Chapter

Vineyard and Olive Orchard Management to Maintain Yield and Quality Under Abiotic Stress Conditions

Manuel Oliveira and Anabela Fernandes-Silva

Abstract

Yield and quality of fruits are multifaceted traits involving various plant and fruit processes that, for a given genetic makeup, depend on environmental factors and agronomic practices. Crop yield has to meet the demand of a growing population, but crop quality is a challenging issue affected by consumer's behavior and increasingly associated with food security. The projected climate scenario for South Mediterranean Europe predicts lower precipitation and higher temperatures that will negatively affect agricultural activity. A warmer and drier climate is expected to cause changes in crop yield and its quality. Higher temperatures affect photosynthesis, causing alterations in sugars, organic acids, flavonoid contents, firmness, and antioxidant activity. Reduced soil water availability will impact on the capacity of plants to accumulate biomass and when conjugated with warmer weather, it can trigger disorders like fruit sunburn further depressing crop yields. New cultivation techniques are necessary to produce sufficient food supplies to meet the basic nutrient requirements of the growing human population and support the agriculture economy. We focus on the production of olives and wine grapes, two of the most cultivated fruit crops of Southern Europe, which is certainly strongly affected by changing weather conditions. We review the recent developments on agronomic practices to counter or minimize the projected environmental changes, and we will report on our own experiences.

Keywords: abiotic stress, temperature, drought, climate change, grapevine, berry quality, olive tree, olives quality, olive oil quality

1. Introduction

Fruit production is a major agricultural activity all over the world. In 2016 the global production was above 33×10^6 metric tons and occupied about 5.6×10^6 hectares [1]. According to a survey in 2013, 1.55 million holdings in the European Union (UE) managed fruit orchards, and in 2015 3.2 million hectares were dedicated to fruit growing that represented more than 28×10^6 euros in 2018 [2]. In 2017, the world area under vines rose to 7534 kha, and grape production reached 73 million tons most of it for wine production estimated at 279 million hectoliters in 2018 [3]. Europe is a leading producer of wine grapes with 3.2 million hectares under vines worth of almost 22 billion euros of wine exports [2]. In 2018, the global production of table olives was estimated in 1.8×10^6 tons (EU 0.9×10^6) and 3.1×10^6 tons of olive oil (EU 2.2×10^6), representing a trade value of 2.8×10^6 euros for olive oil (EU 2.1 million euros) [2]. These figures render the importance of fruit production on a global scale that is likely to increase in the near future in tandem with larger demand for food, fiber, and fuel as a result of growing population, change in dietary preferences, and bioenergy policies [4]. The food demand driven by a larger and more affluent population challenges the agricultural systems to increase the output with reduced external inputs and minimal environmental impacts [5, 6] all under more difficult environmental conditions given the forecasts of an increased temperatures and more irregular rainfalls that negatively affect agriculture [7], and the Southern Europe will be strongly affected where yield losses and impaired product quality are expected [8, 9].

2. Abiotic stresses: temperature and water availability

Average temperature is expected to rise somewhere between 1.5 and 4°C from pre-industrial time until the end of the century [7]. Temperature increase affects photosynthesis, causing changes in concentration of sugars and organic acids, flavonoid contents, fruit firmness, and antioxidant activity [10].

Some unripe fruits with green skin can photosynthesize, but the fruits are primarily a sink of photosynthetic products with origin in the leaves. The temperature of the leaves follows approximately the air temperature, and net photosynthesis increases with temperature up to a certain limit that is species dependent, but in general at values greater than 35°C, there is a reduction of photosynthetic activity [11]. Temperature has strong influence on leaf water potential (ψl), stomatal conductance (gs), and intercellular CO_2 concentration [12]. Rising temperatures increase the water loss from the leaves, and their water potential becomes more negative to a point the stomata start closing reducing stomatal conductance and the flow of intercellular CO_2 that further impairs photosynthesis [13]. High temperature also diminishes starch and sucrose synthesis, by reduced activity of sucrose phosphate synthase, ADP-glucose pyrophosphorylase, and invertase [14]. Heat stress can reduce the total leaf area of the plants and trigger earlier leaf senescence that have a negative impact on the total photosynthesis performance [12]. Prolonged periods of low photosynthetic activity deplete reserves of carbohydrates, and plants might starve [15].

Soluble sugars (sucrose, glucose, and fructose) and organic acids (tartaric, malic, and citric acids) are major osmotic compounds that accumulate in fleshy fruits [15]. The biosynthesis of these compounds is related to photosynthesis that uses light (solar radiation) as source of energy, and it has been shown that the photosynthetic rate is positively correlated with light intensity till a saturation point is reached depending on the plant species and on temperature [12]. Increased light intensity also raises the temperature, and, above a critical level, protein and enzymes are broken, photosynthetic tissue is killed, cells might die, and fruits are sunburnt, all resulting in yield loss and low-quality produce [16].

At molecular level, temperature influences the protein structure, and the activity of cellular proteins becomes less stable under high and low temperatures indirectly affecting the activity of transmembrane transporters necessary to import assimilates and nutrients and to accumulate sugars and polyphenols in the fruit for the completion of the maturation process [17].

Fruits and vegetables contain different antioxidant compounds such as vitamin C, vitamin E, carotenoids, and polyphenol compounds. Among the polyphenols, flavonoids (flavanols, flavonols, and anthocyanins) are largely present in plants, and their content is partially responsible for antioxidant activity. Temperature is the most significant factor affecting antioxidant activity in vegetables and fruits, and, as temperature raises, the enzyme reactions are accelerated, antioxidant activity is augmented, and existing antioxidants decline [18].

Stressful conditions related to high temperatures are coupled with water availability that can mitigate or aggravate the effects of temperature. The increase in water demand when temperature rises is driven by plant transpiration necessary just to keep their canopies cool by water evaporation. Thus, water demand will increase at the same time as rainfall is scarcer and irregular in its frequency; therefore, an efficient use of water is particularly important for agriculture, which is the major sector for the use of freshwater resources and whose economic viability is dependent on water availability. Water uptake from the soil brings mineral nutrients that are circulated together with organic nutrients through the vascular tissues of the plant as water circulates throughout the plant. Water retention determines cell turgor, drives plant cell expansion, and permits many plant functions such as stomatal movements and transpiration [19]. Water is the abiotic factor that exerts a major effect on growth and productivity of agricultural crops, and increasingly frequent periods of drought, particularly in the Mediterranean region, is expected to be the most adverse among the abiotic factors [20].

