

This study examines wine samples made from introduced grape varieties grown on the Absheron Peninsula. The influence of the specific marine terroir on the ripening processes of introduced grape varieties and the formation of their biochemical composition remains poorly understood under the conditions of the Absheron Peninsula. Systematic data on the sugar-acid balance, phenolic complex, and technological parameters of wines produced from these varieties under local conditions are lacking.

Therefore, a comprehensive assessment of the ripening dynamics of grape varieties cultivated in the terroir of the Absheron Peninsula was conducted; the quality parameters of wines produced from these varieties were examined. Parameters such as mass concentration of sugars, titratable acidity, and pH were determined in the grape berries. Wine samples were analyzed for ethanol by volume, residual sugar, titratable and volatile acids, extract, total and free sulfur dioxide, total phenolic compounds, anthocyanins, and tannins.

Marine factors, which shape the specific terroir, have a significant impact on the biochemical composition of grapes and the quality of wine. The highest mass concentration of sugars was found for Cabernet Sauvignon (23.2 g/100 cm³), while the highest titratable acidity was noted in Rkatsiteli (4.8 g/L). The interaction of topography, sea winds, solar radiation, and temperature played a key role in shaping the sugar-acid balance of grapes. The marine terroir creates favorable environmental conditions for the production of high-quality, competitive industrial grapes, confirming the industry's potential for sustainable development in the region

Keywords: *Absheron Peninsula, terroir, grape varieties, grape ripening, wine, quality indicators*

INVESTIGATION OF PATTERNS ASSOCIATED WITH THE EFFECT OF SOIL AND CLIMATIC CONDITIONS AT THE ABSHERON PENINSULA ON THE QUALITY INDICATORS OF INTRODUCED GRAPE VARIETIES AND WINE SAMPLES PREPARED FROM THEM

Movlud Huseynov

Doctor of Philosophy in Technics, Associate Professor*

ORCID: <https://orcid.org/0000-0002-8774-3661>

Afet Gasimova

Corresponding author

Doctor of Philosophy in Technics, Associate Professor

Department of Food Engineering and Winemaking

Azerbaijan Technological University (ATU)

Shah Ismayil Khatai ave., 103, Ganja, Azerbaijan, AZ 2011

E-mail: a.qasimova@atu.edu.az

ORCID: <https://orcid.org/0000-0002-9814-4488>

Vugar Salimov

Doctor in Agrarian Sciences, Associate Professor, Director**

ORCID: <https://orcid.org/0000-0002-5041-6958>

Garay Mirzayev

Doctor in Biological Sciences, Associate Professor*

ORCID: <https://orcid.org/0000-0003-2827-4508>

Gultakin Gasimova

Doctor of Philosophy in Biology, Acting Assistant Professor

Department of Ecology and Nature Conservation

Ganja State University

Haydar Aliyev str., 429, Ganja, Azerbaijan, AZ 2001

ORCID: <https://orcid.org/0009-0001-2876-4155>

Umida Majnunlu**

Doctoral Student, Lecturer*

ORCID: <https://orcid.org/0000-0002-6251-2330>

*Department of Engineering and Applied Sciences

Azerbaijan State University of Economics (UNEC)

Istiglaliyyat str., 6, Baku, Azerbaijan, AZ1001

**Scientific-Research Institute of Viticulture and Winemaking

20 yanvar str., 16, Baku, Azerbaijan, AZ0118

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1. Introduction

Ensuring the development of viticulture and winemaking by enhancing the competitiveness of products made using

new technologies is one of the country's top economic priorities. Targeted measures taken in this direction have created favorable conditions for strengthening winemaking in Azerbaijan, including the revival of traditional wine-producing

regions to diversify the economy. The country's favorable soil and climate conditions and available labor force are conducive to the development of viticulture and winemaking. The ability to meet the processing industry's needs for raw materials through local production opens new prospects for the industry's further development. The presence of large export markets in the region and its significant export potential contribute to the further development of viticulture and winemaking.

