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CURRENT PROBLEMS OF THE TECHNOLOGY OF RED TABLE DRY WINES IN THE CONDITIONS OF CLIMATE CHANGE

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Abstract. Production and demand for red table dry wines is stable. Climate change is one of the main factor in the annual variation of the total volume of wine produced in the world. Minimizing the impact of climate change on the quality characteristics of wine is a strategic direction of research at OIV. This work is devoted to the literary review of the current problems of the technology of red table dry wines in the conditions of climate change over the last 10 years. It was established that the increase in average annual temperature in comparison with the pre-industrial period is from 0.8 to 1.2°C. In addition, a decrease in precipitation during the grape growing season is predicted. Those regions that are currently considered cool will become suitable for growing grapes. Thus, it is possible to lose the typicality of wines from traditional wine-growing regions. Acceleration of ripening leads to the accumulation of high sugar content, high pH, low acidity, modification of varietal aromatic compounds, changes in the timing of phenolic ripening, and a general decrease in yield. Water stress increases the content of tannins and anthocyanins, negatively affects productivity. An increase in carbon dioxide content leads to a decrease in the concentration of anthocyanins and the intensity of color. Exposure to ultraviolet radiation contributes to the accumulation of more anthocyanins, quercetin and trans-resveratrol. Short-term and long-term adaptation strategies to climate change conditions are implemented to obtain high-quality grapes. The most important aspect is the reduction of alcohol content. Different techniques of maceration affect the organoleptic characteristics and the phenolic complex. It is promising to use non-Saccharomyces yeast to reduce alcohol content and form organoleptic characteristics and phenolic complex. The choice of stabilizing materials affects the phenolic composition and color stability. Aging techniques affect the phenolic complex and organoleptic characteristics. The current problems of technology are focused on preserving the quality and typicality of wine styles and at the same time take into account the changing taste preferences of consumers.

Key words: red wine, climate change, yeasts, phenolic complex, anthocyanins.

Introduction. Formulation of the problem

The global and Ukrainian wine production and consumption market shows stable growth. At the same time, the share of red table dry wines remains unchanged even against the background of general trends of growth in the consumption of sparkling and white wines. The evaluation of possible agroclimatic resources of Ukraine in the conditions of climate change shows a decrease in the negative impact of limiting factors for viticulture. Accordingly, the list of regions favorable for viticulture will expand. Changeable and unpredictable from year to year temperature regimes and the amount of precipitation affect the physicochemical and organoleptic characteristics of grapes. Most research in viticulture and winemaking related to climate change is concerned with viticultural strategies.

The use of technological techniques will allow controlling the influence of climatic changes on the typicality of the obtained wines within one year. The relevance of the problem lies in the solution of an important task for Ukrainian winemaking - the determination of technological techniques that will level and preserve the typical physico-chemical and organoleptic features of red table dry wines in the conditions of climate change.

The purpose and objectives of the research.

The purpose of this work is the literary review of the current problems of the technology of red table dry wines in the conditions of climate change.

The research objectives are:

1. Analyze the current state in red wine production in the world and in Ukraine.

2. Analyze current research on the impact of temperature changes on the geography of production and quality of dry red table wines.
3. Analyze current research on the impact of changing water regimes on the geography of production and quality of dry red table wines.
4. Analyze current research on the impact of changes in carbon dioxide content on the geography of production and quality of dry red table wines.
5. Analyze current research on the impact of changes in ultraviolet radiation on the geography of production and quality of dry red table wines.
6. Analyze current research on adaptation strategies for grape growing in the conditions of climate change.
7. Analyze current research on the adaptation of dry red table wine technology in the conditions of climate change.

To determine the actual problems of the technology of red table dry wines in the conditions of climate change the analysis of the publications and research of the last 10 years have been made.

Analysis of recent research and publications

The current state in red wine production in the world and in Ukraine.

According to the annual report of the International Organization of Vine and Wine, in 2022 the volume of wine production was about 259.9 million hl. This is slightly below the 20-year average and, tentatively, 1% below 2021. One of the reasons is a higher-than-expected crop in Europe despite drought and heat in the spring and summer. In general, dry and hot conditions were observed in various regions of the world in 2022 and resulted in early harvests and average production volumes, but generally of good quality [1].

Meanwhile, the 2021 report indicates that expected volume is down 4% from 2020 (which was already below average) and 7% below the 20-year average [2]. This is the result of unfavorable climatic conditions, which in 2021 strongly affected the main wine-producing countries of Europe. The Southern Hemisphere and the US appear to be the exception to this overall negative scenario and tend to offset the volume decline seen in the EU. This is the third year in a row that world wine production is below average [1].

Industrial vineyards of Ukraine are located in the south in Odesa, Kherson, Mykolaiv, Zaporizhzhia regions, the Autonomous Republic of Crimea and Transcarpathia. About 60% of the area is in the zone of cover viticulture on grafted culture. Only on the sandy soils of the Kherson region (Tsiurupinsky and Kakhovsky districts) is possible the root culture of grapes [3,4]. As of 2020, the total area of grape plantations at fruit-bearing age in Ukraine is 24.5 thousand hectares in agricultural enterprises and 12.7 thousand hectares in households. The gross collection for these categories of farms, respectively, amounted to 98.7 and 182.3 thousand tons [5].

The State Register of Plant Varieties of Ukraine for 2020 includes 45 grape varieties and 5 rootstocks [6], of which 21 are table varieties, 20 are technical varieties, and 4 are universal varieties [7].

As of 2021, in Ukraine in the group of technical varieties, 30.4% are red grape varieties. Among which Cabernet Sauvignon accounts for 13.4% of the total volume of processed grapes, Merlot – 5.9%, Pinot white, Pinot black, Pinot gris – 4.0%, Saperavi Northern – 5.0%, Odesa Black – 2.1 % [8].

Ukraine is a developing agricultural country in Eastern Europe with great potential in viticulture and winemaking. Despite existing problems, primarily related to legislation in this area, Ukraine today is taking the right steps towards the development of the industry, including thanks to the EU. Moreover, taking into account climate change, Ukraine expects a decrease in the impact of negative limiting factors. In addition, it should be noted that a small amount of precipitation negatively affects the possibility of damage to vineyards by mold and fungal diseases, which makes Ukraine a promising platform for the development of organic winemaking [9].