Moderate drought reduces yields but can have a beneficial effect in fruit quality via two major mechanisms: (a) reduction in leaf stomatal conductance that results in a decrease in net photosynthesis and (b) exacerbation of oxidative stress/oxidative signaling. Net photosynthesis is responsible for primary metabolites that are the major source of precursors for the biosynthesis of phenolic compounds, carotenoids, and ascorbate. Oxidative stress may trigger the biosynthetic pathways of these compounds [21, 22]. The balance between productivity and quality benefits from a certain level of water deficit, but it depends upon the intensity, duration, and repetition of events of water deficit [23]. Water deficits during the vegetative growth stages difficult canopy development, flowering and fruit setting, and the accumulation of carbon compounds. On other hand, deficits occurring during the maturation of fruits show positive impacts on soluble sugar accumulation and enhancement of fruit aroma. The level of stress that benefits the entire cycle of the plant is likely to be depend, simultaneously, on species and environmental conditions, but when a certain threshold of water stress is surpassed, the beneficial effects are no longer observed [23, 24].

3. Wine grape quality

The fruit quality is a composition of physicochemical properties and the perception of the consumer allowing for a definition of quality that discriminates between natural characteristics of the fruit and those dictated by socioeconomic and marketing factors [25, 26]. The quality of grapes (*Vitis vinifera* L.) for winemaking is evaluated on characteristics imparted to the final product, and as such their quality is referred to the berry composition, in particular, to the content of sugars, organic acids, amino acids, phenolics, and aroma precursors that are function of genotypic, environmental, and agronomic factors [25, 27].

After fruit setting, the berry pericarp and the seeds augment in volume rapidly; organic acids, mostly malic, tartaric, and citric, accumulate in the mesocarp cell vacuoles. At the end of this period, growth slows down, and the seed maturation is completed. The maturation phase initiates at veraison, when berries of red varieties accumulate anthocyanins (red pigments) in the exocarp, glucose and fructose accumulate, malate is metabolized as a source of carbon for respiration, and volatile organic compounds are biosynthesized [28].

Abiotic stress, temperature, radiation, and water changes the pattern of growth and development of vines, and they trigger the accumulation in berry pulps, seeds, and skins of secondary metabolites (polyphenols and volatiles) as defense against cell damage [29]. The secondary metabolites present in the must contribute to wine characteristics as taste, aroma, antioxidant capacity, and stabilization during the aging process. Thus, the vineyards are managed to influence the profile and concentration of secondary metabolite to obtain the desirable wine typicity.

The Mediterranean-type climate has long warm periods well suited to growth and development of grape vines, but that period is also low in rainfall that can create serious lack of water availability. The wine regions of Northeastern Portugal are distinctively Mediterranean and have already shown the alterations in temperatures and rainfalls expected under the forecasted climatic change. Annual rainfall has been declining since the 1950s, winter temperatures are milder, and average temperatures for the grape growing season are reaching the upper limit for producing high-end wines [30, 31]. To maintain the grape quality desirable to meet the demand of a world market will be a challenging task involving the best suitable varieties and agronomic practices supported on knowledge gained by experience and research.

A clearly noticeable phenomenon resulting from higher temperatures is the advance of the phenological stages of the grapevines, with a short growing season leaving the maturation to develop under hotter and drier conditions [32, 33]. Berries maturing under high temperature have reduced content of anthocyanins [34] that are hydrophilic secondary metabolites that confer orange, red, or blue coloration to grapes and help protecting the plant tissues against abiotic stressors such as high radiation. A lower content of anthocyanins has a negative impact on the color of red wines, an important organoleptic characteristic. Sugar accumulation in the berries increases as the temperature rises, but there is a sharp fall in acidity and malate content creating an imbalance alcohol/acidity that is deleterious to high-quality wines [35, 36]. These phenomena are dependent on variety tolerance to high temperatures [35]; thus, the viticulturists must choose carefully before they start new plantations, reaching for a compromise between adaptability and quality. Usually, native varieties thrive better on a given environment than exotic ones even when conditions suffer large alterations that is the case of Touriga Nacional in Portugal, a valuable premium variety to produce high-quality wines, well adapted to regions with intense solar radiation and warm climates [37, 38], and the adaptability to different climatic conditions is a variety trait important to mitigate the effects of stressful factors on the berry quality [39, 40].

High temperatures increase evapotranspiration that coupled with declining rainfalls further deplete soil water availability, and this is actually the most pressing challenge to wine grape production in areas where aridity is advancing [41]. Nevertheless, berry quality benefits from moderate levels of water stress because skin-to-pulp ratio increases as the berries become smaller [24, 42], elevating the concentration of total soluble solids (mostly sugars) and secondary metabolites, such as phenolic compounds (especially anthocyanins) and aromatic compound (in particular norisoprenoids) whose biosynthesis is enhanced as response of the vine to water stress [43–45]. Higher content on sugar and secondary metabolites in berries will produce wines higher in alcohol, deeper in colors, and richer in aromas but also lower in titrable acidity as organic acids, mainly malic and tartaric, are depleted [24, 44].

Temperature and water stresses have different outcomes on yield and berry quality depending on their intensity and timing related to the development phase of the vine. The vineyard manager can use this knowledge to manipulate agronomic practices and obtain the desirable yield and berry quality with the most efficient use of resources, in particular, water. New vineyards must be planted with known varieties to be well to actual conditions but also with plasticity to withstand more stressful conditions; the vine rows trellised at vertical shoot position are to be oriented north to south where the terrain permits and the location carefully chosen to avoid the most severe effects expected to be brought about by coming changes. In vineyards already under commercial exploration and that are expected to have a life span of a few decades there are technical practices that can reduce the worst effects of excessive temperature and radiation, and of low amount of available soil water.