Historically, winemaking has always made a significant contribution to the country's economic development and has been a leading sector. It is worth noting that, depending on the type of wine, it is rich in organic acids, phenolic substances, vitamins, minerals, and other nutrients essential for the human body. The main reason for this is the availability of healthy raw materials – grapes. Since grapes are the main raw material for winemaking, it is first necessary to know their chemical composition and the changes that can occur in them depending on the degree of ripeness and the soil and climatic conditions of growth.

It's a well-known fact that wine is made only from grapes. The influence of raw materials on the quality of the resulting wines is quite significant. Therefore, winemakers must have extensive knowledge of viticulture to produce high-quality wine. Physicochemical processes constantly occur in grapes and wine. Therefore, researchers have recently been devising winemaking technologies that allow for the production of high-quality wine.

The study of the resource potential of introduced grape varieties, which are adapted to different natural conditions, occupies a special place in the research of many authors. One such region is the Absheron Peninsula. This region is characterized by an arid climate and abundant sunny days. Strong winds and specific soil composition create favorable conditions for the development of the chemical composition of grapes and the resulting wine.

Introduced grape varieties are highly productive and resistant to stress factors. Their yield depends on their adaptation to local soil and climatic conditions and the successful implementation of biochemical processes during the ripening period. The technological and organoleptic properties of grapes and wine are determined by the composition of the raw materials. The chemical composition of raw materials includes sugars, organic acids, vitamins, phenolic compounds, as well as aromatic substances.

Research on the chemical composition of introduced grape varieties has been extensive enough. However, identifying patterns in the influence of soil and climatic conditions on grape ripening dynamics requires further investigation. After all, the quality of the resulting wine ultimately depends on the quality of the raw materials. Therefore, studying the qualitative properties of raw materials and finished products depending on terroir is a relevant task.

2. Literature review and problem statement

Paper [1] gives an overview of the observed phenological characteristics and trends of grapevines in different regions and for different varieties in France, Italy, Spain, Germany, and Slovakia. It is shown that associated climatic changes influenced the timing of phenological development. The results show a significantly earlier onset of phenological events (6–18 days) with shorter intervals between

them (4–14 days) in most regions. Warming trends are also observed in most regions, which clearly influenced these changes in the phenological cycle of grapevines in Europe. Changes are generally greater in minimum temperatures than in maximum temperatures, with an average warming of 1.7°C over the growing season and an increase of almost 300 degree-days or Hooglin index values over the past 50 years. However, despite general studies, how individual grapevine varieties respond to soil and climatic conditions, especially during adaptation, remains unknown. This may be due to objective difficulties. However, it's important to note that the study doesn't sufficiently consider varietal specificity. Grapes exhibit high genetic and phenotypic variability, so it's crucial to consider the response of varieties to climate change. Furthermore, averaging data across regions and varieties reduces the accuracy of the conclusions and limits their practical applicability to specific terroirs. The influence of soil factors is barely considered, while water retention capacity, structure, and mineral composition play a significant role in the development of phenological phases. Ignoring changes in temperature and precipitation patterns could lead to an overestimation of the role of climatic factors.

The authors of [2] demonstrate that, to optimally utilize the solar radiation of mountainous terrain and cool sea breezes, vineyards should be located on mountain slopes and near the sea, which will positively impact the diversity of varieties and their quality. The geographic location of vineyards, including altitude, proximity to water bodies, and the mineral composition of the soil, is considered one of the main factors directly affecting wine quality. The sea, by slowly absorbing and releasing heat, creates a climate with relatively cool summers and mild winters. In areas near water bodies, sharp nighttime fluctuations are softened, and the climate is more stable. Referring to the work, the concept of terroir, widely used in viticulture and winemaking, can be represented as a comprehensive definition that includes geographic location, climatic conditions, soil properties, and cultivation methods. However, such important components as agricultural practices, rootstock selection, crown management methods, and winemaking technologies, without which the aspect of terroir is not fully revealed, are missing. Furthermore, the influence of soil factors is mentioned but not sufficiently explored. Soil mineral composition alone does not directly determine wine quality; far more significant are its physical properties, such as drainage, water holding capacity, structure, and interaction with climatic conditions. Ignoring extreme climatic events, such as droughts, frosts, and heat waves, under the conditions of global climate change, is having an increasingly significant impact on viticulture. Therefore, analyzing these factors requires special study.

