Scientific Papers. Series B, Horticulture. Vol. LXVI, No. 2, 2022
Print ISSN 2285-5653, CD-ROM ISSN 2285-5661, Online ISSN 2286-1580, ISSN-L 2285-5653

RESEARCH ON ADAPTATION MEASURES OF VITICULTURE TO CLIMATE CHANGE: OVERVIEW

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Abstract

The scientific literature of the last decades presents studies on the influence of global warming on vine, a sensitive plant, considered an indicator of climate change. Adaptation of grapevine to climate change is a major challenge for the vine-growing sector. More attention has been given lately to the methods of mitigating its effects, to maintaining the quality and to production sustainability. The latest research identifies many short-term measures (canopy management, application of sunscreen substances, soil management, pest and disease control, irrigation), medium-term (new training systems, minimal pruning, late pruning, shading nets) and long-term measures (relocation of vineyards, planting systems, land selection, scion/rootstock varieties, photovoltaic panels) to combat the negative effects of this phenomenon. This paper aims to present a synthesis of the studies conducted both in our country and worldwide, regarding measures to ensure the adaptation to new conditions.

Key words*: viticulture, adaptation, climate change, strategies.*

INTRODUCTION

Climate is the main factor that determines the development of physiological processes, phenophases, the quality of grapes and wine, depending on the variety and local conditions. Numerous studies over time have established the optimal temperature values for photosynthesis and sugar accumulation in berries (25-30°C), as well as for the accumulation of anthocyanins (17-26°C). Lower values are also favorable for the accumulation of aromatic compounds (Pirie & Mullins, 1977; Mori *et al.,* 2007a; 2007b; Tarara *et al*., 2008; Spayd *et al*., 2002). Coombe's (1987) research in Australia has established that temperatures between 25 and 28°C ensure an optimal ratio between sugars and anthocyanins.

Exceeding these intervals, as a result of global warming, especially during the ripening of grapes, caused a number of negative reactions: advancing phenophases; excessive accumulation of sugars in berries, decrease of titratable acidity, insufficient accumulation of anthocyanins and aromatic compounds, obtaining unbalanced wines, lacking in typicality and with less possibilities of aging (Sadras *et al.*, 2012; Novello & de Palma, 2013; Bucur & Dejeu, 2014; Palliotti *et al.*, 2015; Martinez de Toda & Balda, 2015; van Leeuwen *et al*., 2019; Bucur *et al.*, 2019; Santos *et al.*, 2020; Reynold, 2021).

Climate change in recent decades requires the timely implementation of measures to adapt to changing conditions, depending on local conditions, in order to reduce the risks and preserve the typicality of wines. It is estimated that the development of strategies for adapting viticulture to climate change will be of paramount importance for the sustainability and competitiveness of production (Naulleau *et al*., 2021; Ollat & Tuzard, 2014; Barbeau *et al.*, 2015; Cataldo *et al.*, 2021).

These measures, which can be applied in existing plantations, have proven their effectiveness, can be applied mechanized, have immediate effects and have been considered short-term measures (Palliotti, 2013a).

A lot of data has been accumulated gradually, which will have effects not only in the short term but also in the medium and long term (Malheiro *et al.,* 2010; Neethling *et al.*, 2017; Santos *et al.*, 2020; Gutierrez-Gamboa *et al.*, 2021).

Given the effects of climate change (which will be amplified in the near future) on grapevine, this paper aims to review the latest scientific findings on strategies for adapting viticulture to climate warming and mitigating its effects. These have been grouped into short, medium and long term strategies.

SHORT-TERM ADAPTATION MEASURES

Canopy management

Studies in several European wine-growing countries have recommended the main options for adapting viticulture to climate change in the short term (Santos *et al.,* 2021) (Figure 1).

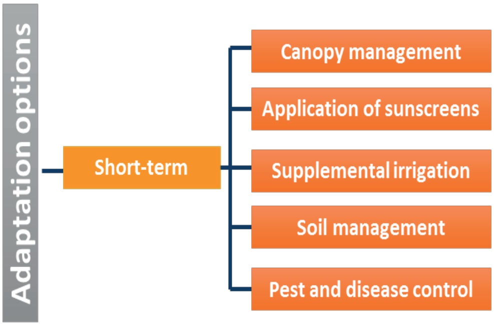

Figure 1. Short-term adaptations options to mitigate climate change impact on viticulture (Santos *et al.,* 2021)

The first measures to adapt to climate warming aimed at delaying the ripening of the grapes at moderate temperatures, avoids excessive heat during summer, maintaining a balance between sugars and acidity, with sufficient accumulations of coloring substances and aromatic compounds, which would ensure balanced, typical wines. As a priority measure to mitigate the effects of global warming on the grapevine, which can be applied during the growing season, shoots thinning, severe trimming of shoots, leaf removal, application of antiperspirants etc., are recommended.