The most common result of high-intensity radiation, usually coupled with elevated temperatures, is the shriveling and sunburn of berries, reducing both yields and quality of the musts. The incidence of these phenomena is felt more acutely in vineyards where the rows are oriented west to east and one of the faces (south face in northern hemisphere) is directly illuminated all day long. One solution is to shade the lower third of the canopy with a vertically placed net close to the canopy during the period when intense radiation and its effects are expected to cause damages. Shaded vineyards maintain much higher yields than non-shaded ones but at the cost of lower concentration of anthocyanins, and their musts render wines with lighter color that can be considered detrimental to its quality [46].

Other techniques that can maintain higher photosynthetic activity and simultaneously reduce the incidence of berry sunburn are canopy coating with kaolin and intermittent nebulization with water at high pressure. They reduce plant temperature and allow for higher stomatal conductance and, consequently, increased photosynthetic rate that contributes to larger berry sugar content [33, 47]. Treated plants keep better yields, produce berries with higher concentration of sugars, and show no significant difference on other must characteristics [33].

Irrigation is already common in many wine-producing regions in Southern Europe, the Western United States, and Australia, among others, and with expected reduction in rainfall, it will be indispensable to maintain the economic activity. The challenge is to keep a balance between productivity, quality, and efficiency in the use of resources, especially water. Moderate water deficits at optimized timing can improve berry quality and support economical yields [40, 48]. Better water use efficiency was reached with no irrigation at all, but the productivity is so low that economically is not viable [49]; irrigation increases the yield but dilutes sugars and compounds responsible for color and aroma rendering a wine of lower quality. An acceptable compromise is to deficit irrigate from flowering to veraison, a phase very sensitive to severe water shortage, and no irrigation after veraison assuming that the soil still stores enough water to dispense up to the completion of the vine cycle. The effects of irrigation on berry composition are subjected to controversy with contradictory results among authors, but the source of these inconsistencies is probably related to the climatic conditions prevalent during the studies that each author carried out [50].

Under increasing competition for scarcer water resources, the imposition of moderate water stress on certain developmental periods of wine grapes is an adequate irrigation strategy to save water and maintain both yields and must quality with positive reflexes on the farm economy. Such strategy, termed by some authors as regulated deficit irrigation (RDI), has received great attention by researchers and producers [51]. Drip irrigation, from aboveground supply lines, is the most efficient form for vineyards, particularly for RDI, as it minimizes runoff and evaporation while delivering water uniformly and directly to the root zone; significant amounts of water are saved, and water contact with the plants is avoided, reducing the risks for disease development [52]. RDI with deliver lines buried underground is an expensive alternative with little benefits to offset its high costs [53].

Recent technical advances permit a more affordable and widespread use of phenomics defined by Houle et al. [54] as "a sub-discipline of biology concerned with the rapid measurement of an organism's phenotype or physical and biochemical make-up." Phenomics can help growers and managers to survey their crops to quantify spatial variability in fruit quality, yield, soil characteristics, and incidence of diseases, among other parameters, with many benefits for the more efficient use of resources and forecasts of yields [55, 56]. One example of such survey is presented by Rossi et al. [57] with the integration of soil spatial information of soil electrical resistivity, obtained automatically with a soil sensor on the go, with variation of vegetative growth and yield permitted to identify areas of a vineyard with similar traits. These areas would be subjected to differentiated agronomic practices to maximize potential benefits in yield and quality and, simultaneously, increase the efficiency of used resources.

4. Olives and olive oil quality

Climatic conditions and different agronomic practices may influence the physiological behavior of the olive tree [58] and consequently the fruit ripening process modifying both the amount and oil quality in *Olea europaea* L., although the response is cultivar dependent [59–61].

Olive oil quality may be defined from commercial, nutritional, or organoleptic perspectives. The overall quality of olive oil, from production to consumption, is strongly related to oxidative stability and its impact on the evolution of flavor, taste, color, and the content of endogenous antioxidants and other minor constituents that are beneficial to health. The International Olive Oil Council [62] and the EEC [63] have defined the quality of olive oil based on parameters that include free fatty acid (FFA) content, peroxide value (PV), ultraviolet (UV)-specific extinction coefficients (K_{232} and K_{270}), and sensory score. In particular, commercial quality is based on FFA as an important factor for classifying olive oil into commercial grades and sensory characteristics (taste and aroma). The nutritional value of olive oil arises from high levels of oleic acid and minor and health-related and antioxidative components such as phenolic compounds, tocopherols, chlorophyll, and carotenoids [64], whereas the aroma is strongly influenced by volatile compounds [65].

Fatty acid composition is one of the primary chemical parameters used to distinguish virgin olive oil from other vegetable oils [66]. Fatty acid profile may be greatly affected by environmental factors. Variability in acid composition has been correlated to the temperature sum of the period from fruit setting to fruit maturation by regulating fatty acid desaturases [67]. In fact, it has been reported that the contents of oleic acid decreased during ripening, while that of linoleic acid increased due to the transformation of oleic acid into linoleic acid by the oleate desaturase activity, which is active during triacylglycerol biosynthesis [68].

Despite the response being cultivar dependent, it has been shown that high temperatures during the maturation of olive fruits, early in the triacylglycerol biosynthesis, reduced oleic acid which is accompanied by increased palmitic and/or linoleic acids [69, 70]. In cv. Arauco, García-Inza et al. [71] observed that oleic acid concentration decreased linearly 0.7% per °C, while palmitic, linoleic, and linolenic acid percentages increased with increasing temperature. In cv. Arbequina, Rondanini et al. [72] reported a higher reduction of oleic acid with high temperatures (2% per °C).

Solar radiation and water availability are crucial not only for tree productivity, [60] but also they clearly affect olive oil quality. In cv. Frantoio, palmitoleic and linoleic acids increased in oils obtained from fruits exposed to high solar radiation intensity, whereas oleic acid and the oleic-linoleic acid ratio decreased [61].

To overcome the negative effects of combined heat and high radiation stresses, application of kaolin in olive trees growing in rainfed conditions has been used. The kaolin coat film could reduce solar radiation damage; reduce heat stress by reflecting UV light, decreasing leaf temperature, and reducing transpiration rate; increase photosynthetic efficiency in plants grown under high level of photosynthetic active radiation; and reduce heat caused by radiation [73, 74]. Khaleghi et al. [75] evaluated the effect of kaolin application in rainfed olive orchard, and they found that the highest palmitic acid was observed in olive oil obtained from untreated trees and that kaolin increased oleic acid but decreased linoleic and linolenic acid contents. Also, the percentage of monounsaturated fatty acids (MUFA) and oleic acid/linoleic acid ratio were higher in the oil obtained from trees treated with kaolin than that obtained from untreated trees. Moreover, saturated and polyunsaturated fatty acids (PUFA) were higher in untreated trees. Therefore, it can be expected that extracted olive oil from kaolin-treated trees has a higher oxidative stability and shelf life than the oil from untreated trees.

