to both phylloxera and nematode damage than V.vinifera, provide better resistance to grafted varieties against these pests. In Figure 5, the characteristics of some commonly used rootstocks and their abiotic stress resistance status are reported. Also A diagram of commonly used rootstocks and their parents is given in Figure 6. The breeding of new rootstocks that can provide tolerance or resistance to biotic/abiotic stresses and improve positively to grape ripening also quality is a very important stage for the next generation viticulture. In this regard, breeding studies are still continuing in different institutions and countries [**76**].

2.9. Covering Systems

Producing more sustainable production and using decreasing water resources effectively in arid and semi-arid regions where table grapes are produced is a very challenging issue. Water use is significantly affected by some climatic conditions (such as excessive solar radiation, high air temperature, strong wind, high humidity). By minimizing the negative effects of the climate; In order to control excessive sun, wind, heat, hail, frost and humidity, the covering of table grapes with different plastics has started to increase in different parts of the world. This situation has a direct relationship with the negative effects of climate change [84,85].

These covers are used protection for hail, high temperature, wind and botrytis disease. In the coming years, it is inevitable that they will be used more widely against the increasing negative effects of the climate [86].

Sometime bunches are partially or completely covered for different purposes. While almost all of the table grape vineyards are covered, especially in countries such as Korea and Japan, the number of covered table vineyards is also quite high in Italy and Spain. It is estimated that the use of these systems will increase in the case of an increase in grape prices in countries such as Chile, South Africa, Turkey, Egypt and Iran, where table grape production is high [87].

Agronomic and physiological measurements were compared in the studies carried out by covered cultivation with different plastic films. Plastic covers are very effective in providing specific leaf area with adequate shoot growth rate. When grapevines without plastic cover are compared with

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 October 2023 doi:10.20944/preprints202310.0297.v1

those with which plastic cover is applied, great differences are observed in terms of values such as leaf area, leaf chlorophyll content and pruning weight. Additionally, plastic cover for grape vines; It causes low photosynthesis, transpiration and stomatal conductance. It has been reported that plastic covers do not change the amounts of important components such as starch, glucose and fructose in the leaves, but only transparent plastic covers can reduce the amount of sucrose in grape leaves. In addition, plastic cover increased the water potential of leaves and stems, reduced rotting, and increased bunch weight, resulting in higher yields. Also, berries under common plastic showed the highest concentration of anthocyanins. These results show that greenhouse cultivation gives very advantageous results, especially under increasing temperatures and limited irrigation opportunities [88,89].

Along with climate change, excessive precipitation that can sometimes be seen in summer causes significant quality loss in table and wine grapes harvested in this season. Moisture-related rain increases the incidence of vine botrytis as well as other fungal diseases. In addition, the increased soil moisture resulting from high rainfall destabilizes vegetative and reproductive development, raises the pH and acid content of the juice, and excessive shoot growth shade the grains, reducing the anthocyanin content and thus the coloration [88,89].

Agrivoltaic (AV) is a new concept that can protect plants from the harmful effects of climate for quality production, while providing the energy needed in agricultural production by placing photovoltaic panels a few meters above the soil surface and vegetation. In the current situation of energy demand from renewable sources, agrivoltaic systems with grape plants under photovoltaic panels tend to become increasingly common. It has been determined that photovoltaic panels affect the microclimate of the vineyard. While vine productivity parameters (especially yield, number of clusters and weight) affect it to a limited extent; It has been reported that anthocyanins, TSS and polyphenols are reduced in grape must. These findings have been reported in studies that affect the vine microclimate and physiology of the panels and that yield decreases may occur under photovoltaic panels, but the results should be evaluated together for both energy and fruit production in hot and dry weather conditions [**92**].

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 October 2023 doi:10.20944/preprints202310.0297.v1

High tolerance — Low tolerance

Rootstock	Scion vigour	Phylloxera	Drought	Salinity	Iron chlorosis
101-14	L				
110 Richter	M				
1103 Paulsen	M-H				
140 Ruggeri	H-M				
196.17 castel	H-M				
3309C	M-L				
41B	M-L				
420A	L				
5BB Kober	M-H				
5C	M				
M1	L				
M2	M				
M3	L				
M4	M-H				
Schwarzmann	M-L				
SO4	M				

Figure 5. Commonly used vine rootstocks and abiotic stress responses. Low (L), medium (M) and high (H) (Scion vigor). Different degrees of tolerance to abiotic stress (phylloxera, salinity, drought, and iron chlorosis).