Shoots thinning before flowering, keeping 14 shoots on the stem, followed by leaf removal applied in the area of the grapes, before the veraison lead to obtaining appropriate quality parameters for the Sangiovese variety, under conditions of climate change (Silvestroni *et al.,* 2016).

Severe trimming of shoots and increased competition from lateral shoots can contribute to delayed grape ripening (Martinez de Toda *et al.*, 2013). By delayed trimming of shoots, one week after the grape veraison, Filippetti *et al.,* (2011) obtained a significant reduction in the concentration of sugars in the must, without changing the pH, organic acids, the content of anthocyanins in the skins of the berries and the tannins in the seeds. With a severe trimming of shoots applied one week after the berries were tied, the harvest date of the Grenache grape was delayed by two weeks, reaching the same concentration in sugar and a higher one in anthocyanins, compared to the non-trimming control (Martínez de Toda *et al.,* 2013).

Leaf removal has proven to be an important measure of adaptation to climate change, by delaying grape ripening. In the past it was recommended to apply the leaf removal to the veraison, in the area of the grapes, aiming at their better maturation and reducing the attack of gray rot.

Today, under the conditions of global warming, the intended effect of this operation is different: reduction of the effect of excessive temperatures and solar radiation on grapes (Mereanu, 2010; Palliotti *et al.,* 2014; Bucur, 2021). The recommendation is to remove 30-35% of the leaves above the grape area, which are photosynthetically active, preventing excessive sugar accumulation, sunburn on the grapes.

Severe leaf removal from the area above the grapes before veraison has delayed the ripening of the grapes in the Rhin Riesling variety by about 2 weeks (Stoll *et al.,* 2009).

Leaf removal applied after grape veraison, at the age of 50-60 days (the most active photosynthetically) causes a slowdown in the accumulation of sugars. Research conducted by Palliotti *et al.* (2014) on the Sangiovese variety in central Italy, with the removal of 30-35% of the leaf area of the shoots (from the middle-upper part) when the sugar concentration of the must was 14-15°Brix reduced it by 1.2°Brix when the grapes were harvested, without affecting the titratable acidity, the anthocyanin content and the total polyphenols.

Large-scale removal of leaves is an important measure for delaying grape harvesting and obtaining low-alcohol wines with pleasant aromas in hot and dry years, without affecting the quality of white wines (Heßdörfer, 2020). By changing the ratio of leaf area to yield ratio, the development of phenophases is delayed, harvesting of grapes takes place after the heat waves and the quality of production improves (Martinez de Toda & Balda, 2013; Parker *et al.*, 2014; 2015).

Leaf area to fruit weight ratio, which decreases as a result of applying these green operations at values of 0.6-0.8 m^2/kg, contributes to the delay of the grape harvest and to the decrease of the sugar concentration of the berries. The reduction of this ratio to the Fetească regală variety to values lower than 0.6 m^2/kg (Figure 2) lead to a significant reduction of the sugar concentration, by over 20 g/L (Dejeu *et al.*, 2005).

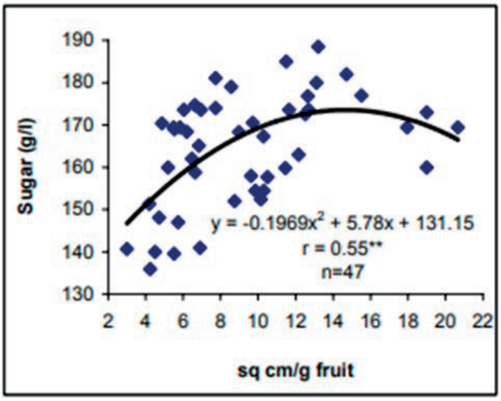

Figure 2. Correlation between cm^2 leaf area/g fruit and the sugar accumulations in the fruit (g/l), 2004

The research carried out at Valea Călugărească for the Cabernet Sauvignon variety confirmed that at low values of the leaf area to fruit weight ratio (6-8 cm^2/g grape, respectively 0.6-0.8 m^2/kg) the obtained sugar concentrations was 180-185 g/L, compared to 197-205 g/L (Figure 3), at optimal values of 1.0-1.7 m^2/kg (Belea, 2008).