The ratio of unsaturated/saturated fatty acids influences the viscosity of oils, increasing with the amount of saturated fatty acids. This has an effect on the sensation of "fatty" on the oral cavity as a viscose oil has more time in contact with the mucous membranes of the oral cavity, giving rise to the "fatty" defect [76]. Moreover, the degree of unsaturation of fatty acids affects the oxidative stability. A high degree of unsaturation of a fatty acid increases the susceptibility to oxidation and shortens the olive oil shelf life [77]. Dag et al. [78] reported that in cv. Koroneiki, the monounsaturated/polyunsaturated fatty acid ratio and free fatty acid content generally decreased with the increased tree water deficit. Besides, olive oil oxidative stability might depend on some synergistic effects among fatty acid composition, phenolic compounds, tocopherols, carotenoids, and chlorophylls [79].

A water deficit during the initial development of the fruit can result in a decrease in the size of the cells of the mesocarp that cannot be recovered. Water deficit affects fruit maturation, which occurs earlier and more rapidly, and can result in more intense preharvest fruit fall [80]. However, a number of studies have shown that the water status of the plant has marginal, if any, effects on free acidity and peroxide value of the olive oil produced [81, 82].

Minor constituents of olive oil, such as phenolic and volatile compounds, are also influenced by the degree of maturation of the olive fruit. So, environmental factors or agronomics practices that affect the evolution of maturation of the drupe can also affect the qualitative characteristics of the resulting olive oil [83]. For example, a very high temperature sum also tends to reduce the total polyphenol content [84]. A positive correlation between the temperature sum from August to October and the total polyphenol content of olive oil was reported by Tura et al. [85].

It has been recognized that polyphenols and tocopherols are substances with natural antioxidant properties and their presence in olive oils has been associated to their general quality, improving stability, nutritional value, and sensorial properties. In cv. Cobrançosa, Fernandes-Silva et al. [82] reported a good linear relationship between total polyphenols and water stress integral. Therefore, olive trees that had been exposed to a certain level of water deficit produced oils with higher concentrations of polyphenols which were seemingly richer in the olive fruit [86, 87].

Virgin olive oil (VOO) obtained from rainfed olive orchards shows the highest resistance to oxidation in relation to irrigated olive orchards as a result of higher values of oxidative stability. The decrease in oxidative stability with water applied by irrigation is usually explained by the decrease in natural antioxidants like polyphenols and tocopherols [82, 86]. Given this assumption, several researchers have tried to find which of the mentioned substances is more correlated with oxidative stability. A number of studies have demonstrated that polyphenol contents are, among the minor compounds, the group more correlated with this parameter [88]. The antioxidant behavior of tocopherols represents a complicated phenomenon as they are efficient antioxidants at low concentrations, but they steadily lose efficiency as their oil content in the vegetables increases [76].

Olive tree water status has marked effects on concentrations of volatile compounds in the oil. Thus, olive oil from plants grown under water deficit-conditions can be bitter and pungent to the taste in opposite to those obtained in well-watering conditions [81, 89]. Williams and Harwood [90] have clearly shown that drought regimes, in Crete, reduced the relative activity of enzymes of lipoxygenase pathway and consequently the volatile compounds.

Regulated deficit irrigation (RDI) in olive orchard is an agronomic practice in which plants were irrigated avoiding water deficit during phases I and III of olive fruit growth and saving water during phase II, the noncritical phenological period of pit hardening [91]. This strategy of irrigation can affect some table olives' characteristics, for example, phenolic composition, antioxidant activity, fatty acid composition, volatile compounds, and phytoprostanes [92]. Table olives from RDI belong to a group of vegetable products named *hydroSOStainable* which are characterized by having distinctive proprieties such as high content of some nutritional and functional compounds, high intensity of sensorial attributes, and are produced with reduced use of water, which is a benefit for both farmers and for the environment [93]. Sánchez-Rodríguez et al. [93] reported that *hydroSOStainable* table olives (cv. "Manzanilla") showed the most attractive shape and color with highest fruit weight, roundest fruit, hardest texture, and a lightest and greenest color than control olives, whereas minerals, antioxidants, phenols, and organic acids and sugars of *hydroSOStainable* olives were similar to well-irrigated olives. Hence, *hydroSOStainable* table olives have advantages over those obtained in well-watered conditions reducing the use of freshwater, while they have better morphological traits that are more attractive for consumers.

5. Conclusions

Lower latitudes of temperate regions are expected to experience climate changes in coming decades that will bring about conditions less favorable to agriculture activities. Yields are likely to decrease, and the quality of produce might suffer a negative alteration. Commercial wine vines and olive trees are very sensitive to their environment, and to keep their economic value, it is necessary to adopt agronomic practices to minimize the adverse effects of climate change. The less favorable location for their growth and development might be abandoned, the choice of varieties to plant will be selected among the best adapted to future conditions, and management techniques of highly efficient irrigation, shading, spraying with reflecting materials, and tight control of canopy development, among others, will have to be commonly adopted.

Acknowledgements

This work was possible thanks to the contribution of our university, Universidade Trás-os-Montes e Alto Douro.

This work is supported by European Investment Funds by FEDER/COMPETE/POCI-Operational Competitiveness and Internationalization Programme, under Project POCI-01-0145-FEDER-006958, and National Funds by the FCT (Portuguese Foundation for Science and Technology), under the project UID/AGR/04033/2013.

Conflict of interest

We report no conflict of interests and no other benefit from our work.