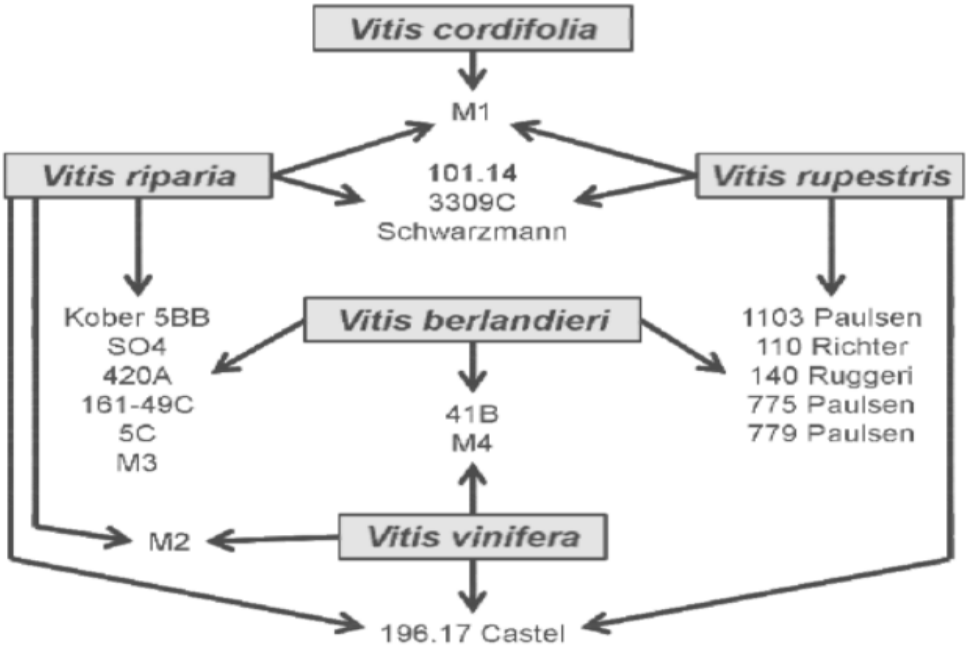

Figure 6. Main rootstocks and their parents.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 October 2023 doi:10.20944/preprints202310.0297.v1

2.10. Irrigation

One of the most important effects of climate change in viticulture and especially in table grape cultivation is related to irrigation water. Increasing temperatures not only cause more water consumption in plants, but also decrease irrigation water resources. It is reported that irrigation management in table grapes has become more important with climate change [**93**].

It is reported that water availability for table grapes will decrease further as a result of increased water demands and competition forecasts, which may affect high sensitivity and uncertainty for both production and human consumption. Conventional surface-applied irrigation methods can include easier installation and maintenance, along with lower infrastructure costs. However, these irrigation methods promote water loss through evaporation and seepage of soil water, which reduces water use efficiency, which is a critical problem in semi-arid and arid regions [94,95]. Different micro irrigation methods, a low pressure, low flow irrigation technique, with a relatively higher initial cost, have the capacity to reduce the use of water resources and increase the yield and economic return of vine crops. Although drip irrigation has become the most common micro irrigation method used in vineyards, it is insufficient to use water more efficiently with increasing temperatures [96].

Direct root-zone irrigation is a novel subsurface drip irrigation strategy for water conservation. When surface drip irrigation and direct root zone irrigation are compared, it can improve grape yield by 9-12% and crop water use efficiency by 9-11% in different climatic conditions. It has been reported that direct root zone irrigation can potentially promote deep rooting in vines under drought stress to alleviate water stress and can be used as a successful tool to increase yield and quality [97].

Irrigation of vines is an important part of vineyard management, and it is especially important for table grapes. In addition, increasing temperatures and decreasing water resources due to climate change have increased this importance even more. With more precise and efficient programming of water resources, water needs can be met more efficiently. Typically, irrigation plans are created using mathematical models. While irrigation systems can be created with the help of technology in many developed countries, such models often have significant problems in implementation in most developing countries, often due to incomplete data [98,99].

2.11. Precision Viticulture

Climate change is becoming an increasingly big problem for the grape industry on a global scale, affecting all aspects of the different development stages of the vine and also deteriorating the quality of the fruits. Because grapevine development is highly dependent on the weather and some climatic conditions, climate change can affect production costs and growth in different regions. Innovative technologies are needed against these problems. One of the more significant and recent conceptual developments in viticulture is precision viticulture (PV). With PV, it can be applied effectively especially in the following topics; Weather monitoring, Pest management, Water Management, Harvest management, Soil management, Canopy Management, Weed Management. Recently, different remote sensing systems have begun to be used to monitor the microclimate of vineyard areas and vine plants. Different sensors integrated with drones, mini planes or satellites began to be used for irrigation programs. Also soil electrical conductivity sensors for soil mapping have also been developed in recent years. Soil and vine water monitoring devices will be used more in vineyard areas in order to protect from the negative effects of climate change due to more technological developments such as sensitive viticulture and artificial intelligence in vineyards [100,101].

It is based on combining technical advances in global positioning system (GPS), onsite or aerial measurements of local microclimatic conditions, details of vineyard water and nutrient status, with measurements of several vine physiological parameters. These data can be correlated down to the level of individual vines and their topographic details. It can helps to make protective applications in the vineyard in advance, especially against sudden climatic events and the negative effects of climate change [102–104].

It is reported that by combining sensor monitoring and precision farming techniques, it can provide yield and quality improvements in grape production in plants under plastic cover systems [105].

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 October 2023 doi:10.20944/preprints202310.0297.v1

3. Conclusions

Climate change causes inevitable damage to different species and varieties all over the world, and unfortunately, these damages are increasing. Appropriate strategies should be determined against this situation and sustainable viticulture models should be developed. When developing varieties and rootstocks that are more resistant to high temperatures, they should be planted in the appropriate location and orientation. It should definitely benefit from technology and especially precision viticulture. Vineyards should be protected from the negative effects of the climate by covering them with different plastic materials. Underground irrigation systems should be preferred against water scarcity and appropriate modifications should be made in the cultivation technique, especially against high temperature and drought. In weed control, weedy systems that reduce water loss can be preferred rather than herbicide-containing systems.

For a sustainable viticulture, the number of breeding programs aimed at developing genotypes that are resistant to environmental stresses should be increased and these new varieties should be delivered to grape growers.

Funding: No funding.

Conflicts of Interest: "The authors declare no conflict of interest.".