In [3], the authors argue that most of the world's top wine regions show a warming trend during the growing season. Crop quality ratings for the same period have increased significantly, while interannual variations have decreased. Although improved viticultural knowledge and agricultural practices contribute to higher crop quality, climate has been shown to play, and likely will always play, a significant role in quality variations. This is because the impact of climate change will not be the same for all varieties and regions. Many European regions appear to be at or near their optimal growing season temperatures, while the relationship is less pronounced in New World wine regions. For future climate conditions, modeling results for the world's wine regions project an average warming of 2°C over the next 50 years.

For regions producing high-quality grapes at the edge of their climate limits, these results suggest that future climate changes will exceed the climate threshold. Therefore, the ripening of balanced fruit required for existing varieties and wine styles will gradually become more challenging. In other regions, historical and projected climate change may result in some areas experiencing more optimal climatic conditions for growing existing grape varieties. Furthermore, warmer conditions may make regions further from the poles potentially more favorable for grape growing and wine production. However, the cited study does not emphasize the influence of consistent light winds, which improve ventilation, reducing the risk of disease and being beneficial for viticulture. The maritime influence is typically noticeable in vineyards located several kilometers from the coast. Vineyards' proximity to the sea allows them to benefit from the climatic moderation of the sea and winds. The process of chemical accumulation is extremely complex due to the interaction of soil climate, grape variety, and cultivation methods. Ultimately, all these factors combine to form the terroir effect. However, it's important to note that improvements in wine quality are linked not only to climate but also to advances in winemaking technologies, improved agricultural practices, selection, and more precise yield management. Furthermore, the conclusion that many European regions are already at their optimal temperature level requires a cautious approach. Optimality varies depending on the grape variety, wine type, and local conditions. Further increases in temperature may not improve wine quality but rather lead to a deterioration in quality due to an imbalance of sugars and acids.

In [4], data from two experiments on grape berry development were analyzed. The berry mass distribution was studied with an emphasis on undissolved substances (mainly water) and dissolved substances (mainly sugar). The product of mass and juice content in °Brix was used. This approach is based on the assumption that, since xylem flow is blocked after ripening, the time curves of berry solute content indicate the activity of phloem transport into the berry during ripening. In one of the experiments, measurements of Muscat Gordo Blanco berries from inflorescences with different flowering times showed typical double sigmoid volume/time curves, but with divergent rates and magnitudes of volume increase. Despite this divergence, the °Brix curves after ripening were virtually identical, since in each case the rate of increase in berry solute content was proportional to the rate of berry volume increase. These results demonstrated that the increase in sugar and water content after ripening is linked to and dependent on the same source, namely, phloem sap. Another experiment analyzed data on the Shiraz cultivar, revealing divergence in berry weight curves between treatments and years. The difference was that all berries decreased in size after reaching their maximum weight 91 days after anthesis (at approximately 20 °Brix). At this point, the berry solute curves slowed and then stabilized, indicating a restriction of phloem sap flow. Before size reduction, berries accumulated primary metabolites (mainly phloem sugars), but during size reduction, when berries were isolated from vascular transport, non-anthocyanin glycosides accumulated. These results have implications for studying berry aroma formation and composition, as well as for understanding resource competition within the grapevine, fresh and dried berry yields, and juice Brix levels. It should be noted that °Brix reflects sugar concentration but does not account for changes in cell volume, osmotic effects, water redistribution, or metabolic

transformations within the berry. This indicator does not always accurately reflect the actual amount of nutrients absorbed or synthesized. When analyzing the Shiraz grape variety, a decrease in berry weight after reaching the maximum nutrient composition is indicated as a result of limited phloem transport. However, this may be due to water loss due to transpiration, changes in skin permeability, or stressful conditions such as water deficit or high temperature. Issues related to the shift in phenological phases, which affect the chemical composition of berries, remain unresolved. Organic acids, minerals, amino acids, and phenolic compounds are synthesized during the early stages of berry development, as well as the organoleptic properties of the finished product.