Author details

Manuel Oliveira* and Anabela Fernandes-Silva
Centre for the Research and Technology of Agro-Environmental and Biological Sciences (CITAB), University of Trás-os-Montes and Alto Douro (UTAD), Vila Real, Portugal

*Address all correspondence to: mto@utad.pt

References

[1] Statistica. The Statistical Portal. 2018. Available from: https://www.statista.com/statistics/262266/global-production-of-fresh-fruit/ [Accessed: January 15, 2019]

[2] European Commission. The Fruit and Vegetable Sector in the EU—A Statistical Overview. 2018. Available from: https://ec.europa.eu/eurostat/statistics-explained/index.php/The_fruit_and_vegetable_sector_in_the_EU_-_a_statistical_overview [Accessed: January 15, 2019]

[3] OIV. Report on the World Vitivinicultural Situation. 2018. Available from: http://www.oiv.int/en/oiv-life/oiv-2018-report-on-the-world-vitivinicultural-situation [Accessed: January 15, 2019]

[4] Bais-Moleman AL, Schulp CJE, Verburg PH. Assessing the environmental impacts of production- and consumption-side measures in sustainable agriculture intensification in the European Union. Geoderma. 2019;**338**:555-567. DOI: 10.1016/j.geoderma.2018.11.042

[5] Foley JA, Ramankutty N, Brauman KA, Cassidy ES, Gerber JS, Johnston M, et al. Solutions for a cultivated planet. Nature. 2011;**478**:337-342. DOI: 10.1038/nature10452

[6] Godfray HCJ, Garnett T. Food security and sustainable intensification. Philosophical Transactions of the Royal Society, B: Biological Sciences. 2014;**369**:20120273. DOI: 10.1098/rstb.2012.0273

[7] Auffhammer M. Quantifying economic damages from climate change. Journal of Economic Perspectives. 2018;**32**:33-52. DOI: 10.1257/jep.32.4.33

[8] Holman IP, Brown C, Janes V, Sandars D. Can we be certain about future land use change in Europe? A multi-scenario, integrated-assessment analysis. Agricultural Systems. 2017;**151**:126-135. DOI: 10.1016/j.agsy.2016.12.001

[9] Bisbis MB, Gruda N, Blanke M. Potential impacts of climate change on vegetable production and product quality—A review. Journal of Cleaner Production. 2018;**170**:1602-1620. DOI: 10.1016/j.jclepro.2017.09.224

[10] Moretti CL, Mattos LM, Calbo AG, Sargent SA. Climate changes and potential impacts on postharvest quality of fruit and vegetable crops: A review. Food Research International. 2010;**43**:1824-1832. DOI: 10.1016/j.foodres.2009.10.013

[11] Lin YS, Medlyn BE, Ellsworth DS. Temperature responses of leaf net photosynthesis: The role of component processes. Tree Physiology. 2012;**32**:219-231. DOI: 10.1093/treephys/tpr141

[12] Greer DH, Weedon MM. Modelling photosynthetic responses to temperature of grapevine (*Vitis vinifera* cv. Semillon) leaves on vines grown in a hot climate. Plant, Cell & Environment. 2012;**35**:1050-1064. DOI: 10.1111/j.1365-3040.2011.02471.x

[13] Ashraf M, Hafeez M. Thermotolerance of pearl millet and maize at early growth stages: Growth and nutrient relations. Biologia Plantarum. 2004;**48**:81-86. DOI: 10.1023/B:BIOP.0000

[14] Djanaguiraman M, Sheeba JA, Devi DD, Bangarusamy U. Cotton leaf senescence can be delayed by nitrophenolate spray through enhanced antioxidant defense system. Journal of Agronomy and Crop Science. 2009;**195**:213-224. DOI: 10.1111/j.1439-037X.2009.00360.x

[15] Ripoll JL, Staudt M, Lopez-Lauri F, Bidel LPR, Bertin N. Water shortage and quality of fleshy fruits-making the most of the unavoidable. Journal of Experimental Botany. 2012;**65**: 4097-4117. DOI: 10.1093/jxb/eru197

[16] Musacchi S, Serra S. Apple fruit quality: Overview on pre-harvest factors. Scientia Horticulturae. 2018;**234**:409-430. DOI: 10.1016/j.scienta.2017.12.057

[17] Gomez C, Conejero G, Torregrosa L, Cheynier V, Terrier N, Ageorges A. In vivo grapevine anthocyanin transport. Plant Cell Physiology. 2011;**54**: 1200-1216. DOI: 10.1093/pcp/pct071

[18] Garcıa-Alonso M, de Pascual-Teresa S, Santos-Buelga C, Rivas-Gonzalo JC. Evaluation of the antioxidant properties of fruits. Food Chemistry. 2004;**84**:113-118. DOI: 10.1016/S0308-8146(03)00160-2

[19] Blatt MR, Chaumont F, Farquhar G. Focus on water. Plant Physiology. 2014;**164**:1553-1555. DOI: 10.1104/pp.114.900484

[20] Shao HB, Chu LY, Jaleel CA, Zhao CX. Water-deficit stress-induced anatomical changes in higher plants. Comptes Rendus Biologies. 2008;**331**:215-225. DOI: 10.1016/j.crvi.2008.01.002

[21] Fanciullino AL, Bidel LPR, Urban L. Carotenoid responses to environmental stimuli: Integrating redox and carbon controls into a fruit model. Plant, Cell and Environment. 2014;**37**:273-289. DOI: 10.1111/pce.12153

[22] Beauvoit B, Belouah I, Bertin N, Cakpo CB, Colombié S, Dai Z, et al. Putting primary metabolism into perspective to obtain better fruits. Annals of Botany. 2018;**122**:1-21. DOI: 10.1093/aob/mcy057

[23] Ripoll J, Urban L, Staudt M, Lopez-Lauri F, Bidel LPR, Bertin N. Water shortage and quality of fleshy fruits—Making the most of the unavoidable. Journal of Experimental Botany. 2014;**65**:4097-4117. DOI: 10.1093/jxb/eru197

[24] Mirás-Avalos JM, Intrigliolo DS. Grape composition under abiotic constrains: Water stress and salinity. Frontiers in Plant Science. 2017;**8**:851. DOI: 10.3389/fpls.2017.00851

[25] Kyriacou MC, Rouphael Y. Towards a new definition of quality for fresh fruits and vegetables. Scientia Horticulturae. 2018;**234**:463-469. DOI: 10.1016/j.scienta.2017.09.046

[26] Schreiner M, Korn M, Stenger M, Holzgreve L, Altmann M. Current understanding and use of quality characteristics of horticulture products. Scientia Horticulturae. 2013;**163**:63-69. DOI: 10.1016/j.scienta.2013.09.027