Application of sunscreen substances

The use of substances with antitranspirant action causes a partial closure of the stomata, a reduction of photosynthesis and water loss through transpiration, preventing the berry shrivelling under conditions of water stress (Rosati, 2007).

Foliar treatments with ***kaolin***, a natural clay rock, white $Al_2Si_2O_5(OH_4)$ cover the leaves and berries with a film of nanoparticles, provide sun protection, reduce the effects of heat stress, reduce leaf temperature by 4-6°C, prevent phenomena photoinhibition, avoids leaf discoloration, sunburn, and improve the quantity and quality of yield (Frioni *et al.,* 2019).

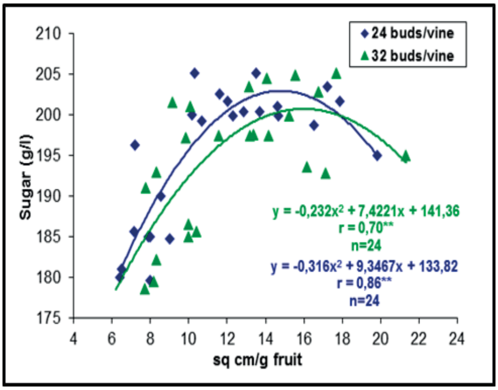

Figure 3. Correlations between the values of the ratio cm^2 leaf area/g fruit and the sugars accumulation in the fruit (g/l), depending on the buds load, average 2004-2006 (Belea, 2008)

It has been found that the use of antitranspirants reduces water loss through transpiration by preventing the berry shrivelling and sunburn under conditions of heat, water and radiation stress. These substances provide sun protection, forming a film of inert particles on the surface of leaves and berries that improves plant metabolism under such conditions (Santos *et al.,* 2020).

The use of kaolin under conditions of heat and water stress, combined with deficit irrigation, increased the anthocyanin content in Merlot berries (Song *et al.,* 2012).

The use of kaolin with pinolen in Cabernet Sauvignon under water stress in southern Italy has increased the efficiency of water use, without affecting the weight of grapes and berries, or the concentration of sugars; instead, the anthocyanin content increased significantly, the quality of the wine obtained being improved (Brillante *et al.,* 2016).

Leaf removal, combined with kaolin treatment, has increased the anthocyanin content of berries in the Muscat de Hamburg variety, without affecting the composition of volatile substances (Kok & Ball, 2018).

By foliar application, immediately after the grape veraison, of a repeated treatment with kaolin (5%), Dinis *et al.* (2016) under conditions of heat and water stress, the Touriga National variety cultivated in the Douro region

(Portugal) showed a 40% increase in the total phenol content, 24% increase in flavonoids and 32% in the anthocyanin content. It has also improved the antioxidant capacity of berries as a result of increasing the content of secondary metabolites.

Other authors have showed the protective effect of kaolin on the anthocyanin content of grapes (Kok & Bal, 2018).

The use of kaolin and ***zeolite*** in a concentration of 3%, in two rounds at the beginning of the grape ripening, in the Sangiovese variety, on leaves and grapes, determined a reduction of the berries' temperature, without affecting the gas exchange, grape yield and sugar accumulation. Moreover, the cooling effect of the berries contributed to the increase of the anthocyanin content in grapes and wine (Valentini *et al.,* 2021).

Chitosan, a natural biopolymer applied to leaves and grapes, also has an antitranspirant effect, thus avoiding the negative effects of water stress (Khalil & Badr Eldin, 2021).

Other sunscreens have also been used with good results, such as ***calcium carbonate*** ($CaCO_3$) and ***potassium silicate*** (K_2SiO_3) (Santos *et al.,* 2020).

A natural product obtained by distilling coniferous resins, ***based on pinolen*** (2%) applied after the grape veraison, leaves in a few hours after treatment, a thin, transparent film, which partially limits the gas exchange for a period of 40-50 days, causing a significant reduction or delay in the accumulation of sugars in the berries (Palliotti *et al*., 2013b). The treatment is recommended to be applied when the concentration of sugars in the must is about 14-15° Brix.