The idea of the accumulation of non-anthocyanin glycosides during the berry mass reduction phase has not been sufficiently explored. It is unclear whether these compounds are a product of ongoing metabolism within the berry or the redistribution of already accumulated substances. The impact of this process on wine's sensory characteristics is also not discussed. The cited study highlights the significance of the results for understanding aroma formation, yield, and resource competition, but fails to demonstrate the connection between physiological parameters and product quality. It would be beneficial to integrate agronomic and technological parameters.

Research accumulated over the years [5] confirms that the ripening stage is characterized by berry growth, a decrease in acidity, accumulation of sugars, an increase in pH, and the formation of aromatic compounds. Temperature accelerates the phenological stages of the vine; however, excessively high temperatures can reduce berry size and their quality. Wind increases evaporation and transpiration, affecting berry size and their chemical composition. Information is provided on the grapevine growth cycle, water relations, photosynthesis, and respiration. The stages of grapevine formation, plant mineral nutrition, the dynamics of yield formation, and berry composition are studied. However, the work does not reveal the mechanism by which high temperature affects berry quality; an imbalance of sugars and organic acids, the breakdown of aromatic substances, or the suppression of phenolic compound synthesis play a role here. The work does not reflect the dual nature of the influence of wind; for example, increased transpiration can have both a negative (water stress) and a positive (reduction in disease) effect on the plant. In addition, there is no clear distinction between environmental factors and internal physiological mechanisms. For example, how photosynthesis and respiration influence changes in berry quality and yield is not discussed. The study provides no information on the selection of resistant varieties, water management, or protective agricultural practices. The crucial interactions between temperature, water management, nutrition, and agricultural practices must be considered comprehensively, as they shape terroir. However, the research paper implies this interaction but does not analyze it. Therefore, it was crucial to address the development of effective agricultural and breeding measures to adapt viticulture to climate change.

The author of [6] explains the mechanisms of nutrient uptake by plants and how the transport of these nutrients must be selective. This selectivity is particularly well demonstrated in algal cells, where the external and internal (cell sap) solutions are separated by only two membranes: the plasma membrane and the tonoplast. Although usually less noticeable, selective uptake of ions is also a typical feature

of higher plants. When plants are grown in a limited volume of nutrient solution, external ion concentrations change over time. The rate of uptake, especially of potassium and calcium, varies among plant species (e.g., maize and beans). The concentration of ions in the root sap is typically higher than in the nutrient solution; this is most obvious for potassium, nitrate, and phosphate. The movement of low molecular weight solutes (e.g., ions, organic acids, amino acids, sugars) from the external solution into the cell walls of individual cells or roots is a non-metabolic, passive process driven by diffusion or mass flow. The plasma membrane is also the primary site of active transport in both directions. The ability of biomembranes to transport dissolved substances and their regulations are closely linked to their chemical composition and molecular structure. The energy costs of ion uptake by roots are significant, especially during rapid vegetative growth. However, questions remain regarding the influence of changes in nutrient solution composition, pH, temperature, and other environmental factors on transport selectivity. These difficulties stem from the fact that when plants are grown in a limited volume of solution, the ion concentration constantly changes, making it difficult to control experimental conditions and interpret data. Furthermore, the work indicates that the plasma membrane is the site of active transport. This statement is generally correct, but the tonoplast also plays a key role, regulating the intracellular distribution of ions and their deposition in vacuoles. Without considering this aspect, the picture of cellular transport remains incomplete. The comparison of higher plant cells with algal cells presented in this paper can be considered useful. However, in higher plants, transport processes are significantly more complex due to tissue differentiation, the presence of xylem and phloem, and whole-organism regulation. The causes of changes in ion uptake rates are insufficiently elucidated, and the characteristics of the root system, the activity of transport proteins, or adaptation to environmental conditions are not taken into account. The cited paper fails to identify patterns of interaction between ion uptake processes and factors such as soil moisture, temperature, pH, and salinity. These factors significantly influence the availability of nutrients and the efficiency of their absorption.