[27] Darriet P, Thibon C, Dubourdieu D, Gerós H, Chaves MM, Delrot S. Aroma and aroma precursors in grape berry. In: Gerós H, Chaves MM, Delrot S, editors. The Biochemistry of the Grape Berry. Bussum, The Netherlands: Bentham Science; 2012. pp. 111-136. DOI: 10.2174/97816080536051120101

[28] Lund ST, Bohlmann J. The molecular basis for wine grape quality-a volatile subject. Science. 2006;**311**:804-805. DOI: 10.1126/science.1118962

[29] Cramer GR, Urano K, Delrot S, Pezzotti M, Shinozaki K. Effects of abiotic stress on plants: A systems biology perspective. BMC Plant Biology. 2011;**11**:163. DOI: 10.1186/1471-2229-11-163

[30] Gallego MC, Trigo RM, Vaquero JM, Brunet M, García JA, Sigró J, et al. Trends in frequency indices of daily precipitation over the Iberian Peninsula during the last century. Journal of Geophysical Research. 2011;**116**:D02109. DOI: 10.1029/2010JD014255

[31] Jones GV. A Climate Assessment for the Douro Wine Region: An Examination of the Past, Present, and Future Climate Conditions For Wine Production. 2012. Available from: http://www.advid.pt/imagens/outros/1368437718350.pdf [Accessed: January 15, 2019]

[32] Duchêne E, Huard F, Dumas V, Schneider C, Merdinoglu D. The challenge of adapting grapevine varieties to climate change. Climate Research. 2010;**41**:193-204. DOI: 10.3354/cr00850

[33] Oliveira M. Viticulture in warmer climates: Mitigating environmental stress in Douro region, Portugal. In: Jordão AM, Cosme F, editors. Grapes and Wines - Advances in Production, Processing, Analysis and Valorization. Rijeka, Croatia: InTech; 2018. pp. 59-75. DOI: 10.5772/intechopen.71155

[34] Mori K, Goto-Yamamoto N, Kitayama M, Hashizume K. Loss of anthocyanins in red-wine grape under high temperature. Journal of Experimental Botany. 2007;**58**: 1935-1945. DOI: 10.1093/jxb/erm055

[35] Greer DH, Weedon MM. Temperature-dependent responses of the berry developmental processes of three grapevine (*Vitis vinifera*) cultivars. New Zealand Journal of Crop and Horticultural Science. 2014;**42**:233-246. DOI: 10.1080/01140671.2014.894921

[36] Keller M. Managing grapevines to optimize fruit development in a challenging environment: A climate change primer for viticulturists. Australian Journal of Grape and Wine Research. 2010;**16**:56-69. DOI: 10.1111/j.1755-0238.2009.00077.x

[37] De Pinho PG, Falqué E, Castro M, Silva E, Machado B, Ferreira AC. Further insights into the floral character of Touriga Nacional wines. Journal of Food Science. 2007;**72**:S396-S401. DOI: 10.1111/j.1750-3841.2007.00405.x

[38] Zarrouk O, Garcia-Tejero I, Pinto C, Genebra T, Sabir F, Prista C, et al. Aquaporins isoforms in cv. Touriga Nacional grapevine under water stress and recovery—Regulation of expression in leaves and roots. Agricultural Water Management. 2016;**164**:167-175. DOI: 10.1016/j.agwat.2015.08.013

[39] Di Vittori L, Mazzoni L, Battino M, Mezzetti B. Pre-harvest factors influencing the quality of berries. Scientia Horticulturae. 2018;**233**:310-322. DOI: 10.1016/j.scienta.2018.01.058

[40] Torres N, Hilbert G, Luquin J, Goicoechea N, Antolín MC. Flavonoid and amino acid profiling on *Vitis vinifera* L. cv Tempranillo subjected to deficit irrigation under elevated temperatures. Journal of Food Composition and Analysis. 2017;**62**:51-62. DOI: 10.1016/j.jfca.2017.05.001

[41] Schultz HR, Stoll M. Some critical issues in environmental physiology of grapevines: Future challenges and current limitations. Australian Journal of Grape and Wine Research. 2010;**16**:4-24. DOI: 10.1111/j.1755-0238.2009.0074.x

[42] Roby G, Harbertson JF, Adams DA, Matthews MA. Berry size and vine water deficits as factors in winegrape composition: Anthocyanins and tannins. Australian Journal of Grape and Wine Research. 2008;**10**:100-107. DOI: 10.1111/j.1755-0238.2004.tb00012.x

[43] Savoi S, Wong DCJ, Arapitsas P, Miculan M, Bucchetti B, Peterlunger E, et al. Transcriptome and metabolite profiling reveals that prolonged drought modulates the phenylpropanoid and terpenoid pathway in white grapes (*Vitis vinifera* L.). BMC Plant Biology. 2016;**16**:67-83. DOI: 10.1186/s12870-016-0760-1

[44] Romero P, Fernández-Fernández JI, Martínez-Cutillas A. Physiological thresholds for efficient regulated deficit-irrigation management in winegrapes grown under semiarid conditions. American Journal of Enology and Viticulture. 2010;**61**:300-312

[45] Song J, Shellie KC, Wang H, Qian MC. Influence of deficit irrigation and kaolin particle film on grape composition and volatile compounds in merlot grape (*Vitis vinifera* L.). Food Chemistry. 2012;**134**:841-850. DOI: 10.1016/j.foodchem.2012.02.193

[46] Oliveira M, Teles J, Barbosa P, Olazabal F, Queiroz J. Shading of the fruit zone to reduce grape yield and quality losses caused by sunburn. Journal International des Sciences de la Vigne et du Vin. 2014;**48**:1-9. DOI: 10.20870/oeno-one.2014.48.3.1579

[47] Greer DH, Weston C. Heat stress affects flowering, berry growth, sugar accumulation and photosynthesis of *Vitis vinifera* cv. Semillon grapevines grown in a controlled environment. Functional Plant Biology. 2010;**37**: 206-214. DOI: 10.1071/FP09209

[48] Torres N, Goicoechea N, Antolín MC. Influence of irrigation strategy and mycorrhizal inoculation on fruit quality in different clones of tempranillo grown under elevated temperatures. Agricultural Water Management. 2018;**202**:285-298