In connection with climate changes, viticulture is considered one of the most promising areas of the agricultural industry in Vinnytsia [10]. All aspects and opportunities for the development of viticulture, as well as the launch of large winemaking facilities in the southern regions of the region, are being studied. The average yield of grapes in Ukraine in 2018 from 1 hectare of plantings at the fruit-bearing age was 127 quintals, while in the Vinnytsia region it was 39,6 t/ha.

The impact of temperature changes on the geography of production and quality of dry red table wines.

Human-induced warming has reached about 1°C (likely between 0.8°C and 1.2°C) compared to pre-industrial levels, increasing by 0.2°C in 2017 (likely between 0.1 °C and 0.3°C) per decade (high confidence). Global warming is defined in this report as an increase in the combined surface air and sea surface temperature averaged over the globe and over a 30-year period. Unless otherwise stated, warming is expressed relative to the period 1850–1900, which is used as a proxy for pre-industrial temperatures. For periods shorter than 30 years, warming means the estimated 30-year average temperature centered on that shorter period, taking into account the effects of any temperature fluctuations or trends during those 30 years. Accordingly, warming from pre-industrial levels to the decade 2006–2015 is estimated at 0.87°C (probably between 0.75°C and 0.99°C). Since 2000, the estimated level of warming caused by human activity is equal to the level of observed warming with a probable range of ±20%, taking into account the uncertainty due to the influence of solar and volcanic activity during the historical period (high confidence) [11].

The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change. Under the Climate Change 2022: Impacts, Adaptation and Vulnerability programme, the contribution of Working Group II in the Sixth Report assesses impacts of climate change, looking at ecosystems, biodiversity and human communities at the global and regional levels. It also examines the vulnerabilities, capacity and limitations of the natural world and human societies to adapt to climate change. A comprehensive study of the impact on the winemaking industry outlines the main directions of further research both in viticulture and in winemaking technology and related industries [12].

Climate directly affects the suitability of grown grapes for wine production. Altered patterns in temperature and precipitation due to climate change are likely to affect this relevant socio-economic sector across Europe. Prospects for future bioclimatic indicators associated with viticultural zoning are derived from observed and predicted daily meteorological data. The results show that the cultivation of grapes will have a negative impact on the south of Europe. Table grape production and technical grape production in this region are expected to decline due to future increases in cumulative heat stress and drought during the growing season. In addition, projected precipitation will decrease and higher evaporation rates due to a warmer climate will likely increase water demand. On the other hand, high-quality areas for viticulture will expand significantly northward in Western and Central Europe. The proposed Mid-Century Viticulture Zoning could facilitate the better development of new strategies and management methods that will benefit the European wine sector. More efficient irrigation methods are proposed in the Mediterranean, it may be necessary to change the grape varieties currently grown and to breed varieties that are better adapted to warmer climates. On the contrary, areas of northern Europe, which are currently unsuitable for growing grapes, may be used in the near future. In the same study, the Haglin and Winkler indices are used to distinguish wine-growing zones, which depend on the sum of positive or higher than 10˚C temperatures during the growing season [13].

Thus, according to the Haglin index (HI), regions are divided into:

1. Very warm (HI + 3) HI >3000 In certain cases in intertropical climates it is possible to get more than one harvest per year.

2. Warm (HI + 2) 2400 < HI ≤3000 Potential that exceeds the heliothermal requirements for ripening cultivars (with some associated stress risks).

3. Moderately warm (HI + 1) 2100 < HI ≤2400 Grenache, Carginan, Aramont, Tempranillo and Mourvèdre can ripen.

4. Moderate (HI - 1) 1800 < HI ≤2100 Later varieties such as Cabernet Sauvignon Uni Blanc and Syrah can reach maturity.

5. Cool (HI-2) 1500 < HI ≤1800 Allows a very large number of grape varieties (white or red) to ripen: Chardonnay, Merlot, Pinot Noir, Cabernet Franc, etc.

6. Very cool (HI-3) HI ≤1500 Only very early/early varieties can reach maturity (e.g. Pinot Blanc, Gewurztraminer)

According to the Winkler index (WI), wine-growing regions are divided into:

1. Too cold, WI < 1111. Only very early ripening varieties achieve high quality, mostly hybrid grapes and some Vitis vinifera.

2. Region I, 1111 < WI < 1389. Only early ripening varieties achieve high quality, mostly hybrid grape varieties and some Vitis Vinifera (e.g. Chablis, Champagne)

3. Region II, 1389 < WI < 1667 Early and mid-ripening table wine grapes produce quality wines (eg Alsace, Bordeaux).

4. Region III, 1667 < WI < 1944 Favorable for quality production of standard to good quality table wines (eg Piedmont, Rioja).

5. Region IV, 1944 < WI < 2222 Favorable for quality production, but at best acceptable quality table wine (e.g. Montpellier).

6. Region V, 2222 < WI < 2500 Usually only suitable for very high quality production, grapes grown for very good to good quality table wines intended for early season consumption (eg Greek Islands, Sicily, Jerez).

7. Region VI, 2500 < WI < 2778 Only suitable for extremely high quality production.

8. Too warm, WI > 2778 Not suitable for Vitis production [13].

Most modern regions will change the classification by one level, becoming warmer and suitable for growing new grape varieties that are not traditional for them. Thus, the forecast warns of a possible threat of making it impossible to cultivate technical grapes in traditional Mediterranean regions, for example: in the south of Spain, the islands and coasts of Italy and the coasts of Greece. On the contrary, most regions of the northern and central part of Europe will become suitable for the cultivation of early-ripening Vitis vinifera grape varieties [13].

The estimated forecast indicates that most of the modern wine-growing regions of Europe will receive 8–32% less precipitation in 2046–2070, while evaporation will increase by 6–24%. At the same time, the water balance will decrease by 40–160 mm [13].

According to the research results [13], two main parameters in the conditions of climate change are highlighted: temperature and precipitation. Climatic changes, in addition to changing the geographical distribution of wine-growing regions, threaten to change the typicality of wines. Accordingly, it is noted that climate change will require the implementation of timely, appropriate and cost-effective adaptation strategies, which must also be carefully planned and adapted to local conditions for effective risk reduction [14].