Work [7] cites that grape phenols are not only an indicator of wine quality but also important biologically active substances for human health. Plant phenolic compounds have been the subject of intense scientific and applied interest for many years. Phenolic compounds in grape berries affect organoleptic properties, color, and protection from environmental influences. Climate change has already led to significant warming in most viticultural regions of the world, and climatic conditions largely determine the grape varieties that can be grown, as well as wine quality. In particular, heat, drought, and light/UV intensity strongly influence the metabolism of phenolic compounds and, consequently, the composition and development of grapes. In the Chardonnay variety, water stress increases the content of flavanols and reduces the expression of genes involved in the biosynthesis of stilbene precursors. Furthermore, the polyphenolic profile is largely dependent on the genotype and interactions with the environment. This review examines the diversity and biosynthesis of phenolic compounds in grapes, from a general overview to a more detailed level, examining the influence of environmental factors on key pathways of phenolic compound metabolism. A thorough understanding of how and when specific phenolic compounds accumulate

in grapes is paramount for adjusting agricultural practices. Conversely, understanding how the metabolism of a specific grape variety responds to the environment plays a crucial role in regulating the organoleptic characteristics of wine. The study does not adequately address the influence of climatic factors on phenolic composition. It is stated that heat and drought "strongly influence" phenolic metabolism. This is true, but these effects can be both positive (stimulation of the synthesis of protective compounds) and negative (inhibition of biosynthetic pathways under extreme conditions). The study does not clearly describe the influence of individual phenolic compounds on wine quality. When considering the significance of phenolic compounds for human health, their antioxidant activity and anti-inflammatory effects should have been highlighted.

The data reported in [8] indicate that during wine production, phenolic compounds are converted into complex pigments that ensure color stability and enrich aromatic properties.

Wine contains numerous phenolic compounds, most of which originate from grape berries. Phenolic compounds perform a number of important functions in wine, influencing bitterness and astringency, particularly in red wine. Secondly, the color of red wine is determined by phenolic compounds. Thirdly, phenolic compounds are a key preservative in wine and the basis for long-term aging. Finally, since phenolic compounds are easily oxidized, they are the ones that suffer from oxidation and develop a brown color in wine (and other products) when exposed to air. Phenolic compounds in wine include nonflavonoids: hydroxycinnamates, hydroxybenzoates, and stilbenes; as well as flavonoids: flavan-3-ols, flavanols, and anthocyanins. Although polymeric condensed tannins and pigmented tannins make up the majority of wine's phenolic compounds, their large size hinders absorption and is therefore unlikely to have significant health effects. The total amount of phenols in a glass of red wine is approximately 200 mg, compared to about 40 mg in a glass of white wine.

The cited paper understudies the mechanisms of phenolic compound transformation during vinification. It would have been useful to highlight the polymerization reactions between anthocyanins and tannins, as they contribute to the wine's stable color. The potential negative effects of excessive tannin extraction, which lead to harsh astringency and oxidative defects in wine, are not addressed. Furthermore, the study does not give data on the phenolic content of introduced and locally adapted grape varieties. The influence of temperature changes and soil composition on phenolic compound composition is not emphasized. These difficulties arise from simultaneously studying the effects of multiple interrelated soil and climatic factors.