Foliar treatments with a natural ***product derived from inactivated yeast*** (*Saccharomyces cerevisiae*), in a dose of 1 kg/ha, applied in two stages, at the beginning of the grapes veraison and the second, after 12 days, determined an improvement in balanced wines of the Syrah variety grown in Hungary (Villangó *et al.,* 2015).

Foliar treatments with 3 elicitors ***(methyl jasmonate, commercial yeast extract and chitosan)*** applied to Tempranillo variety, to the grape veraison and one week later, increased the anthocyanin content of grapes and wine, in the case of the first two substances (Portu *et al.*, 2016).

Application before veraison of ***exogenous auxins*** (naphthyl acetic acid) at a concentration of 50 mg/L on grapes of the Shiraz variety grown in Australia (two treatments every 5 days) delayed the ripening of the grapes by 10 days, without affecting the accumulation of sugars, the anthocyanins and the organoleptic properties of wines (Böttcher *et al.,* 2011).

Irrigation

Irrigation is used to improve grape yield and quality, whenever rainfall is scarce, to ensure water requirements for vines, especially under conditions of drought exacerbated by climate change.

The measure is based on deficit irrigation (DI) strategies (e.g.: deficit regulated irrigation, sustainable deficit irrigation, partial drying of the root zone) to take advantage of the relationship between soil water, plant and yield/quality ratio. Considering these strategies, drip irrigation is generally implemented as the most efficient method of saving water (Santos *et al.,* 2020).

Deficit irrigation during grape ripening has led to a significant increase in the content of anthocyanins and tannins in the Merlot variety (Bucchetti *et al.,* 2011).

Deficit irrigation applied to the Sangiovese variety, with the use of a volume of water equivalent to 33% of the consumption by evapotranspiration achieved in the previous week, in the interval between the beginning of berries growth and grapes veraison led to an increase in yield, a reduction in soluble content from must, without affecting the concentration in anthocyanins and phenolic substances (Lanari *et al.,* 2014).

Late irrigation, applied to the veraison, has a greater effect if combined with the shoots topping because it causes a greater number of lateral shoots, which intensifies the competition for synthesized substances (Palliotti *et al.,* 2014; Santesteban *et al.,* 2017).

The combination of irrigation with the shoots topping causes a delay in the grape ripening, allowing full ripening at lower temperatures and a pronounced synthesis of aromas and phenolic substances.

Late application of irrigation, combined with the shoot topping, can be used to invigorate vegetative growth, leaving young lateral shoots, thus slowing down the accumulation of sugars in the berries.

The application of irrigation only during the veraison-harvesting period, under conditions of a warm, arid climate in Spain has led to a reduction in the accumulation of sugars in berries of Cabernet Sauvignon, without changing the composition of phenols and wine quality (Fernandez *et al.*, 2013).

For efficient water use, the use drip irrigation, deficit irrigation strategies is recommended. The application of deficit irrigation with the partial replacement of water consumed by evapotranspiration in different periods (even in the veraison - grapes harvest) under conditions of water stress has led to an optimization of vegetative, productive and qualitative performance of vines (Costa *et al.,* 2016; Keller *et al.,* 2016).

Numerous studies have been conducted, highlighting the deficit regulated irrigation, as well as that by partial drying of the root zone, which improve the efficiency of water use, in areas affected by drought (Romero *et al.,* 2022).

Deficit controlled irrigation together with Zn foliar fertilization of Alphonse Lavallée and Italy varieties have improved berries' color and their physical characteristics (pedicel peeling strength and resistance to berry cracking) (Sabir *et al.,* 2021).

Soil management

In the face of climate change, soil management needs to be reconsidered and less applied to keep water in the soil, especially on shallow and eroded soils on sloping land.

The application of the soil management must take into account the pedoclimatic conditions (the capacity of the soil to retain water, the volume of precipitation, excessive temperatures, increased evapotranspiration, etc.).

In general, under conditions of water stress, it is recommended to reduce the number of soil mobilizations (Walg, 2009; Dobrei *et al.*, 2015). Cataldo *et al.* (2021) appreciate that proper soil management for new conditions improves the quality of production.