According to the International Organization of Vine and Wine, the wine-growing regions cover 7.4 million hectares, valued at US$35 billion in 2018. Important regions (Italy, France, Spain, USA, Argentina, Australia, South Africa, Chile, Germany, China, Argentina) are located in areas where the average annual temperature ranges from approximately 10°C to 20°C. It is emphasized here that temperature is the main factor in the development of grapes. Recent warming trends have accelerated flowering, ripening and harvest (with high confidence estimates), and wine-growing regions have moved beyond normal temperature limits for local varieties (with limited evidence, with high agreement). Milder winters affected yields in icewine grape growing regions. Higher temperatures have a mixed effect depending on the location, but generally reduce the quality of the grapes. Heating increases the accumulation of sugar and reduces acidity. Secondary metabolites are negatively affected. Developmental phases are predicted to proceed faster in response to warming (with high confidence). However, extremely high temperatures can also inhibit development [12].

According to the authors [15], if during the ripening period of grapes the temperature is kept up to +20˚C, then sugars are spent on plant respiration, if the temperature is from +20 to +30˚C - malic acid is consumed, if it is above +30˚C – tartaric acid. Therefore, if the weather is hot during the ripening period of grapes, their juice contains low acidity.

The observed warming of the climate is already causing new phenomena associated with changes in the speed of development (premature phenological events, shortening of phenological intervals, lengthening of the growing season, earlier harvesting), changes in product quality (sugar-alcohol content, phenolic ripeness, pH and acid content), a heterogeneous effect on the yield of the vine and the emergence of new viticultural areas with a cool climate, which indicates the revival of cultivation in the northern and central parts of the continent. The vulnerability of the viticultural ecosystem prompts the integration of innovative and sustainable solutions to counter the effects of climate change and preserve the productive (quantitative and qualitative) capacity of viticultural systems in Europe in a constantly changing environment. Winemakers report incomplete phenolic ripening and a mismatch between high sugar content and reduced acidity in the berries, resulting in high alcohol content in wines [16].

Another study notes that among the most important effects associated with climate change are earlier harvest times and temperatures, increased concentration of grape sugar leading to higher alcohol levels in wine, reduced acidity and modification of varietal aromatic compounds. At extremely high temperatures, already experienced in some regions, grape metabolism can be inhibited, leading to reduced accumulation of metabolites, which can affect the aroma and color of the wine. Wort with a high sugar content causes a stress reaction in the yeast, leading to an increase in the production of fermentation byproducts such as acetic acid. If not controlled by acid addition, higher pH can lead to significant changes in the microbial ecology of must and wine and increase the risk of spoilage and organoleptic degradation [17].

In regions where low temperature is a limiting factor, warming will allow producers to grow a wider range of varieties and produce better wines (with high authenticity). Subtropical and Mediterranean regions experience a significant decline in grape quality for high-quality (high-authentic) wines. These changes will also affect wine tourism [12].

Similar conclusions were found in another study [18]. Global warming will cause grape growing to move to northern Europe and places along the Canada-US border. Scientists from the Earth Institute at Columbia University (USA) came to the conclusion that in the case of a 2°C increase in air temperature, the regions suitable for growing grapes may decrease by 56%. And with a warming of 4°C, 85% of the existing areas will not be able to produce high-quality grapes. However, it will be possible to significantly reduce losses from global warming by replacing grape varieties with others more suitable for the new climate. Under such conditions, with a warming of 2°C, losses will amount to only 24%, and if the temperature rises by 4°C, then 58% [19].

Using fine-resolution predictions of future climate scenarios for south-west England and grapevine phenological models, it has been found [20] that the UK and many other cool climate regions will benefit from increased heat availability to grow grapes. However, the risk of late spring frosts coinciding with flowering increases under many future climate scenarios.

Denmark (south point 54˚ north latitude) in 2000 was officially recognized by the European Union as a wine-producing country. The Danish Winemakers' Guild currently has 700 members. In 2006, a record production of 50,000 bottles of wine was recorded. Danish winemakers have already laid the foundation for quality production by dividing the vineyards into four regional controlled appellations, officially recognized by the European Union in 2005 [21].

However, some studies emphasize that it is difficult to establish strict temperature thresholds for the optimal composition of berries and wine quality. Two of the world's top wine regions, Napa and Bordeaux, are warming at an extraordinary rate, and their warming patterns mirror the global changes seen in other Earth systems over the same period. For example, a past study using data up to 1999 predicted an optimum average growing season temperature of 17.3°C for Bordeaux. However, Bordeaux overcame this barrier more than ten years ago. Grape parameters, such as sugar-phenolic dynamics presented in the study and/or specific secondary metabolites (e.g., kaempferol), may be better indicators of warming-related grape quality losses. In Napa and Bordeaux, viticulture has successfully adapted to drastic climate changes, but grape indicators raise concerns that we are approaching a tipping point [22].

The study indicates that extreme heat can have a very strong effect on the yield of grapes. However, these effects are highly dependent on the dates of onset and duration of heat waves. The greatest negative impact could lead to a decrease in yield of up to −35% in some regions. The results show that regions with peak vulnerability on August 1 are more negatively affected than other regions. In addition, the geographic representation of yield reduction indicates a latitudinal gradient of heat wave effects, indicating stronger reductions in cooler regions of Central Europe than in warmer regions of Southern Europe [23].

At the 14th international congress on terroir, the issue of the importance of the aromatic maturity of grapes in the conditions of future climate change was raised. It is noted that aromatic maturity is perhaps the most important of the four in determining the quality and typicity of a wine, including terroir, that is, the identifiable taste of a wine in relation to its origin. Optimal terroir expression can be achieved when technological, phenolic and aromatic maturity are reached simultaneously or within a short period of time. This is possible when ripening takes place at moderate temperatures, not too cool and not too hot. The expressiveness of the aroma in the wine can be controlled, in order from low to high ripeness, green, herbal, spicy, floral, fresh fruit. aromas of ripe fruit, jam, dried fruit, candied fruit or cooked fruit. Aromas of green and cooked fruit are undesirable in red wines, while the level of other aromatic nuances contributes to the typicality of the wine in relation to its place of origin. Wines produced in cool climates or on cool soils in temperate climates are likely to exhibit herbal or fresh fruit aromas, while wines produced in warm climates or on warm soils in temperate climates may express ripe fruit, fruit jam or candied fruit . Overly green aromas (such as tomato leaves, freshly cut grass) are not desirable for red wines, nor are overly ripe aromas (such as cooked fruit or oxidizing nuances of prunes). Between these extremes, aroma nuances ranging from herbal, spicy, floral, fruity to jammy create the typicality of the aroma and give the wine an identity related to its place of origin. Markers of aromatic maturity in grapes for red wines are still insufficient, especially related to the aroma of cooked fruits [24].