References

1. FAOSTAT. Available online: https://www.fao.org/faostat/en/#data/QCL(accessed on 10 April 2023).
2. Fraga, H. Viticulture and Winemaking under Climate Change. *Agronomy.* **2019**, *9, 783*. https://doi.org/10.3390/agronomy9120783
3. Sgroi, F.; Sciancalepore, V.D. Climate change and risk management policies in viticulture. *J. Agric. Food Res.* **2022**, *10, 100363*. https://doi.org/10.1016/j.jafr.2022.100363
4. Ollat, N.; Cookson, S.J.; Destrac-Irvine, A.; Lauvergeat, V.; Ouaked-Lecourieux, F.; Marguerit, E.; Barrieu, F.; Dai, Z.; Duchêne, E.; Gambetta, G.A.; Gomès, E.; Lecourieux, D.; van Leeuwen, C.; Simonneau, T.; Torregrosa, L.; Vivin, P.; Delrot, S. Grapevine adaptation to abiotic stress: an overview. *Acta Hortic*. **2019**, *1248, 497-512*. https://doi.org/10.17660/ActaHortic.2019.1248.68
5. Grillakis, M.G.; Doupis, G.; Kapetanakis, E.; Goumenaki, E. Future shifts in the phenology of table grapes on Crete under a warming climate. *Agric. For Meteorol*. **2022**, *318, 108915*. https://doi.org/10.1016/j.agrformet.2022.108915
6. Fahim, S.; Ghanbari, A.; Naji, A.M.; Shokohian, A.A.; Maleki Lajayer, H.; Gohari, G.; Hano, C. Multivariate Discrimination of Some Grapevine Cultivars under Drought Stress in Iran. Horticulturae **2022**, 8, *871.* https://doi.org/10.3390/horticulturae8100871
7. Lyubchich, V.; Newlands, N.K.; Ghahari, A.; Mahdi, T.; Gel, Y.R. Insurance risk assessment in the face of climate change: Integrating data science and statistics. *WIREs Comput Stat*. **2019**, *11*, e1462. https://doi.org/10.1002/wics.1462
8. Fraga, H.; Malheiro, A.C.; Moutinho-Pereira, J.; Santos, J.A. An overview of climate change impacts on European viticulture. *Food Energy Secur*, **2012**, *1*, 94-110. https://doi.org/10.1002/fes3.14
9. Zhang, P.; Guo, Z.; Ullah, S.; Melagraki, G.; Afantitis, A.; Lynch, I. Nanotechnology and artificial intelligence to enable sustainable and precision agriculture. *Nat. Plants* **2021**, 7, 864–876. https://doi.org/10.1038/s41477-021-00946-6
10. Brauer, V.S.; Rezende, C.P.; Pessoni, A.M.; De Paula, R.G.; Rangappa, K.S.; Nayaka, S.C.; Gupta, V.K.; Almeida, F. Antifungal Agents in Agriculture: Friends and Foes of Public Health. Biomolecules **2019**, 9, 521. https://doi.org/10.3390/biom9100521
11. Popp, J.; Pető, K.; Nagy, J. Pesticide productivity and food security. A review. *Agron. Sustain. Dev.* **2013**, *33*, 243–255. https://doi.org/10.1007/s13593-012-0105-x
12. Godfray, H.C.J.; Beddington, J. R.; Crute, I.R.; Haddad, L.; Lawrence, D.; Muir, J.F.; et al. Food security: The challenge of feeding 9 billion people. *Science* **2010**, *327(5967*), 812–818. https://doi.org/10.1126/science.1185383
13. Reisch, B.I.; Owens, C.L.; Cousins, P.S. Grape. In: Fruit Breeding, eds. M. L. Badenes and D. H. Byrne (Boston, MA: Springer Science+Business Media, LLC) **2012**, pp. 225–262. https://doi.org/10.1007/978-1-4419-0763-9_7
14. Buonassisi, D.; Colombo, M.; Migliaro, D. et al. Breeding for grapevine downy mildew resistance: a review of "omics" approaches. *Euphytica* **2017**, *213*, 103. https://doi.org/10.1007/s10681-017-1882-8
15. Meshram, S.G., Kahya, E., Meshram, C. et al. Long-term temperature trend analysis associated with agriculture crops. *Theor. App.l Climatol.* **2020**, *140*, 1139–1159. https://doi.org/10.1007/s00704-020-03137-z

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 October 2023 doi:10.20944/preprints202310.0297.v1