[49] Oliveira M, de Freitas V, Sousa T. Water use efficiency and must quality of irrigated grapevines of North-Eastern Portugal. Archiv für Acker und Pflanzenbau und Bodenkunde. 2012;**58**:871-886. DOI: 10.1080/03650340.2011.551875

[50] Herrera JC, Hochberg U, Degu A, Sabbatini P, Lazarovitch N, Castellarin SD, et al. Grape metabolic response to postveraison water deficit is affected by interseason weather variability. Journal of Agricultural and Food Chemistry. 2017;**65**:5868-5878. DOI: 10.1021/acs.jafc.7b01466

[51] Houle D, Govindaraju DR, Omholt S. Phenomics: The next challenge. Nature Reviews Genetics. 2010;**11**:855-866

[52] Fereres E, Evans RG. Irrigation of fruit trees and vines: An introduction. Irrigation Science. 2006;**24**:55-57. DOI: 10.1007/s00271-005-0019-3

[53] Goldammer T. Grape Grower's Handbook. A Guide to Viticulture for Wine. Centreville (VA), USA: Apex Publishers; 2018. 482 p. ISBN (13): 978-0-9675212-5-1

[54] Houle D, Govindaraju DR, Omholt S. Phenomics: The next challenge. Nature Reviews Genetics. 2010;**11**:855-866. DOI: 10.1038/nrg2897

[55] Bramley RGV, Siebert TE, Herderich MJ, Krstic MP. Patterns of within-vineyard spatial variation in the "pepper" compound rotundone are temporally stable from year to year. Australian Journal of Grape and Wine Research. 2017;**23**:42-47. DOI: 10.1111/ajgw.12245

[56] Siebers MH, Edwards EJ, Jimenez-Berni JA, Thomas MR, Salim M, Walker RR. Fast phenomics in vineyards: Development of GRover, the grapevine rover, and LiDAR for assessing grapevine traits in the field. Sensors. 2018;**18**:2924. DOI: 10.3390/s18092924

[57] Rossi R, Pollice A, Diago M-P, Oliveira M, Millan B, Bitella G, et al. Using an automatic resistivity profiler soil sensor on-the-go in precision viticulture. Sensors. 2013;**13**:1121-1136. DOI: 10.3390/s130101121

[58] Fernandes-Silva AA, López-Bernal A, Ferreira TC, Villalobos FJ. Leaf water relations and gas exchange response to water deficit of olive (cv. Cobrançosa)

in field grown conditions in Portugal. Plant and Soil. 2016;**402**:191-209. DOI: 10.1007/s11104-015-2786-9

[59] Patumi M, d'Andria R, Marsilio V, Fontanazza G, Morelli G, Lanza B. Olive and olive oil quality after intensive monocone olive growing (*Olea europaea* L., cv. Kalamata) in different irrigation regimes. Food Chemistry. 2002;**77**:27-34. DOI: 10.1016/S0308-8146(01)00317-X

[60] Fernandes-Silva AA, Ferreira TC, Correia CM, Malheiro AC, Villalobos FJ. Influence of different irrigation regimes on crop yield and water use efficiency of olive. Plant and Soil. 2010;**333**:35-47. DOI: 10.1007/s11104-010-0294-5

[61] Caruso G, Gucci R, Isabella Sifola MI, Selvaggini R, Urbani S, Esposto S, et al. Irrigation and fruit canopy position modify oil quality of olive trees (cv. Frantoio). Journal of the Science of Food and Agriculture. 2017;**97**: 3530-3539. DOI: 10.1002/jsfa.8207

[62] International Olive Council. Trade Standard Applying to Olive Oil and Olive-Pomace Oil. Madrid, Spain: International Olive Oil Council; 2013

[63] European Committee. On the Characteristics of Olive Oil and Olive Residue Oil and on the Relevant Methods of Analysis. CONSLEG:1991R258-01/11/2005; Office for Official Publications of the European Communities. 2003

[64] Kalua C, Allen M, Bedgood D, Bishop A, Prenzler P, Robards K. Olive oil volatile compounds, flavour development and quality: A critical review. Food Chemistry. 2007;**100**:273-286. DOI: 10.1016/j.foodchem.2005.09.059

[65] Angerosa F. Influence of volatile compounds on virgin olive oil quality evaluated by analytical approaches and sensor panels. European Journal of Lipid Science and Technology. 2002;**104**:9-10. DOI: 10.1002/1438-9312(200210)104:9/10<639::AID-EJLT639>3.0.CO;2-U

[66] Rondanini DP, Castro DN, Searles PS, Rousseaux MC. Contrasting patterns of fatty acid composition and oil accumulation during fruit growth in several olive varieties and locations in a non-Mediterranean region. European Journal of Agronomy. 2014;**52**:237-246. DOI: 10.1016/j.eja.2013.09.002

[67] Hernández ML, María N, Padilla MN, Sicardo DM, Mancha M, Martínez-Rivas JM. Effect of different environmental stresses on the expression of oleate desaturase genes and fatty acid composition in olive fruit. Phytochemistry. 2011;**72**:178-187. DOI: 10.1016/j.phytochem.2010.11.026

[68] Nergiz C, Engez Y. Compositional variation of olive fruit during ripening. Food Chemistry. 2000;**69**:55-59. DOI: 10.1016/S0308-8146(99)00238-1

[69] Magliulo V, d'Andria R, Lavini A, Morelli G, Patumi M. Yield and quality of two rainfed olive cultivars following shifting to irrigation. The Journal of Horticultural Science and Biotechnology. 2003;**78**:15-23. DOI: 10.1080/14620316.2003.11511578

[70] Lombardo N, Marone E, Alessandrino M, Godino G, et al. Influence of growing season temperatures in the fatty acids (FAs) of triacilglycerols (TAGs) composition in Italian cultivars of Olea europaea. Advances in Horticultural Science. 2008;**22**:49-53

[71] García-Inza GP, Castro DN, Hall AJ, Rousseaux MC. Responses to temperature of fruit dry weight, oil concentration, and fatty acid composition in olive (*Olea europaea* L. var. 'Arauco'). European Journal of Agronomy. 2014;**54**:107-115. DOI: 10.1016/j.eja.2013.12.005