In addition to temperature in the conditions of climate change, water plays an important role in ripening grapes. In some cases, irrigation is required, and more frequent droughts are a key problem for grape yield and quality. Water stress reduces the growth of shoots and the size of berries, and also increases the content of tannins and anthocyanins. However, a controlled lack of water has a positive effect on the quality of the wine, increasing the phenolic compounds of the skin. The level of stress will depend on the soil type, texture and organic matter content. Increased water demands with potential negative consequences from increased soil salinity are among the most common effects of climate change in irrigated regions (with moderate evidence and high agreement) [12].

The impact of changing water regimes on the geography of production and quality of dry red table wines.

The estimated water deficit (the difference between the amount of evaporation and precipitation) during the flowering period affected the yield of grapes. This value increased due to a decrease in precipitation and an increase in evapotranspiration. Productivity can decrease by 30 kg/ha for every millimeter increase in the estimated water deficit [25].

A possible relationship between water and nitrogen regimes measured in the vineyard and the aromatic compounds responsible for the aging bouquet of red wines was sought in a study of Bordeaux wines. The wines were produced in the Bordeaux region and aged for 10 to 20 years. The level of aromatic compounds such as tabanones and dimethyl sulphide was found to depend on the availability of water and nitrogen to the vines. The composition of residual nitrogen in the wines also corresponded to the nitrogen status in the vines and indicates the presence of aromatic precursors and microbiological instability [26].

Additive effects (i.e., no interaction) between temperature and water were found for berry mass and berry composition (titrated acidity and pH), grape phenolic substances (extracted with 12.5% ethanol and most of those extracted with 70% acetone), phenolic substances in wine and sensory properties of wine (floral aroma and berry taste). Importantly, previously unreported interactions between temperature and water were found for grape phenolics (70% acetone-extracted skin and seed tannins and total phenolics per berry), wine phenolics (color density, tannins, and phenolics) and sensory properties. wines (floral aromas, flavors of cooked fruits and tannic structure). As a conclusion, the effect of water deficit, which leads to colorful and aromatic wines rich in phenolic substances, cannot be sustained at high temperature for Shiraz [27].

The impact of changes in carbon dioxide content on the geography of production and quality of dry red table wines.

Under conditions of climate change, the content of carbon dioxide (CO_2) in the atmosphere is increasing. Increased atmospheric CO_2 will have mixed effects on grapevine growth and quality (moderate evidence, high agreement). An increase in the concentration of CO_2 will negatively affect the quality of wine due to a decrease in the concentration of anthocyanins and the intensity of color [12].

An increase in topsoil temperature is another result of climate change that will affect the distribution of microbial populations, the rate of decomposition of organic matter, or the ability to store organic carbon in soil. All of this affects greenhouse gas emissions and water viscosity in the soil-plant pathway, changing water transport. Interactions between microorganisms in the rhizosphere, the grapevine root system, the processes of organic carbon degradation and fixation are complex and poorly understood, but they respond to environmental factors (such as increased soil temperature), plant material (e.g. rootstock) and cultivation system (e.g. , organic versus traditional, use of cover crops versus open tillage) [28].

Another study investigated the effect on fruit composition of a modest increase (+20%; CO_2) in carbon dioxide concentration, as projected for 2050, in Cabernet Sauvignon. Growth, ripening dynamics and composition of berries were determined, primary (sugars, organic acids, amino acids) and secondary metabolites (anthocyanins) were analyzed. Compared to previous results from the early phase of vineyard adaptation, the results show little effect of CO_2 treatment on the composition of primary metabolites in berries. However, the total anthocyanin concentration in the berry skin was lower for the CO_2 treatment in the hot and dry season of 2020, although the ratio between anthocyanin derivatives did not differ [29].

The impact of changes in ultraviolet radiation on the geography of production and quality of dry red table wines.

The role of light and temperature in the accumulation of the plant compound 2-methoxy-3-isobutylpyrazine (MIBP) in grape berries (Vitis vinifera L.) was determined. The concentration of MIBP in berries increases after berry setting, reaches a maximum before the onset of ripening, and then decreases until harvest. The results show that both light and temperature significantly affect MIBP in harvested grapes, but light during ripening does not significantly affect MIBP concentration in berries at harvest [30].

Because the chemical and sensory characteristics of wines are related to the geographical origin of the grapes as a result of the interaction between the plant material, its acclimatization to the environment and the human factor that affects both the vineyard and the winery. This study evaluated the independent and interactive effects of Cabernet Sauvignon plant materials implanted in different geographical indications of Mendoza, Argentina, on yield and phenolic profiles of wines. Grapes were harvested at 24 °Brix, analyzed and wines were produced according to a standardized protocol. Anthocyanin and non-anthocyanin phenolic profiles of wines were determined using high-performance liquid chromatography with a diode array and fluorescence detection. Increased amounts of anthocyanins, quercetin, and trans-resveratrol have been associated with increased exposure to ultraviolet radiation radiation in plants at high altitudes [31].

Adaptation strategies for grape growing in the conditions of climate change.

In the conditions of climate change, the influence on the suitability for obtaining quality grapes can change the geographical distribution of wine-growing regions. The viability of wine-growing regions will depend on the knowledge of local climatic variability and the implementation of adaptation strategies, such as the use of adapted plant rootstocks, varieties and clones, viticultural techniques (for example, changing the height of the trunk, leaf area to the ratio of fruit weight, pruning time), irrigation, technological interventions for control of alcohol and acidity, as well as political incentives and support of states [12].

Grape growers are among the fastest responders to climate change, as their crops are extremely sensitive to weather and climate change. Creating a vineyard takes a long time - up to five years, until the vines give a full harvest. Producers have to orient themselves to farming in the medium to long term, taking into account climate change projections and market trends a decade or more ahead. Successful managers recognize the need for harmonious cooperation to achieve positive results [32].

Viticulture is susceptible and vulnerable to extreme weather and climate changes. In Europe, due to the high socio-economic value of the wine sector, the development of adaptation strategies to mitigate the effects of climate change will be of paramount importance for its future sustainability and competitiveness. Some short-term adaptation strategies collected by the Clim4Vitis project:

1. Adapted vine crown management;
2. Application of sunscreen materials;
3. Additional watering;
4. Soil management;
5. Pest and disease control [33].