16. Lokmic-Tomkins, Z.; Nayna Schwerdtle, P.; Armstrong, F. Engaging with our responsibility to protect health from climate change. *J. Adv. Nurs*. 2022, 1–4. https://doi.org/10.1111/jan.15508
17. Torky, M.; Gad, I.; Darwish, A.; Hassanien, A.E. Artificial Intelligence for Predicting Floods: A Climatic Change Phenomenon. In: Hassanien, A.E., Darwish, A. (eds) The Power of Data: Driving Climate Change with Data Science and Artificial Intelligence Innovations. Studies in Big Data, **2023**, Vol. 118. Springer, Cham. https://doi.org/10.1007/978-3-031-22456-0_1
18. Kogan, F. Causes of Climate Warming. In: Remote Sensing Land Surface Changes. **2022**, Springer, Cham. https://doi.org/10.1007/978-3-030-96810-6_6
19. Li, J.; Xu, X. Glacier Change and Its Response to Climate Change in Western China. *Land* **2023**, *12*, 623. https://doi.org/10.3390/land12030623
20. Schmidhuber, J.; Tubiello F.N. Global food security under climate change. *PNAS* **2007**, 104, *50*. 19703-19708. https://doi.org/10.1073/pnas.0701976104
21. Gbejewoh, O.; Keesstra, S.; Blancquaert, E. The 3Ps (Profit, Planet, and People) of Sustainability amidst Climate Change: A South African Grape and Wine Perspective. *Sustainability* **2021**, *13*, 2910. https://doi.org/10.3390/su13052910
22. Pizarro, E.; Galleguillos, M.; Barría, P.; Callejas, R. Irrigation management or climate change ? Which is more important to cope with water shortage in the production of table grape in a Mediterranean context. *Agricultural Water Management*, **2022**, *263*, 107467. https://doi.org/10.1016/j.agwat.2022.107467
23. Manolis, G.G.; Georgios, D,; Kapetanakis, E.; Goumenaki, E. Future shifts in the phenology of table grapes on Crete under a warming climate. *Agricultural and Forest Meteorology*, **2022**, *318*, 108915. https://doi.org/10.1016/j.agrformet.2022.108915
24. Zúñiga-Espinoza, C.; Aspillaga, C.; Ferreyra, R.; Selles, G. Response of Table Grape to Irrigation Water in the Aconcagua Valley, Chile. Agronomy ***2015***, 5, *405-417*. https://doi.org/10.3390/agronomy5030405
25. Pertot, I.; Caffi, T.; Rossi, V.; Mugnai, L.; Hoffmann, C.; Grando, M.S.; Anfora, G.; et al.. A critical review of plant protection tools for reducing pesticide use on grapevine and new perspectives for the implementation of IPM in viticulture. *Crop Prot*., **2017**, *97*, 70-84. https://doi.org/10.1016/j.cropro.2016.11.025
26. Gianfranco R.; Katerji, N.; Introna, M.; Hammami, A. Microclimate and plant water relationship of the "overhead" table grape vineyard managed with three different covering techniques. *Scientia Horticulturae*, **2004**, *102(1),* 105-120. https://doi.org/10.1016/j.scienta.2003.12.008
27. Fuentes, S.; Tongson, E.J. Editorial: Special Issue "Implementation of Sensors and Artificial Intelligence for Environmental Hazards Assessment in Urban, Agriculture and Forestry Systems". Sensors, **2021**, 21, *6383. https://doi.org/10.3390/s21196383*
28. Tardaguila, J.; Stoll, M.; Gutiérrez, S.; Proffitt, T.; Diago, M.P. Smart Applications and Digital Technologies in Viticulture: A Review. *Smart Agric. Technol.* **2021**, *1,* 100005. https://doi.org/10.1016/j.atech.2021.100005
29. Bois, B.; Zito, S.; Calonnec, A. Climate vs grapevine pests and diseases worldwide: the first results of a global survey. *OENO One*, **2017**, *51(2),* 133–139. https://doi.org/10.20870/oeno-one.2017.51.2.1780
30. Santos, J.A.; Fraga, H.; Malheiro, A.C.; Moutinho-Pereira, J.; Dinis, L.-T.; Correia, C.; Moriondo, M.; Leolini, L.; Dibari, C.; Costafreda-Aumedes, S.; Kartschall, T.; Menz, C.; Molitor, D.; Junk, J.; Beyer, M.; Schultz, H.R. A Review of the Potential Climate Change Impacts and Adaptation Options for European Viticulture. *Appl. Sci*. **2020**, *10*, 3092. https://doi.org/10.3390/app10093092
31. Malik, A.; Mor, V.S.; Tokas, J.; Punia, H.; Malik, S.; Malik, K.; Sangwan, S.; Tomar, S.; Singh, P.; Singh, N.; Himangini; Vikram; Nidhi; Singh, G.; Vikram; Kumar, V.; Sandhya; Karwasra, A. Biostimulant-Treated Seedlings under Sustainable Agriculture: A Global Perspective Facing Climate Change. *Agronomy* **2021**, *11*, 14. https://doi.org/10.3390/agronomy11010014
32. Van Leeuwen, C.; Destrac-Irvine, A.; Dubernet, M.; Duchêne, E.; Gowdy, M.; Marguerit, E.; Pieri, P.; Parker, A.; de Rességuier, L.; Ollat, N. An Update on the Impact of Climate Change in Viticulture and Potential Adaptations. *Agronomy,* **2019**, *9*, 514. https://doi.org/10.3390/agronomy9090514
33. Van Leeuwen, C.; Darriet, P. The Impact of Climate Change on Viticulture and Wine Quality. *Journal of Wine Economics*, **2016**, *11(1),* 150-167. https://doi.org/10.1017/jwe.2015.21
34. Drappier, J.; Thibon, C.; Rabot, A.; Geny-Denis, L. Relationship between wine composition and temperature: Impact on Bordeaux wine typicity in the context of global warming—Review, *Critical Reviews in Food Science and Nutrition*, **2019**, *59(1),* 14-30. https://doi.org/10.1080/10408398.2017.1355776
35. Yang, C.; Menz, C.; Fraga, H.; Costafreda-Aumedes, S.; Leolini, L.; Ramos, M.C.; Molitor, D.; van Leeuwen, C.; Santos, J.A. Assessing the grapevine crop water stress indicator over the flowering-veraison phase and the potential yield lose rate in important European wine regions. *Agricul. Water Manag*. **2021**, *261*, 107349. https://doi.org/10.1016/j.agwat.2021.107349
36. Naulleau, A.; Gary, C.; Prévot, L.; Hossard L. Evaluating Strategies for Adaptation to Climate Change in Grapevine Production–Ap Systematic Review. *Front. Plant Sci*. **2021**, *11*, 6078592021. https://doi.org/10.3389/fpls.2020.607859

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 October 2023 doi:10.20944/preprints202310.0297.v1