[72] Rondanini DP, Castro DN, Searles PS, Rousseaux MC. Fatty acid profiles of varietal virgin olive oils (*Olea europaea* L.) from mature orchards in warm arid valleys of Northwestern Argentina (La Rioja). Grasas y Aceites. 2011;**62**:399-409. DOI: 10.3989/gya.125110

[73] Nakano A, Uehara Y. The effects of kaolin clay on cuticle transpiration in tomato. Acta Horticulturae. 1996;**440**:233-238. DOI: 10.17660/ActaHortic.1996.440.41

[74] Wand SJE, Theron KI, Ackerman J, Marais SJS. Harvest and postharvest apple fruit quality following applications of kaolin particle film in south African orchards. Scientia Horticulturae. 2006;**107**:271-276. DOI: 10.1016/j.scienta.2005.11.002

[75] Khaleghi E, Arzani K, Moallemi N, Barzegar M. The efficacy of kaolin particle film on oil quality indices of olive trees (*Olea europaea* L.) cv 'Zard' grown under warm and semi-arid region of Iran. Food Chemistry. 2015;**166**:35-41. DOI: 10.1016/j.foodchem.2014.06.006

[76] d'Andria R, Lavini A, Morelli G, Patumi M, Terenziani S, Calandrelli D, et al. Effects of water regimes on five pickling and double aptitude olive cultivars (*Olea europaea* L.). The Journal of Horticultural Science and Biotechnology. 2004;**79**:18-25

[77] Kamal-Eldin A. Effect of fatty acids and tocopherols on the oxidative stability of vegetable oils. European Journal of Lipid Science and Technology. 2006;**58**:1051-1061

[78] Dag A, Naor A, Ben-Gal A, Harlev G, Zipori I, Schneider D, et al. The effect of water stress on super-high-density 'Koroneiki' olive oil quality. Journal of the Science of Food and Agriculture. 2015;**95**:2016-2020. DOI: 10.1002/jsfa.6913

[79] Aparicio R, Roda L, Albi MA, Gutiérrez F. Effect of various compounds on virgin olive oil stability measured by rancimat. Journal of Agricultural and Food Chemistry. 1999;**47**:4150-4155. DOI: 10.1021/jf9812230

[80] Inglese P, Barone E, Gullo G. The effect of complementary irrigation on fruit growth and ripening pattern and oil characteristics of olive (*Olea europaea* L.) cv. Carolea. The Journal of Horticultural Science and Biotechnology. 1996;**71**:257-263. DOI: 10.1080/14620316.1996.11515404

[81] Servilli M, Esposto S, Lodolini E, Selvaggini R, Taticchi A, Urbani S, et al. Irrigation effects on quality, phenolic composition, and selected volatiles of virgin olive oils cv. Leccino. Journal of Agricultural and Food Chemistry. 2007;**55**:6609-6618. DOI: 10.1021/jf070599n

[82] Fernandes-Silva AA, Gouveia JB, Vasconcelos P, Ferreira TC, Villalobos FJ. Effect of different irrigation regimes on the quality attributes of monovarietal virgin olive oil from cv. 'Cobrançosa'. Grasas y Aceites. 2013;**64**:41-49. DOI: 10.3989/gya.06971

[83] Fiorino P, Griffi N. Olive maturation and variations in certain oil constituents. Olivae. 1991;**35**:25-33

[84] Ripa V, De Rose F, Caravita ML, Parise MR, Perri E, Rosati A, et al. Qualitative evaluation of olive oils from new olive selections and environment on oil quality. Advances in Horticultural Science. 2008;**22**:95-103

[85] Tura D, Failla O, Pedò S, Gigliotti C, Bassi D, Serraiocco A. Effects of seasonal weather variability on olive oil composition in northern Italy. Acta Horticulturae. 2008;**791**:769-776. DOI: 10.17660/ActaHortic.2008.791.117

[86] Tovar MJ, Romero MP, Girona J, Motilva MJ. L-Phenylalanine

ammonia-lyase activity and concentration of phenolics in developing olive (*Olea europaea* L. cv. Arbequina) fruit grown under different irrigation regimes. Journal of the Science of Food and Agriculture. 2002;**82**:892-898. DOI: 10.1002/jsfa.1122

[87] Machado M, Felizardo C, Fernandes-Silva AA, Nunes FM, Barros A. Polyphenolic compounds, antioxidant activity and L-phenylalanine ammonia-lyase activity during ripening of olive cv. 'Cobrançosa' under different irrigation regimes. Food Research International. 2013;**51**:412-421. DOI: 10.1016/j.foodres.2012.12.056

[88] Gómez-Alonso S, Salvador MD, Fregapane G. Phenolic compounds profile of cornicabra virgin olive oil. Journal of Agricultural and Food Chemistry. 2002;**50**:6812-6817. DOI: 10.1021/jf0205211

[89] Fernandes-Silva AA, Falco V, Correia CM, Villalobos FJ. Sensory analysis and volatile compounds of olive oil (cv. Cobrançosa) from different irrigation regimes. Grasas y Aceites. 2013;**61**:59-67. DOI: 10.3989/gya.069712

[90] Williams M, Harwood JL. Effect of drought on volatile production by the lipoxygenase pathway in olive fruit. Biochemical Society Transactions. 1997;**25**:499S

[91] Fernandes-Silva A, Oliveira M, Paço AT, Ferreira I. Deficit irrigation in Mediterranean fruit trees and grapevines: Water stress indicators and crop responses. In: Ondrasek G, editor. Irrigation in Agroecosystems. London, United Kingdom; 2019. DOI: 10.5772/intechopen.80365

[92] Cano-Lamadrid M, Hernandez F, Corell M, Burlo F, Legua P, Moriana A, et al. Antioxidant capacity, fatty acids profile, and descriptive sensory analysis of table olives as affected by deficit irrigation. Journal of the Science of Food and Agriculture. 2017;**97**:444-451. DOI: 10.1002/jsfa.7744

[93] Sánchez-Rodríguez L, Corell M, Hernández F, Sendra E, Moriana A, Carbonell-Barrachina AA. Effect of Spanish-style processing on the quality attributes of HydroSOStainable green olives. Journal of the Science of Food and Agriculture. 2019;**99**:1804-1811. DOI: 10.1002/jsfa.9373