Long-term adaptation strategies adapted to local terroirs and regional climate change forecasts will contribute to the sustainable development of the wine sector. They include:

1. Changes in vine formation systems;
2. Clonal selection of scion-rootstock;
3. Choice of variety;
4. Moving the location of the vineyard [34].

The most radical and premature way of adapting to climate change conditions is to change grape varieties. Thus, wine producers in Australia are recommended to pay attention to the potential of new grape varieties on the market and the possible need to increase the future cultivation of these varieties. Such a move will help preserve a more sustainable wine industry in the future. Among them are Touriga Nacional and Nero d'Avola, which have been compared with traditional Cabernet Sauvignon, Grenache and Shiraz [34].

One of the proposed methods of short-term influence is the opening of shoots and other ways of caring for the vine in the summer. They are considered key to the production of high-quality wine. Overall, Cabernet Franc treatments that did not use secondary shoot removal and/or shoot removal resulted in greater canopy area, increased wood and leaf pruning layers, and had greater Fv/Fm on warm days compared to pruned shoots. This was due to a year-dependent modulation of wort quality parameters, in which the long shoot treatment generally produced the highest polyphenol and anthocyanin content and wort acidity. The data indicate the potential expediency of maintaining dense crowns under conditions of high temperature and high light with a desirable effect on leaf photosynthesis and wort quality when combining long shoots was used [35].

Increasing organic carbon stocks is proposed as a mitigation measure for soil GHG emissions with the potential to improve the balance between GHG emissions and carbon removal from the atmosphere. It was shown that the preservation of cut wood and the use of a full cover crop led to an increase in organic carbon by 16.2 t C / ha over time. However, CO_2 emissions over the simulated time period were only slightly smaller than soil C accumulation. It is concluded that cover crops in vineyards help to achieve CO_2-neutrality, but additional measures are needed to make vineyards significant sinks of C [27].

The adaptation of dry red table wine technology in the conditions of climate change.

It is significant that as part of the development of its strategic plan, the International Organization of Vine and Wine annually provides scholarships for research in priority areas of the program [36]. Priority topics for research grants in 2022 include sustainable management and climate change adaptation. Including those related to technology:

1. Research of products and by-products of yeast other than Saccharomyces;
2. Management of instability of wine (instability of Ca^{2+}, mannoproteins);
3. Reduction of sulfur dioxide at the technological and microbiological levels ("wines with minimal intervention", wines without the addition of SO_2").

In conditions of insufficient amount of anthocyanins and tannins for Pinot Noir wines, the self-flowing wort ("saignée") can be filtered with the help of nanofiltration, and then, in order to promote the diffusion of anthocyanins, the retentate fraction is immediately returned to the tank, and the permeate fraction is returned at different densities during alcoholic fermentation. This extraction strategy is promising as an alternative to thermovinification [37].

Studying the influence of different infusion techniques on phenolic compounds, macro- and microelements, and taste sensory properties of red wines is important in the context of climate change. Thus, the study of red wines from the Teran grape variety, produced using different infusion techniques, showed different effects on taste qualities and phenolic complex. The study included seven days of maceration as a control (TM7), an extended 10-day maceration (TM10), an extended post-fermentation 21-day maceration (TM21), and a 48-hour pre-fermentative maceration at 45 °C followed by an eight-day standard maceration (TPHT). Phenolic compounds were analyzed using high performance liquid chromatography with UV-Vis diode matrix and fluorescence detection. Analysis of macro- and microelements was carried out by optical emission spectrometry with inductively coupled plasma. Sensory profiles of wine samples were obtained using quantitative descriptive analysis and 100-point evaluation according to the method of the International Organization of Vine and Wine. The results showed a significant increase of 25% in the total content of flavan-3-ols in TM21 wine. Concentrations of hydroxybenzoic acids increased significantly after TM21 and TPHT treatment, while individual hydroxycinnamic acids showed significant increases after TPHT treatment. The obtained results showed a difference in the content of macro- and microelements, and TM21 and TPHT wines had significantly higher values of individual elements. The results of the sensory analysis largely corresponded to the chemical composition of the wines. The results showed that TM21 and TPHT treatments have a positive effect on the taste properties of the studied wines [38].

The increased sugar content in grapes affects the production of wines with a high alcohol content. In such conditions, the study of the impact of dealcoholization of wines by reverse osmosis and rotating conical columns on the sensory characteristics of the final product is relevant. Reverse osmosis and rotating conical columns are promising methods for reducing the alcohol content of wines. Most wineries are only interested in reducing the ethanol content by one or two degrees of alcohol to produce more balanced wines. However, new consumption habits and alcohol safety laws have encouraged the wine industry to produce new beverages from alcohol-free or low-alcohol wines [39].

The complexity of the wine's aroma is mainly influenced by the interaction between the grapes and the fermentation agents. This interaction is very complex and depends on many factors, such as varieties, degree of grape ripeness, climate, processing techniques, chemical and physical characteristics of the must, yeasts used in the fermentation process and their interaction with the endogenous grape microbiota, process parameters (including new non-thermal technologies), malolactic fermentation (optional) and phenomena occurring during aging. However, the role of yeast in the formation of aromatic compounds is generally recognized. In fact, yeast (as starters or natural microbiota) can contribute both to the formation of compounds derived from primary metabolism, the synthesis of specific metabolites, and the modification of molecules present in the wort. Among the secondary metabolites, esters, higher alcohols, volatile phenols, sulfur molecules and carbonyl compounds play a key role. In addition, some specific yeast fermentation activities, primarily associated with species other than Saccharomyces , may contribute to the wine's sensory profile through the release of volatile terpenes or other molecules. The study highlighted the main aromatic compounds produced by Saccharomyces cerevisiae and other yeasts of oenological interest due to process conditions, new non-thermal technologies and microbial interactions [40].