It is recommended to apply those works that favor soil fertility, water loss, avoiding the mineralization of organic matter in the soil. Under such conditions, the system of minimum tillage practices, soil mulching and green cover are of particular importance.

Minimum tillage is a system of surface practices characterized by tillage without turning the furrow and partial incorporation of plant debris. The use of the „minimum tillage" system, together with mulching (partial or total) with straw, under conditions of thermo-hydric stress had a favorable effect on production and quality (Enache & Donici, 2014).

Soil mulching made with different materials causes a significant increase in the content of anthocyanins in grapes, soil improvement, improves the microclimate in the vine and prevents weed growth. In such cases, the vine suffers less from heat and water stress (Fraga & Santos, 2018), it prevents soil erosion, maintains soil moisture, prevents water loss through evaporation and the efficient water use improves the penetration of water into the soil. Both organic substances (grape marc, compost, vine pruning, tree bark, plant debris, animal manure, straw) and inorganic substances (plastic, geotextiles, etc.) can be used for mulching (Hosteler *et al.,* 2007).

Following the influence of soil maintenance by mulching in viticulture in an experiment conducted in 6 wine centers in Romania, Şerdinescu *et al.* (2013) found a decrease in the disruptive effect of the climate change. Compared to the maintenance of the soil as a black field (total or partial) mulching has ensured, under conditions of severe drought, reduced water loss through the soil by 14-20%, higher yields by 29-49% in the case of total mulching with straw and 6-22% for partial mulching with grape marc compost. There was also a significant increase in the total number of microorganisms in the case of soil mulching, more pronounced in total straw mulching, compared to maintenance as a black field (Brînduşe *et al.,* 2013; Şerdinescu & Brînduşe, 2014a; 2014b).

Green cover in viticulture (with spontaneous or cultivated species), especially during rainy periods, must take into account the minimum competition for water, favoring the infiltration of water into the soil, improving soil fertility, preventing erosion and leaching in depth of nutrients etc. At the same time, green cover provides favorable conditions for predators and parasites, useful in biological control.

It has been found that the species *Festuca ovina, Festuca arundinacea, Lolium perenne, Hordeum vulgare, Trifolium incarnatum* and *Poa pratensis* and grasses in general are more adapted to global warming. Also, under conditions of excessive temperatures and dry periods, the soil temperature values were lower at green cover.

Abad *et al.,* (2020) found in Spain that the species *Trifolium fragiferum* have favorable influences on the soil and vines, when used for grassing in the direction of the rows (under-vine cover crop), preventing the development of weeds.

Pest and disease control

Climate change can help lower the pressure on diseases and pests, requiring fewer treatments. Disease and pest control must take into account the phenology of the vine that is greatly affected by global warming, changes in plant susceptibility to pathogens, and the behavior of vectors (Reineke & Thiéry, 2016).

Trichogramma, as parasitoid eggs of grapevine moth (*Lobesia botrana*), a wasp useful in biological control is favored by high temperatures and drought.

Scaphoideus titanus, a vector of flavescence dorée phytoplasma is rapidly expanding in the face of climate change.

The vineyards must be carefully controlled under the new conditions to detect the emergence of new diseases and pests.

Global warming influences the manifestation of diseases and pests in vineyards. Thus, it was found that the esca and flavescence dorée are more virulent under the new conditions (Maixner *et al.,* 2007). The main vector of phytoplasma, the causal agent of black wood disease (bois noir) *Hyalesthes obsoletus*, is also favored, and populations of predatory mites are greatly diminished compared to harmful ones (Corino *et al*., 2004).

According to research in northwestern Italy, Caffarra *et al.* (2012) appreciated that global warming is leading to an increase in the number of generations for grape moth (*Lobesia botrana*) and a sensitization of the vine to the attack of powdery mildew (*Erysiphe necator*).

Bois *et al.* (2017) found that gray mold (*Botrytis cinerea*) occurs less frequently in drier conditions.

MEDIUM-TERM ADAPTATION MEASURES

Training systems

Training system by increase trunk height delays grape ripening with 3-5 days, as a result of reducing maximum temperatures in the grape area (van Leeuwen & Destrac-Irvine, 2017). By switching from the low form of the vine to the semi-high form, Matei *et al.* (2009) found a lower accumulation of sugars in the berries of the Fetească regală variety in the period 2006-2008 by 7.2-19.2 g/L.