37. Palliotti, A.; Tombesi, S.; Silvestroni, O.; Lanari, V.; Gatti, M.; Poni, S. Changes in vineyard establishment and canopy management urged by earlier climate-related grape ripening: A review. *Sci. Hortic*. **2014**, *178*, 43–54. https://doi.org/10.1016/j.scienta.2014.07.039
38. Li W, Liu M, Chen K, Zhang J, Xue T, Cheng Z, Zhang B, Zhang K, Fang Y. The roles of different photoselective nets in the targeted regulation of metabolite accumulation, wine aroma and sensory profiles in warm viticulture regions. *Food Chem*. **2022**, *396*, 133629. https://doi.org/10.1016/j.foodchem.2022.133629
39. Wang, Q.-L..; Chen, J.-H.; He, N.-Y.; Guo, F.-Q. Metabolic reprogramming in chloroplasts under heat stress in plants. *Int. J. Mol. Sci*. **2018**, *19*, 849. https://doi.org/10.3390/ijms19030849
40. Wahid, A.; Gelani, S.; Ashraf, M.; Foolad, M. R. Heat tolerance in plants: an overview. *Environ. Exp. Bot*. **2007**, 61, 199–223. doi: 10.1016/j.envexpbot.2007.05.011
41. Hu S, Ding Y and Zhu C.Sensitivity and Responses of Chloroplasts to Heat Stress in Plants. *Front. Plant Sci*. **2020**, *11*, 375. https://doi.org/10.3389/fpls.2020.00375
42. Venios, X.; Korkas, E.; Nisiotou, A.; Banilas, G. Grapevine Responses to Heat Stress and Global Warming. *Plants* **2020**, *9*, 1754. https://doi.org/10.3390/plants9121754
43. White, M.A.; Diffenbaugh, N.S.; Jones, G.V.; Pal, J.S.; Giorgi, F. Extreme heat reduces and shifts United States premium wine production in the 21st century. *Proc. Natl. Acad. Sci. USA*, **2006**, *103*, 11217–11222. https://doi.org/10.1073/pnas.0603230103
44. Zha, Q.; Xi, X.; He, Y.; Jiang, A. Transcriptomic Analysis of the Leaves of Two Grapevine Cultivars under High-Temperature Stress. *Sci. Hortic*. **2020**, *265*, 109265. https://doi.org/10.1016/j.scienta.2020.109265
45. Martínez-Lüscher, J.; Kizildeniz, T.; Vučetić, V.; Dai, Z.; Luedeling, E.; van Leeuwen, C.; Gomès, E.; Pascual, I.; Irigoyen, J.J.; Morales, F. Sensitivity of grapevine phenology to water availability, temperature and CO2 concentration. *Front Environ. Sci*., **2016** *4*, 48. https://doi.org/10.3389/fenvs.2016.00048
46. Fraga, H.; Garcia, de Cortazar Atauri, I.; Malheiro, A.C.; Santos, J.A. Modelling climate change impacts on viticultural yield, phenology and stress conditions in Europe. *Glob. Change Biol*. **2016**, *22*, 3774–3788. https://doi.org/10.1111/gcb.13382
47. Greer, D.H.; Weedon, M.M. Modelling photosynthetic responses to temperature of grapevine (*Vitis vinifera* cv. Semillon) leaves on vines grown in a hot climate. *Plant Cell Environ*. **2012**, *35*, 1050–1064
48. Gouot JC, Smith JP, Holzapfel BP, Walker AR, Barril C (2018) Grape berry flavonoids: A review of their biochemical responses to high and extreme high temperatures. *J. Exp. Bot*. **2018**, *70*, 397–423
49. Lecourieux, D.; Kappel, C.; Claverol, S.; Pieri, P.; Feil, R.; Lunn, J.E.; Bonneu, M.; Wang, L.; Gomès, E.; Delrot, S.; et al. Proteomic and metabolomic profiling underlines the stage-and time-dependent effects of high temperature on grape berry metabolism. *J. Integr. Plant Biol*. **2020**, *62*, 1132–1158. https://doi.org/10.1111/jipb.12894
50. Lecourieux, D.; Kappel, C.; Pieri P.; Charon, J.; Pillet, J.; Hilbert, G.; Renaud, C.; Gomes, E.; Delrot, S.; Lecourieux, D. Dis-secting the biochemical and transcriptomic effectsof a locally applied heat treatment on developing cabernet sauvignon grape berries. *Front Plant Sci*. **2017**, *8*, 53. https://doi.org/10.3389/fpls.2017.00053
51. Hewitt, S.; Hernández-Montes, E.; Dhingra, A.; et al. Heat stress, not water stress, dominates in eliciting metabolic and transcriptomic responses of grape berries, 10 February **2023**, PREPRINT (Version 1) available at *Research Square*. https://doi.org/10.21203/rs.3.rs-2500367/v1
52. Güler, E. Polyphenols, organic acids, and their relationships in red grapes of *Vitis vinifera* and Isabella (*Vitis labrusca*) under arid conditions. *Eur. Food Res. Technol*. **2023**, *249*, 913–921. https://doi.org/10.1007/s00217-022-04183-9
53. Chrysargyris, A.; Xylia, P.; Litskas, V.; Mandoulaki, A.; Antoniou, D.; Boyias, T.; Stavrinides, M.; Tzortzakis, N. Drought Stress and Soil Management Practices in Grapevines in Cyprus under the Threat of Climate Change. *J. Water Clim. Change* **2018**, *9*, 703–714. https://doi.org/10.2166/wcc.2018.135
54. Vanden Heuvel, J.; Centinari, M. Under-Vine Vegetation Mitigates the Impacts of Excessive Precipitation in Vineyards. *Front. Plant Sci*. **2021**, *12*, 713135. https://doi.org/10.3389/fpls.2021.713135
55. Marín, D.; Armengol, J.; Carbonell-Bejerano, P.; Escalona, J.M.; Gramaje, D.; Hernández-Montes, E.; Intrigliolo, D.S.; Martínez-Zapater, J.M.; Medrano, H.; Mirás-Avalos, J.M.; Palomares-Rius, J.E.; Romero-Azorín, P.; Savé, R.; Santesteban, L.G.; de Herralde, F. Challenges of viticulture adaptation to global change: Tackling the issue from the roots. *Australian Journal of Grape and Wine Research*, **2021**, *27(1)*, 8– 25. https://doi.org/10.1111/ajgw.12463
56. Aguirre-Liguori, J.A.; Morales-Cruz, A.; Gaut, B.S. Evaluating the persistence and utility of five wild *Vitis* species in the context of climate change. *Molecular Ecology*, **2022**, *31*, 6457– 6472. https://doi.org/10.1111/mec.16715
57. Nowlin, J. W.; Bunch, R. L.; Jones, G. V. Viticultural site selection: Testing the effectiveness of North Carolina's commercial vineyards. *Applied Geography*, **2019**, *106*, 22– 39. https://doi.org/10.1016/j.apgeog.2019.03.003
58. Moriondo, M.; Jones,G.V.; Bois, B.; Dibari, C.; Ferrise, R.; Trombi,G.; et al. Projected shifts of wine regions in response to climate change. *Clim. Change* **2013,** *119*, 825–839. https://doi.org/10.1007/s10584-013-0739-y