The majority of grape juice fermentation is carried out by the yeast Saccharomyces cerevisiae, but non-Saccharomyces yeasts can modulate many sensory aspects of the final products in obscure ways. In this study, some of these non-conventional yeasts were tested as mixed in a specific growth medium in both simultaneous and sequential inoculation. One strain of Starmerella bacillari and another strain of Zygosaccharomyces bailii were selected for their distinct phenotypic signature and ability to reduce ethanol levels at the end of fermentation. S. bacillaris greatly loses viability at the end of the mixed fermentation, while Z. bailii remains viable. S. bacillaris induces the translation machinery and inhibits vesicular transport. Both non-Saccharomyces yeast strains induce S. cerevisiae glycolytic genes, and this may be related to ethanol reduction, but some aspects of the carbon-related mechanisms are strain-specific. The presence of Z. bailii increases the stress-related polysaccharides trehalose and glycogen, while S. bacillaris induces gluconeogenesis genes [41].

Another study suggested the use of non-Saccharomyces yeasts to reduce alcohol content in winemaking. In this study, 23 non-Saccharomyces yeast strains were tested on a laboratory scale using pre-frozen grape must. Both aerated and standard fermentation conditions were investigated and the fermentation was co-inoculated with a commercial standard yeast strain Saccharomyces cerevisiae. Sugar consumed for percent alcohol produced was calculated from sugar and alcohol measurements. Non-Saccharomyces yeasts showed greater variability in sugar consumption compared to the reference yeast S. cerevisiae. Two yeast strains (Starmerella bacillaris and Wickerhamomyces anomalus) consumed more sugar than the reference yeast S. cerevisiae under the same conditions. These two strains were subsequently used in small-scale wine production trials following a similar aeration and standard fermentation strategy. Wine production trials using aeration compared to the standard strategy showed shorter fermentation times, increased biomass production, more sugar used to produce alcohol, but reduced wine quality. The same yeast under standard fermentation conditions also showed an increase in sugar utilization, but a neutral or positive effect on wine quality. The S. bacillaris strain showed the greatest potential for use in winemaking to reduce alcohol content [42].

Off-flavors caused by unwanted microbial spoilage are a major problem in wineries because they affect wine quality. This situation is worse in warmer regions affected by climate change due to the higher pH in wines. Natural biotechnologies can help effectively control these processes while reducing the use of chemical preservatives such as SO2. Biological acidification reduces the growth of spoilage yeasts and bacteria, but also increases the amount of molecular SO2, allowing for lower overall levels. The use of non-Saccharomyces yeasts such as Lachancea thermotolerans results in efficient acidification by producing lactic acid from sugars. In addition, high lactic acid content (>4 g/l) suppresses lactic acid bacteria and has some effect on Brettanomyces. In addition, the use of yeasts with hydroxycinnamate decarboxylase activity may be useful in promoting the enzymatic formation of stable vinylphenolic pyranoanthocyanins, reducing the amount of ethylphenol precursors. This biotechnology increases the amount of stable pigments and at the same time prevents the formation of a high content of ethylphenols, even if the wine is contaminated with Brettanomyces [43].

For red wines, an important stage is the determination of the fermentation and malolactic fermentation protocol. For joint inoculation of fermentation and subsequent malolactic fermentation, the following was established in the study:

1. Use of T. delbrueckii promoted malolactic fermentation in red wine with high polyphenol content.
2. The concentration of medium-chain fatty acids was lower in T. delbrueckii wines.
3. Higher concentrations of polyphenols were observed in T. delbrueckii wines.

The use of Torulaspora delbrueckii for alcoholic fermentation is a current trend for improving the quality of red wines. Since the production of red wine usually requires a subsequent malolactic fermentation, the compatibility of this yeast and Oenococcus oeni is a key factor for a successful fermentation process. In this work, the interaction of T. delbrueckii and O. oeni in wines from grapes of different degrees of maturity was studied. The results showed higher values of the total polyphenolic index in T. delbrueckii wines. In addition, the aromatic characteristics of these wines were improved compared to wines inoculated with Saccharomyces cerevisiae alone. A decrease in some inhibitory compounds for O. oeni, such as medium-chain fatty acids, was also observed as a result of fermentation by this non-saccharomycete. In general, the use of T. delbrueckii showed better indicators of malolactic fermentation [44].

Another study determined the following effect of the same yeast:

1. T. delbrueckii occupies a niche as a biodefense, unlike S. cerevisiae.

2. The dosage of non-saccharomycetes significantly affects the chemical composition of red wine.

3. Effect of bioprotection on the chemical and aromatic profile of red wine under conditions of low SO_2 content.

Yeasts other than Saccharomyces have been used for many years for their technological potential, particularly as an "enhancer" of fruity wine aromas in co-fermentation with Saccharomyces cerevisiae. A new application has recently emerged, bioprotection, which consists of environmental colonization in the context of sulfite reduction in wines. The chemical and sensory effects of yeasts other than Saccharomyces according to different application methods in the context of fermentation without the addition of SO2 were evaluated by testing with Merlot N. (Vitis vinifera L.). Efficient niche occupation by yeasts other than Saccharomyces was highlighted during the predominant stages by quantitative PCR and MALDI-TOF MS identification. Chemical analysis (GC-MS and GC-MS/MS) of the finished wine showed a significant dose application effect, with bioprotection characterized by linear esters and sequential application of high-alcohol acetates. In addition, a division by species used in bioprotection was revealed. Finally, sensory analysis by a trained panel confirmed that the use of yeast other than Saccharomyces was a fruit enhancer in sequential inoculation and, to a lesser extent, in biodefense use. This study shows for the first time that the use of non-saccharomycete yeast as a bioprotection has a significant effect on the aroma profile of wines [45].