Carbonneau (2011) recommends lyre or modified lyre systems which could be adapted according to the actual weather situation for optimal berry development. Leaf removal is recommended, as another tool for keeping the traditional wine style.

The choice of pruning systems that do not allow the grapes to be exposed to direct sunlight (pergola, free cordon, Geneva double curtain) ensures conditions that contribute to maintaining the production-quality balance in the context of global warming (Novello & de Palma, 2013). These pruning systems provide diffused light to the grapes, especially in drought conditions.

Delaying of pruning

By delaying pruning when the apical shoots on the canes were 5 cm long, in the New Zealand variety of Merlot, Friend & Trought (2007) obtained a lower accumulation of sugar in the berries and a higher acidity content.

In the case of spur pruning system, applied after budding to the Sangiovese variety grown in central Italy, the content of soluble substances in the must was lower by 1.6°Brix, compared to the usual pruning during the rest period, and the titratable acidity - much higher by 1.8 g/L (Frioni *et al.,* 2016).

Buesa *et al.* (2021) found in the Bobal and Tempranillo varieties grown in eastern Spain, that the late pruning, before the budding of the basal budbreak, delayed the ripening of the grapes, with a greater accumulation of anthocyanins in the berries. The delay of the ripening of the grapes by two weeks was obtained together with the late pruning, the minimum pruning and the severe shoot topping, as well as the leaf removal in the apical area of the shoots (Gutierez-Gamboa *et al.,* 2021).

Minimal pruning

Minimal pruning helps to increase the buds load and the number of shoots on the vine, resulting in an increased number of loose grapes, evenly distributed in the dense foliage wall, so that the skins of the berries become richer in phenols, harvesting can be done at small concentrations of sugars (Clingeleffer, 2007). Minimum pruning in the Rioja region has led to an increase in grape yield, a reduction in grape sugar content and an improvement in anthocyanin content in red wine varieties (Zheng *et al.,* 2017).

Use of shading nets

The use of shading nets is an effective means of mitigating the negative effects of excess radiation and temperature on grapes in warm climates. Nets that provide a shading of 35% installed on the veraison have led to delayed ripening, improved quality and better storage capacity for Sultana Seedless table grapes (Sen *et al.,* 2016).

In a study conducted in Italy, Valenti *et al.* (2012) found that the use of shading nets for Chardonnay and Pinot noir varieties led to a delay in grape ripening, preservation of acidity and improved sensory profile of wines.

The use of shading nets covering the area of grapes, 1 m wide, along the rows, from the veraison to the ripening of the grapes, which ensures a degree of shading of 20%, has led to an increase in the content of anthocyanins in the berries of the Cabernet Sauvignon variety (Martinez-Lüscher *et al.,* 2017).

It has been found that by using shading nets, the temperature of the grapes decreases by up to 7°C (Lobos *et al.,* 2015). Shaded hubs are more susceptible to prolonged summer drought when soil water reserves are low.

LONG-TERM ADAPTATION MEASURES

Relocation of vineyards

The long-term strategy provides for changes in the choice of land for the establishment of plantations (at higher latitudes, as well as at other altitudes, where the most favorable conditions are found). At the same time, land exposures with lower values of solar radiation and air temperature will be chosen.

According to the A1B scenario (2041-2070) Malheiro *et al.* (2010) finds a northward shift in favor of vine cultivation and a decrease in southwestern Europe (Figure 4).

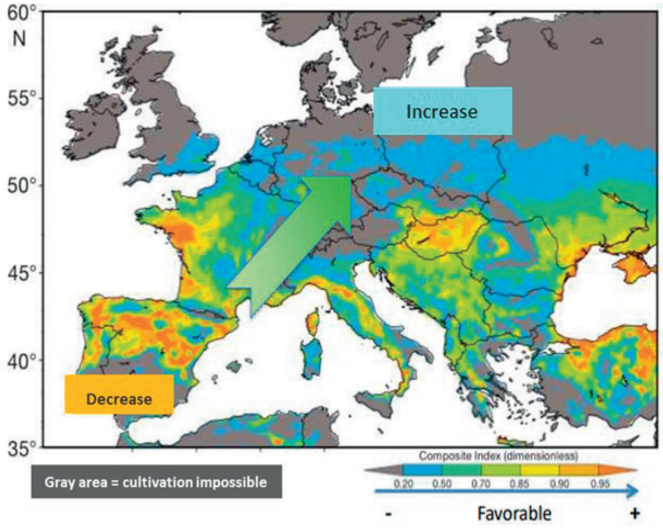

Figure 4. Evolution of lands favorable to vines at European level
(Malheiro *et al.,*2010; Touzard *et al.,* 2021)

In Romania, will a decrease in climate favorability for vines in the southern part of the country and an increase in the northern parts of Moldova, center of Transylvania, the west of the country and the Black Sea coast.