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 October 2023 doi:10.20944/preprints202310.0297.v1

59. Van Leeuwen, C.; Friant, P.; Chone, X.; Tregoat, O.; Koundouras, S.; Dubourdieu, D. Influence of climate, soil, and cultivar on terroir. *Am. J. Enol. Vitic.* **2004,** *55(3),* 207–217
60. Tóth, J.P.; Végvári, Z. Future of winegrape growing regions in Europe. *Aust. J. Grape Wine Res*. **2016,** *22(1),* 64–72. https://doi.org/10.1111/ajgw.12168
61. Dunn, M.; Rounsevell, M.D.A.; Boberg, F.; et al. The future potential for wine production in Scotland under high-end climate change. *Reg Environ Change* **2019,** *19*, 723–732. https://doi.org/10.1007/s10113-017-1240-3
62. Hannah, L.; Roehrdanz, P. R.; Ikegami, M.; Shepard, A. V.; Shaw, M. R.; Tabor, G.; et al.. Climate change, wine, and conservation. *Proc. Natl. Acad. Sci. U.S.A.* **2013,** *110*, 6907–6912. https://doi.org/10.1073/pnas.1210127110
63. Gladstones, J.S. Climate and Australian viticulture. In: dry PR, Coombe BG (eds) viticulture. Volume 1 — resources, 2nd edn. Winetitles Pty Ltd, Adelaide, **2004,** pp 90–118. ISBN: 0975685007
64. Molitor, D.; Caffarra, A.; Sinigoj, P.; Pertot, I.; Hoffmann, L.; Junk, J. Late frost damage risk for viticulture under future climate conditions: a case study for the Luxembourgish winegrowing region. *Aust J Grape Wine Res* **2014,** *20(1)*,160–168. https://doi.org/10.1111/ajgw.12059
65. Neethling, E.;, Petitjean, T.;, Quénol, H. et al. Assessing local climate vulnerability and winegrowers' adaptive processes in the context of climate change. *Mitig. Adapt. Strateg. Glob. Change* **2017**, *22*, 777–803. https://doi.org/10.1007/s11027-015-9698-0
66. Mosedale, J.R.;, Abernethy, K.E.;, Smart, R.E.; Wilson, R.J.; Maclean, I.M.D. Climate change impacts and adaptive strategies: lessons from the grapevine. *Glob. Change Biol.* **2016**, *22*, 3814-3828. https://doi.org/10.1111/gcb.13406
67. Parker, A.K.; De Cortázar-Atauri, I.G.; Chuine, I.; Barbeau, G.; Bois, B.; Boursiquot, J.M.; Cahurel, J.Y.; Claverie, M.; Dufourcq, T.; Gény, L.; Guimberteau, G.; Hofmann, R.W.; Jacquet, O.; Lacombe, T.; Monamy, C.; Ojeda, H.; Panigai, L.; Payan, J.C.; Lovelle, B.R.; Rouchaud, E.; Schneider, C.; Spring, J.L.; Storchi, P.; Tomasi, D.; Trambouze, W.; Trought, M.; van Leeuwen, C. Classification of varieties for their timing of flowering and veraison using a modelling approach: a case study for the grapevine species *Vitis vinifera* L. *Agricultural and Forest Meteorology*, **2013,** *180*, 249–264. https://doi.org/10.1016/j.agrformet.2013.06.005.
68. Reis, S.; Fraga, H.; Carlos, C.; Silvestre, J.; Eiras-Dias, J.; Rodrigues, P.; Santos, J.A. Grapevine phenology in four portuguese wine regions: modeling and predictions. *Applied Sciences*, **2020**, *10(11),* 3708. https://doi.org/10.3390/app10113708.
69. Rodrigues, P.; Pedroso, V.; Reis, S.; Yang, C.; Santos, J.A. Climate change impacts on phenology and ripening of cv. Touriga Nacional in the Dão wine region, Portugal. *International Journal of Climatology* **2022**, *42 (14)*, 7117– 7132. https://doi.org/10.1002/joc.7633
70. Arrigo, N.; Arnold, C. Naturalised Vitis rootstocks in Europe and consequences to native wild grapevine. *PloS One* **2007**, *2(6)*, e521. http://dx.doi.org/10.1371/journal.pone.0000521
71. Riaz, S.; Pap, D.; Uretsky, J.; Laucou, V.; Boursiquot, J.M.; Kocsis, L.; Walker, M.A. Genetic diversity and parentage analysis of grape rootstocks. *Theor. Appl. Genet.* **2019**, *132*, 1847–1860. https://doi.org/10.1007/s00122-019-03320-5
72. Gregory, P. J.; Atkinson, C. J.; Bengough, A. G.; Else, M.A.; Fernández-Fernández, F.; Harrison, R.J.; Schmidt, S. Contributions of roots and rootstocks to sustainable, intensified crop production. *Journal of Experimental Botany*, **2013,** *64*, 1209-1222. http://dx.doi.org/10.1093/jxb/ers385PMid:23378378
73. Marguerit, E.; Brendel, O.; Lebon, E.; Van Leeuwen, C.; Ollat, N. Rootstock control of scion transpiration and its acclimation to water deficit are controlled by different genes. *The New Phytologist*, **2012,** *194*, 416-429. http://dx.doi.org/10.1111/j.1469-8137.2012.04059.xPMid:22335501
74. Mariani, L.; Ferrante, A. Agronomic Management for Enhancing Plant Tolerance to Abiotic Stresses—Drought, Salinity, Hypoxia, and Lodging. *Horticulturae* **2017**, *3*, 52. https://doi.org/10.3390/horticulturae3040052
75. Delrot, S.; Grimplet, J.; Carbonell-Bejerano, P.; Schwandner, A.; Bert, P-F.; Bavaresco, L.; et al. Genetic and genomic approaches for adaptation of grapevine to climate change, in Genomic Designing of ClimateSmart Fruit Crops, ed. by Kole C. Springer International Publishing, Cham, Switzerland, **2020,** pp. 157–270. https://doi.org/10.1007/978-3-319-97946-5_7
76. Corso, M.; Bonghi, C. Grapevine rootstock effects on abiotic stress tolerance. *Plant Sci. Today* **2014**, *1(3),* 108-13. Available from: https://horizonepublishing.com/journals/index.php/PST/article/view/64
77. Fahim, S.; Ghanbari, A.; Naji, A.M.; Shokohian, A.A.; Maleki Lajayer, H.; Gohari, G.; Hano, C. Multivariate Discrimination of Some Grapevine Cultivars under Drought Stress in Iran. Horticulturae **2022**, 8, 871. https://doi.org/10.3390/horticulturae8100871
78. Marusig, D.; Tombesi, S. Abscisic Acid Mediates Drought and Salt Stress Responses in *Vitis vinifera*—A Review. Int. J. Mol. Sci**. 2020**, 21, 8648. https://doi.org/10.3390/ijms21228648
79. Cramer, G.R. Abiotic stress and plant responses from the whole vine to the genes. *Australian Journal of Grape and Wine Research*, **2010**, *16*, 86-93. https://doi.org/10.1111/j.1755-0238.2009.00058.x