Since wine is one of the oldest products where microbiological processes significantly affect the overall quality of the product, malolactic fermentation is an important technological step in the production of red wines. Lactic acid bacteria – mainly Oenococcus oeni – induce malolactic fermentation and decarboxylation of L-malic acid into L-lactic acid, resulting in a milder taste to the wine. In addition, this process provides biological stability and improves the final aroma of wines by modifying fruit aromas and producing aromatic compounds. Glycoside compounds make up the stock of powerful odor-active compounds, which are mainly present in grapes in the form of β-D-glucosides, since monoterpenes, C13-norisoprenoids and benzene derivatives often dominate the composition of the aglycon. O. oeni strains, well adapted to perform malolactic fermentation, can represent a source of glycosidase enzymes capable of working in oenological conditions. In Argentine wines, O. oeni was the predominant bacterium, resulting in the isolation of 68% of the total number of lactic acid bacteria, which in high proportions showed notable levels of β-glucosidase activity; in whole cells at the end of exponential growth, in MRS medium adjusted to pH 4.8. A study of the effects of winemaking factors such as L-malic, citric acid and sulfur dioxide on the growth and β-glucosidase activity of six strains of O. oeni from Argentine wines at pH levels of 4.8 and 3.8 showed that they all grew up. in the studied conditions. Analysis of sugar and organic acid utilization profiles revealed interesting characteristics of these strains: 1) Glucose and organic acids are metabolized regardless of the medium composition and initial pH values; and 2) high levels of L-lactic acid are recovered by decarboxylation of L-malic acid, confirming their good malolactic potential. In addition, all strains showed β-glucosidase activity at initial pH values of 4.8 and 3.8, even if they were >4.8. Overall, L-malic and citric acids stimulate β-glucosidase activity, thus partially reversing the inhibition caused by acid stress. Using different cell fractions, the β-glucosidase activity of the studied O. oeni strains was associated with the cell surface. This fact is a consequence of the great interest in their potential technological application as a source of enzyme that could improve wine quality and aromatic complexity under winemaking conditions. When the influence of grape glycosides on the growth, malolactic fermentation and glycosidase activity of three selected strains of O. oeni was investigated in a wine-like environment, the obtained results showed that the process of malolactic fermentation contributes to the enhancement of taste in winemaking. In addition, natural glycosides had a positive effect on growth parameters, L-malic acid degradation rate, and glycosidase activity. These increases were correlated with significant changes in the volatile profile, mainly the formation of aromatic esters and to a lesser extent higher alcohols and other compounds, indicating the presence of ester-synthesizing enzymes in O. oeni strains, which, in combination with glycosidic activity, may play an important role role in improving wine quality. Therefore, O. oeni prevails as a candidate for malolactic fermentation due to its growth ability, production of non-biogenic amines, malolactic potential and glycosidic activity. Thus, the obtained results contribute to the potential use of selected strains as an effective tool for enhancing the complexity of wine aroma during malolactic fermentation [46].

The study of the influence of the structural features of carboxymethylcellulose on the effectiveness of preventing the precipitation of potassium hydrotartrate in red wines shows the influence on the phenolic composition, chromatic characteristics and color stability. The degree of substitution of carboxymethyl cellulose was important for its effectiveness in highly volatile wines. The use of carboxymethyl cellulose does not lead to a significant change in the phenolic, monomeric anthocyanin composition, color intensity and chromatic characteristics of red wines. Sensory analysis also showed that carboxymethyl cellulose had no significant effect on the sensory properties of the wine. Carboxymethylcellulose does not reduce color fastness. The use of turbidity to assess color stability in wines has serious drawbacks because the measured turbidity value may not be related to the amount of suspended material. Thus, the use of carboxymethyl cellulose in red wines is effective in increasing tartar stability without affecting phenolic composition, sensory characteristics, and color stability. Carboxymethyl cellulose does not alter tartaric acid, phenolic compounds and sensory profile in red wines [47].

Aging is important for improving the quality of wine, especially for red wine and special types of wine. High-quality wines are traditionally produced by aging them in oak barrels, some special wines are also produced by aging on lees, temperature aging, biological aging, etc. They are very time-consuming and expensive, which seriously affects the production capacity and economy, the advantages of winemaking enterprises. The research first examined the principles and changes in the aging process of oak and other traditional aging methods, and analyzed the improvement of the aging effect and the influencing factors of modern technologies that can simulate aging in oak, such as micro-oxygenation, oak products, bonding technology, etc. The use of artificial aging technology to reduce aging time, improve wine quality, and reduce production costs and meet market demand has become an inevitable trend. However, unclear reaction principles and process variation and unstable quality limit the commercialization of artificial aging technology. Therefore, promising future research is identified as needed to further refine, regulate and optimize artificial aging technologies that perfectly mimic the traditional barrel aging environment to truly promote application in the wine industry Artificial aging has been identified to shorten aging time and reduce production costs, traditional methods aging is still difficult to replace, methods of artificial aging and regulation of aging are the basis of industrialization and need to be refined [48].

In continuation, a pilot-scale study of accelerated aging of Tempranillo red wine using the combined application of ultrasound, micro-oxygenation and shavings of different types of oak (American, French and Spanish) determined the phenolic and volatile content of the aged samples and their sensory profiles. Wine samples aged with micro-oxygenation, French or American oak chips and ultrasound were found to have similar polyphenol content to those aged without this latter acceleration technique. Holding time with high extraction kinetics was the most significant variable for polyphenol content. In terms of volatiles, wine samples from Spanish and French oak wood showed a similar behavior closely related to aging time, while American oak wood reached a rather low enrichment of volatile components, resulting in a poor sensory profile of the final wines, which was particularly bad, in the case of wines aged by ultrasound. Low impact of ultrasound on polyphenolic and volatile compounds was also determined [49].

Another promising direction is defined in the study of the effect of high hydrostatic pressure (HHP) treatment on the composition of phenolic compounds of red wine after storage. Red wines under pressure of 500 and 600 MPa at 20 °C for 5 and 20 minutes, respectively, showed a lower content of monomeric anthocyanins (13–14%), phenolic acids (8–11%) and flavonols (14–19%).) after 5 months of storage compared to wine without pressure. These results, together with the different degrees of tannin polymerization and flavan-3-ol content in wines under pressure, suggested the influence of high hydrostatic pressure on the increase of polymerization reactions and cleavage of proanthocyanidins. Sensory analysis of pressurized wines showed lower astringency, higher intensity of fruit aroma and lower intensity of fruity notes compared to non-pressurized wine. These effects are related to effects observed during wine aging [50].

In addition to directly researching ways to preserve the typicality of red table dry wines in conditions of climate change, it is necessary to pay attention to a possible change in consumer preferences. Thus, from the point of view of a young consumer [51], the most important characteristics of red table dry wines are: taste and aroma, prices and protected designation of origin of wines, lower ratio of phenolic compounds/polysaccharides, floral aromas (β-phenylethanol and β-damascenone), benzenoids are positively correlated with negative emotions.