This category also includes the orientation of the rows, which ensures better shading of the vines, which can ensure a proper maturation, avoiding sunburn and reducing the attack of gray rot (*Botrytis cinerea*) (Friedel *et al.,* 2013). In the future, the lands with northern, north-western and western exposures will be preferred, where the heliothermal resources reach lower values. Naulleau *et al.* (2021) emphasized the importance of east-west row orientation in reducing water stress.

If until three or four decades ago, the northern limit of cultivation of red wine and table grapes varieties with large berries was in the southern half of our country (Oşlobeanu *et al.,* 1991), as a result of the increase in thermal and solar radiation resources, the cultivation has expanded considerably throughout the country.

A good example is the success of the Syrah variety of Mediterranean origin, together with Merlot and Cabernet Sauvignon, in the Răteşti wine center - Beltiug area in Satu Mare county (Popescu, 2011).

Also, as a result of climate change, in the last decade, red wines have started to be produced in the Cotnari vineyard, and plantations for white wines were relocated to altitudes higher than 200 m (Irimia *et al.,* 2012; Quènol *et al.,* 2016).

It is also estimated that at European level, due to global warming, the northern limit of vine cultivation will move north to the latitude limit of 55° (Malheiro *et al.,* 2010). As early as 1992, Kenny and Harrison forecasted a displacement of the northward limit of the viticulture in Europe by 10-30 km per decade by 2020, with this rate doubling between 2020 and 2050.

The combined effect of heat, radiation and water stress can also be avoided by using land with different exposures to the southern ones (or close to them), which leads to a lower interception of solar radiation, and a decrease in water consumption through evapotranspiration.

The risks of sunburn are lower if the rows are oriented, when setting up plantations, in an east-west direction (Friedel *et al.,* 2013).

Choice of varieties and clones adapted to global warming

The diversity of vine varieties is an important resource for adapting to climate change (Destrac-Irvine *et al.,* 2016; 2020; Antolin *et al.,* 2021).

The choice of varieties when setting up plantations is a long-term measure and an important means of delaying grape ripening by up to two weeks. This choice can be made from existing varieties (for example, Cabernet Sauvignon can be planted instead of Merlot, which ripens up to two weeks later, under more favorable conditions). At the same time, new varieties can be introduced, better adapted to climate change.

Viticulture has many varieties, with different ripening periods, from early to very late, the latter undergoing the phenophase of ripening grapes at more favorable temperatures in early autumn. Following the adaptation to climate change of a large number of varieties (52) cultivated in the Bordeaux region, Destrac - Irvine *et al.* (2016) found differences in flowering of up to 20 days, and in the veraison of about 40 days.

Sadras *et al.* (2013) found differences between varieties in terms of the effects of rising air temperatures; there were highlighted substantial changes in titratable acidity and pH in Cabernet Franc and Chardonnay varieties, while in Shiraz varieties the changes were insignificant.

Many research projects have been carried out in different European countries on measures to adapt to climate warming, with special reference to the behavior of varieties under the new conditions (LACCAVE, Clim4Vitis and ADVICLIM, etc.) (Quénol *et al.,* 2014; Ollat & Touzard, 2014; Santos *et al.,* 2021; Touzard *et al.,* 2021).

Under the conditions of climate change, it is interesting to cultivate many varieties with late maturation, resistant to heat waves and drought (Cabernet Sauvignon, Syrah, Sangiovese, Carignan, Grenache, Mourvèdre, Marcelan, etc.).

A priority objective for the genetic improvement of vines is to obtain varieties adapted to the new global warming conditions, which ensure sustainable, high quality production (Duchêne *et al.,* 2010). Based on the results obtained in some wine centers in the western part of the country, Dobrei *et al.,* (2015) appreciated that the local viticultural germplasm, well adapted to the new conditions, can be a viable alternative to climate change and an important source of typicity and authenticity of wines.