Work [9] considers the economic and health value of grapes, where the conducted research is aimed at improving the chemical composition of grape products and their processing. The study aimed to determine the quality parameters and the relationship between local (Khindogni, Bayanshir, Madrasa, and Shirvanshahi) and imported (Russian, Chardonnay, and Carignan) grape varieties (*Vitis vinifera L.*) grown in the mountainous Shirvan region of Azerbaijan. Only a few vineyards planted with ancient varieties remain, which puts the wine industry in a difficult situation. Local varieties of Madrasa, Shirvanshahi, and Bayanshir, grown in the Shamakhi region of Azerbaijan, could become an incentive for the modernization of the wine industry. Abroad,

consumers prefer wines made from ancient technical grape varieties. Despite the interest in the Madras, Bayanshir, Khindogni, and Shirvanshahi varieties, the industrial grape varieties Chardonnay, Roussanne, and Carignan occupy the leading positions in grape cultivation. Various characteristics of bunches and berries have been the most studied parameters in these grape genotypes. However, the cited study does not take into account the ecological and geographical zonal characteristics of grape varieties. Local soil and climate conditions are not indicated as having an impact on the quality of table wines. Difficulties arise from the diversity of soil characteristics, which complicates the determination of their precise influence on the chemical composition of grapes.

The authors of study [10] argue that during storage, in addition to natural weight loss, grapes also undergo spoilage, mainly caused by fungal infections. The study aimed to investigate the composition of the epiphytic microflora of grapes immediately after harvesting and long-term refrigeration storage, and to determine the effectiveness of using sulfur dioxide to prevent grape spoilage. Sulfur dioxide fumigation helped suppress the activity of harmful microorganisms. In fresh grapes, the microbiology of contamination varied significantly depending on the grape variety. Fungi of the genus *Aspergillus* were detected in the Gara Shaani variety, and *Penicillium* in the Ag Shaani variety. The results also demonstrated the effectiveness of using sulfur dioxide, which leads to a significant reduction in the number of fungi. However, the study left unresolved issues related to the effect of sulfur dioxide on enzyme activity. The lack of a quantitative characteristic of microbial contamination makes it impossible to evaluate the degree of microflora reduction and the effectiveness of the treatment in numerical terms. Furthermore, microflora analysis is limited to only certain genera of fungi (*Aspergillus*, *Penicillium*), whereas the epiphytic microbiota of grapes is significantly more diverse and includes yeasts, bacteria, and other molds. When formulating differences between the varieties (Gara Shaani and Ag Shaani), it was important to consider berry morphology, chemical composition, and growing conditions. It was also important to identify the impact of residual SO₂ on organoleptic properties, potential health risks, and regulatory restrictions associated with its use. Storage temperatures, sulfur dioxide concentrations, and fumigation regimens also needed to be clarified.

According to the authors of [11], the Caspian Sea is the largest natural body of water on Earth. Under the influence of natural and climatic factors, water levels periodically fluctuate. According to observations conducted in the Caspian Sea over the past 400 years, the lowest water level (a drop of 29 m) was reached in 1977. Currently, the water level in the Caspian Sea is 28 m below sea level. In terms of hydrology and bottom topography, the division of the Caspian Sea led to the formation of three parts – the North Caspian, Central Caspian, and South Caspian. The relief of the Absheron Peninsula, located on the coast of the Caspian Sea, was formed under the influence of hydrological and climatic factors. The species composition of macrozoobenthos, depth distribution and seasonal changes in the South Caspian sector of Azerbaijan were studied. During the 2018–2019 study period, 56 macrobenthic organisms representing 10 taxonomic groups were identified in the Azerbaijani sector of the South Caspian Sea. The greatest number of species was recorded in spring and summer (48–56 species), while the fewest were recorded in autumn (28–32 species). However, the study does not report results on the influence of macrozoobenthos on

the composition of coastal soils, due to objective difficulties associated with the limited long-term observations, reduced accuracy in assessing stable factors, and long-term impacts. Establishing the relationship between macrozoobenthos structure and changes in soil structural properties remains an unresolved and challenging task.