Because tartness assessment is an important quality management tool in red wine production. The content of tannins is one of the most important parameters affecting astringency and poor dryness. Polyphenol content and color index are also positively correlated with tartness perception. Tannin concentration affects the performance of analytical methods as estimators of wine astringency. Principal component analysis showed that tannin content was the most important parameter affecting overall astringency and dryness, followed by polyphenol content, color index and, to a lesser extent, pH and alcohol content. Given that astringency is a structural sensation caused by the interaction between salivary proteins and tannins, a comparison was made between two tannin precipitation assays (i.e., methylcellulose and Harbertson-Adams assay) to assess their ability to evaluate red wine, i.e., astringency. The results of sensory correlations showed that methyl cellulose and the Harbertson-Adams analysis have different behavior regarding the intensity of astringency and dryness, mainly under the influence of tannin concentration. The Harbertson-Adams analysis showed a sigmoidal behavior with a better predictive performance for astringency in the range of low and medium tannin concentrations, while methyl cellulose showed a linear behavior with better performance in the range of high tannin concentrations [52].

Conclusion

The analysis of the current research and publication has highlited trends according to the objectives:

The current state in red wine production and demand for red table dry wines is stable according to Annual reports of the International Organization of Vine and Wine and data from the State Statistics Service of Ukraine. At the same time climate change is noted as one of the main factors in the annual variation of the total volume of wine produced in the world.

The impact of temperature changes has been shown by the increase in average annual temperature compared to the pre-industrial period from 0.8 to 1.2°C. It is predicted that the temperature will increase and the amount of precipitation will decrease during the growing season of the grape vine. Due to the impact of climate change, those regions that are currently considered cool will become suitable for growing grapes. In addition, the typicality of wines from traditional regions may be lost. Since temperature is the main indicator of climate change, acceleration of ripening leads to the accumulation of high sugar content, high pH, low acidity, modification of varietal aromatic compounds, changes in the timing of phenolic ripening and overall yield reduction. The effect of increasing temperature on the aromatic profile of red table dry wines will require further study, as the available studies are few.

The impact of changing water regimes, such as water stress, which is observed under conditions of climate change, contributes to an increase in the content of tannins and anthocyanins, negatively affects the productivity of red technical grape varieties.

The increased content of carbon dioxide leads to a decrease in the concentration of anthocyanins and the intensity of color. The effect of carbon dioxide on the accumulation of anthocyanins in grapes requires further study, as some authors note the possibility of a correlation with elevated temperatures and water deficit.

With increased exposure to ultraviolet radiation, the accumulation of a greater amount of anthocyanins, quercetin and trans-resveratrol has been established.

Adaptation strategies for grape growing in the conditions of climate change are determining by the short-term and long-term in order to obtain high quality grapes.

Regarding the adaptation of dry red table wine technology ways to minimize the impact of climate change on the quality characteristics of wine are strategic directions of research by the International Organization of Vine and Wine. Reducing the alcohol content and the impact of this process on the organoleptic characteristics of wines is one of the most important issues in the context of the impact of climate change on the physicochemical and organoleptic characteristics of wines. Many publications point to an increase in temperature during the growing season of the grapevine as the main factor influencing climate change, which leads to the accumulation of more sugars and, as a result, higher alcohol content in wines. Selection of duration and technique of infusion affects organoleptic characteristics and phenolic complex. The use of non-Saccharomyces yeasts to mitigate the effects of climate change on the characteristics of finished wine is a promising direction for further research. Current publications note their positive impact on reducing alcohol content, forming organoleptic characteristics and the phenolic complex. The choice of preparations for processing red wines affects the phenolic composition and color stability. The research of different aging techniques of red table dry wines are promising directions for identifying the influence on the phenolic complex and organoleptic characteristics. Traditional methods of aging in oak containers are still preferred, but alternative techniques are noted for the speed and economy of the process. Research into the possibility of reducing the impact of climate change on the physico-chemical and organoleptic parameters of red table dry wines should be conducted in parallel with research into changes in consumer preferences. In addition to the need to preserve the typical physico-chemical and organoleptic characteristics of red table dry wines, some studies emphasize the need to adapt to changing consumer needs.

Thus, the improvement of the technology of red table dry wines in the conditions of climate change in order to preserve the quality and typicality of styles in accordance with the peculiarities of the production area can be carried out by researching the taste preferences of consumers, improving the processing processes at the stages of wort clarification, fermentation, malolactic fermentation, stabilization and aging.

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АКТУАЛЬНІ ПРОБЛЕМИ ТЕХНОЛОГІЇ ЧЕРВОНИХ СТОЛОВИХ СУХИХ ВИН В УМОВАХ ЗМІНИ КЛІМАТУ

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Анотація. Виробництво та попит на червоні столові сухі вина стабільний. Зміна клімату один із основних факторів щорічного варіювання загального обсягу виготовленого вина у світі. Мінімізація впливу зміни клімату на якісні характеристики вина зазначаються стратегічним напрямком досліджень в OIV. Ця робота присвячена літературному огляду актуальних проблем технології червоних столових сухих вин в умовах зміни клімату за останні 10 років. Встановлено, що зростання середньорічної температури у порівнянні з доіндустріальним періодом становить від 0,8 до 1,2°C. Крім того, прогнозується зниження кількості опадів під час вегетаційного періоду виноградної лози. Для вирощування винограду стануть придатними ті регіони, які наразі вважаються прохолодними. Таким чином, можлива втрата типовості вин з традиційних виноробних регіонів. Пришвидшення визрівання призводить до накопичення високого вмісту цукрів, високого pH, низької кислотності, модифікації сортових ароматичних сполук, зміни термінів фенольного визрівання та загального зниження врожайності. Водний стрес сприяє підвищенню вмісту танінів та антоціанів, негативно впливає на урожайність. Підвищення вмісту вуглекислого газу призводить до зниження концентрації антоціанів та інтенсивності кольору. Вплив ультрафіолетового випромінювання сприяє накопиченню більшої кількості антоціанів, кверцетину та транс-ресвератролу. Короткострокові та довгострокові стратегії адаптації до умов зміни клімату імплементовані для отримання винограду високої якості. Найважливіший аспект – зниження вмісту алкоголю. Різні техніки настоювання м'язги впливають на органолептичні характеристики та фенольний комплекс. Перспективним є використання дріжджів не Saccharomyces для зниження вмісту алкоголю і формування органолептичних характеристик та фенольного комплексу. Вибір препаратів для обробки впливає на фенольний склад та стабільність кольору. Техніки витримки впливають на фенольний комплекс та органолептичні характеристики. Актуальні проблеми технології орієнтовані на збереження якості та типовості стилів вин і водночас враховують зміну смакових уподобань споживачів.

Ключові слова: червоне вино, зміни клімату, дріжджі, фенольний комплекс, антоціани.