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 October 2023 doi:10.20944/preprints202310.0297.v1

80. Zhao, F.; Zheng, T.; Liu, Z.; Fu, W.; Fang, J. Transcriptomic Analysis Elaborates the Resistance Mechanism of Grapevine Rootstocks against Salt Stress. Plants **2022**, 11, 1167. https://doi.org/10.3390/plants11091167
81. Gohari, G.; Zareei, E.; Rostami, H.; Panahirad, S.; Kulak, M.; Farhadi, H.; Amini, M.; del Carmen Martinez-Ballesta, M.; Fotopoulos, V. Protective effects of cerium oxide nanoparticles in grapevine (*Vitis vinifera* L.) cv. Flame Seedless under salt stress conditions. *Ecotoxicol. Environ. Saf.* **2021**, *220*, 112402.v https://doi.org/10.1016/j.ecoenv.2021.112402
82. Karimi, R.; Salimi, F. Iron-chlorosis tolerance screening of 12 commercial grapevine (*Vitis vinifera* L.) cultivars based on phytochemical indices. *Sci. Hortic*. **2021**, *283*, 110111. https://doi.org/10.1016/j.scienta.2021.110111
83. Zebec, V.; Lisjak, M.; Jović, J.; Kujundžić, T.; Rastija, D.; Lončarić, Z. Vineyard Fertilization Management for Iron Deficiency and Chlorosis Prevention on Carbonate Soil. Horticulturae **2021**, 7, 285. https://doi.org/10.3390/horticulturae7090285
84. De Palma, L.; Vox, G.; Schettini, E.; Novello, V. Reduction of Evapotranspiration in Microenvironment Conditions of Table Grape Vineyards Protected by Different Types of Plastic Covers. Agronomy **2022**, 12, 600. https://doi.org/10.3390/agronomy12030600
85. Silva, J.R.; Rodrigues, W.P.; Ferreira, L.S.; Bernado, W.D.; et al. Deficit irrigation and transparent plastic covers can save water and improve grapevine cultivation in the tropics. *Agric. Water Manag.* **2018,** *202*, 66-80. https://doi.org/10.1016/j.agwat.2018.02.013
86. Tarricone, L.; Debiase, G.; Masi, G.; Gentilesco, G.; Montemurro, F. Cover Crops Affect Performance of Organic Scarlotta Seedless Table Grapes Under Plastic Film Covering in Southern Italy. Agronomy **2020**, 10, *550.* https://doi.org/10.3390/agronomy10040550
87. Pisciotta, A.; Barone, E.; Di Lorenzo, R. Table-Grape Cultivation in Soil-Less Systems: A Review. *Horticulturae* **2022**, *8*, 553. https://doi.org/10.3390/horticulturae8060553
88. Souza, C.R.; Mota, R.N.; Dias, N.F.A.; Melo, E.T.; Pimentel, R.M.A.; Souza, L.R.; Regina, M.A. Physiological and agronomical responses of Syrah grapevine under protected cultivation. *Bragantia* **2015**, *74 (3).* https://doi.org/10.1590/1678-4499.0047
89. Holcman, E., Sentelhas, P.C., Conceição, M.A.F. et al. Vineyard microclimate and yield under different plastic covers. *Int J Biometeorol* **2018**, 62, *925–937* (). https://doi.org/10.1007/s00484-017-1494-y
90. Jackson, D. I., & Lombard, P. B. (). Environmental and management practices affecting grape composition and wine quality: a review. *American Journal of Enology and Viticulture,* **1993**, *44*, 409-430.
91. Dry, P. R., & Loveys, B. R. (1998). Factors influencing grapevine vigour and the potential for control with partial rootzone drying. *Australian Journal of Grape and Wine Research*, **1998**, *4*, 140-148. http://dx.doi.org/10.1111/j.1755-0238.1998.tb00143.x
92. Ferrara, G.; Boselli, M.; Palasciano, M.; Mazzeo, A. Effect of shading determined by photovoltaic panels installed above the vines on the performance of cv. Corvina (*Vitis vinifera* L.). *Sci. Hortic*. **2023**, *308*, 111595. https://doi.org/10.1016/j.scienta.2022.111595
93. Sharma, J. et al. Effect of Climate Change on Grape and Its Value-Added Products. In: Singh, H., Rao, N., Shivashankar, K. (eds) Climate-Resilient Horticulture: Adaptation and Mitigation Strategies **2013**, Springer, India. https://doi.org/10.1007/978-81-322-0974-4_7