It is also important to obtain new varieties with late maturation, with superior quality characteristics, as well as to reconsider the old local varieties adapted to the new conditions.

An objective of the clonal selection is to obtain clones with lower accumulation of sugars in the berries, with higher content of titratable acidity, without affecting the aromatic and phenolic profile (for red wine varieties).

Urucu (2014) performed a comparative study on the behavior of different Cabernet Sauvignon clones in the Bolovanu-Sâmbureşti wine center, with 4 clones of the Cabernet Sauvignon variety (Table 1), two of French origin (169 and 15) and two from Romania (7-Dg and 4-Iş). This study highlighted a delay in grape ripening and a lower sugar content of 3 clones (169/SO 4; 15/101.14 and 7-Dg grafted on rootstock SO 4), the difference being up to 20-30 g/L, as an average of the period 1999 - 2011.

Choosing clones with larger, loose grapes could counteract the rapid accumulation of sugars in the berries.

It is estimated that viticultural interventions to adapt to climate change are less expensive than those in winemaking, such as de-alcoholization of wines by physical means, such as reverse osmosis and ultrafiltration (Novello & de Palma, 2013; Palliotti *et al.,* 2015).

Table 1. The main characteristics of the grape composition in 4 clones of Cabernet Sauvignon at the time of technological maturity, average data from 2009 -2011 (Urucu, 2014)

Clone/Rootstock	Sugar (g/L)	Titratable acidity (g/L tartaric acid)	Total poliphenols (mg tartaric acid/ kg grapes)	Total anthocyanins (mg/kg grapes)
169/3309	238	6,8	4345	1328
169/SO 4	203	7,5	4931	1504
169/101.14	212	6,2	4588	1332
15/3309	235	5,7	4792	1583
15/101.14	201	7,6	4701	970
15/SO 4	212	6,6	4740	1346
7 Dg/SO 4	208	6,03	2142	900
4 Is/SO 4	213	6,0	2946	1050

Choice of rootstocks

The rootstocks used in the new plantations must not only ensure the resistance to phylloxera, but also to drought, at high temperatures, which will induce the late varieties of grape ripening, without affecting their quality.

The rootstock used for grafting can delay the grape entry in veraison and ripening of the grapes by about a week. There are rootstocks with good drought resistance: 140 Ruggeri; 110 Richter; 1103 Paulsen; 1444 Paulsen etc.

Ion (2006) found the significant influence of the rootstock partner on the accumulation of sugars in the Cabernet Sauvignon, Merlot, Fetească neagră varieties, cultivated in the Valea Călugărească viticultural center. Thus, in the case of the Fetească neagră grape variety grafted on the 140 Ruggeri rootstock, lower concentrations of sugars in the must (209 g/L) were accumulated, compared to the Oppenheim Selection 4 - 4 (222 g/L).

Use of mobile photovoltaic panels

The use of mobile photovoltaic panels above the rows of vines at a height that allows the work to be carried out is also a means of combating climate change. The orientation of the panels to meet the physiological needs of the vine can also ensure maximum shading when the solar radiation is excessive and contributes to reducing water consumption by 20%. At the same time, the panels ensure the production of renewable electricity and under clean conditions. It was found that under the conditions of using solar panels, less alcoholic wines with an improved aromatic profile are obtained (Pelsy & Merdinoglu, 2021).

CONCLUSIONS

The effects of global warming (rising temperatures, solar radiation, drought) on vines require the adoption of measures to mitigate and adapt viticulture to the new conditions.

Given that this phenomenon is expected to intensify in the future, adaptation measures are becoming increasingly important.

We reviewed over 100 papers on adaptation strategies to climate change in vineyards. These have been grouped into short, medium and long-term adaptation strategies. The short-term ones, which become a priority, refer to canopy management, application of sunscreen substances, soil management, pest and disease control.

Medium-term strategies include a series of measures related to changing cultural practices: new training systems, minimal pruning, late pruning, irrigation, use of shading nets.

Long-term strategies for adapting viticulture to climate warming refer to: site selection, relocation of vineyards, row orientation, exploitation of the diversity of vine varieties and the breeding of new varieties and rootstocks tolerant to heat and drought etc.

The application of these measures must take into account climate change evolution and local conditions.

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