94. Li, T.; Zhang, J. Effect of pit irrigation on soil water content, vigor, and water use efficiency within vineyards in extremely arid regions. *Sci. Hort*. **2017**, *218*, 30–37. https://doi.org/10.1016/j.scienta.2017.01.050
95. Marino, G.; Di Martino, S.; Amico Roxas, A.; Caruso, T.; Ferguson, L.; Barone, E., Marra, F.P., 2018. Sustainability of pistachio production (*Pistacia vera* L.) under supplemental irrigation in a Mediterranean climate. *Sci. Hort.* **2018**, *241 (7),* 260–266. https://doi.org/10.1016/j.scienta.2018.06.032
96. Jensen, C.R.; Ørum, J.E.; Pedersen, S.M.; Andersen, M.N.; Plauborg, F.; Liu, F.; Jacobsen, S.E. 2014. A short overview of measures for securing water resources 606 for irrigated crop production. *J. Agron. Crop Sci.* **2014**, *200 (5),* 333–343. https://doi.org/10.1111/jac.12067
97. Xiaochi, Ma.; Karen, A.; Sanguinet, Pete.; Jacoby, W. Direct root-zone irrigation outperforms surface drip irrigation for grape yield and crop water use efficiency while restricting root growth, *Agricultural Water Management*, **2020**, *231,* 105993. https://doi.org/10.1016/j.agwat.2019.105993
98. Zhai, Z.; Martínez, J.F.; Martínez, N.L.; Díaz, V.H. Applying case-based reasoning and a learning-based adaptation strategy to irrigation scheduling in grape farming. *Comput. Electron. Agric*. **2020**, *178*, 105741. https://doi.org/10.1016/j.compag.2020.105741
99. Tsirogiannis, I.L.; Malamos, N.; Baltzoi, P. Application of a Generic Participatory Decision Support System for Irrigation Management for the Case of a Wine Grapevine at Epirus, Northwest Greece. *Horticulturae* **2023**, *9*, 267. https://doi.org/10.3390/horticulturae9020267
100. Sun, L.; Gao, F.; Anderson, M.C.; Kustas, W.P.; Alsina, M.M.; Sanchez, L.; Sams, B.; McKee, L.; Dulaney, W.; White, W.A.; et al. Daily mapping of 30 m LAI and NDVI for grape yield prediction in California vineyards. *Remote Sens*. **2017**, *9*, 317. https://doi.org/10.3390/rs9040317,

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 October 2023 doi:10.20944/preprints202310.0297.v1

101. Sun, Q.; Granco, G.; Groves, L.; Voong, J.; Van Zyl, S. Viticultural Manipulation and New Technologies to Address Environmental Challenges Caused by Climate Change. *Climate* **2023**, *11*, 83. https://doi.org/10.3390/cli11040083
102. Baluja, J.; Diago, M.P.; Balda, P.; et al. Assessment of vineyard water status variability by thermal and multispectral imagery using an unmanned aerial vehicle (UAV). *Irrig. Sci.* **2012**, *30*, 511–522. https://doi.org/10.1007/s00271-012-0382-9
103. Bellvert, J., Marsal, J., Girona, J. et al. Seasonal evolution of crop water stress index in grapevine varieties determined with high-resolution remote sensing thermal imagery. *Irrig. Sci.* **2015**, *33*, 81–93. https://doi.org/10.1007/s00271-014-0456-y
104. Bellvert, J.; Mata, M.; Vallverdú, X.C.; Paris, C.; Marsal, J. Optimizing precision irrigation of a vineyard to improve water use efficiency and profitability by using a decision-oriented vine water consumption model. *Precis. Agric*. **2021**, *22*, 319–341. https://doi.org/10.1007/s11119-020-09718-2
105. Li, Z.; Huang, H.; Duan, Z.; Zhang, W. Control temperature of greenhouse for higher yield and higher quality grapes production by combining STB in situ service with on time sensor monitoring. *Hellyon* **2023**, *9*, e13521. https://doi.org/10.1016/j.heliyon.2023.e13521

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.