Study [12] was conducted in Bordeaux vineyards and examined the effect of water deficit on grapevine shoot growth, berry weight, grape composition, and overall crop quality. Methods for assessing water deficit were compared. The study found that the state of grapevine water balance affects the chemical composition of berries. Water deficit was shown to precede a slowdown in shoot growth, a limitation in berry weight, and an increase in anthocyanin content in berries. Sugar content in berries was highest under moderate water deficit. Stem water potential measurements and carbon isotope discrimination were shown to be accurate tools for assessing grapevine water balance at the site level. Seasonal water deficit at a regional scale can be accurately estimated using water balance models. Crop quality in Bordeaux is determined by the intensity of water deficit, not by temperature. Grapevine phenology and grape ripening are largely dependent on water absorption conditions. Moderate water deficit improves the quality of grapes for red wine production. Vine water status can be accurately assessed using stem water potential or carbon isotope discrimination measured in grape sugars. Quality losses due to severe water stress can be avoided by using drought-tolerant planting material, proper foliar management, reducing yields, or implementing deficit irrigation. The study demonstrates the key role of water stress in the production of high-quality red wine grapes. The cited study argues that for high-quality wine production, environmental conditions should limit excessive vegetative development of the vine and promote balanced growth with moderate water stress and nitrogen content. However, the study's water potential measurement does not take into account the time-of-day dependence. Furthermore, carbon isotope discrimination reflects the integral effect over a period and does not allow for the rapid monitoring of short-term changes. It would be useful to specify the threshold values of water stress at which the optimal effect is achieved. The role of interactions between water and nitrogen nutrition is insufficiently explored; it would be crucial to emphasize how nitrogen influences the balance between vine growth and the accumulation of quality fruit components. It was important to point out how water deficiency disrupts the process of photosynthesis, the accumulation of phenolic compounds, and reduces the quality of raw materials and finished products.

The authors of [13] confirm that the diversity of terroir components significantly affects the uniformity of bunches, ripening dynamics, and berry composition. Specific terroir conditions allow a vineyard to exhibit a unique metabolite profile. Vineyard variability makes it difficult to meet winemakers' requirements for uniform grape lots suitable for specific production streams. The cited study identified and investigated relationships between the chemical and sensory characteristics of wines obtained from different parts of the same site and the biophysical characteristics of these different vineyard sites. Remote sensing of vine vigor, yield mapping, and an EM38 soil survey were used to identify zones of contrasting yield performance in a Cabernet Sauvignon vineyard in the Murray Valley region. Small batches of wines were produced from grapes harvested in these zones. Both sensory and chemical analysis of these wines revealed their

differences. Similarly, soil properties and vine nutritional parameters varied between zones. The work suggests the possibility of establishing reliable relationships between the manageable biophysical characteristics of grape growing sites and the sensory and chemical characteristics of the wines produced from them. It also confirms the notion of spatial terroir variability at the intravineyard scale. The work lays the foundation for further research aimed at establishing how the specific sensory and/or chemical properties of wines can be modified through targeted vineyard management measures. Indeed, research aimed at satisfying these requirements is essential in this regard, which is impossible without adequately characterizing the differences between wines produced from different grape lots. Even vineyard management and understanding the influence of variations in its biophysical characteristics on the composition of the final wine depend on the selection of sites within the same vineyard. The cited work does not specifically indicate which parameters (soil moisture, exposure, organic matter content) influence the quality indicators of raw materials or how they can be influenced. Seasonal variations are not taken into account. It is known that terroir is a fluid system, and differences between plots can vary from year to year depending on weather conditions, making it difficult to establish stable patterns. Furthermore, the technological limitations of implementing precision viticulture management at the microzone level within the vineyard are not considered.

Paper [14] examines flavonoids as a class of compounds, the role of these compounds in plants, their contribution to wine quality, and recent studies on the influence of environmental factors and agronomic practices on the content and composition of flavonoids in grape berries. Flavonoids are a large and diverse group of compounds, the presence or absence of which significantly affects wine quality. Although the content and composition of flavonoids in wine reflect to some extent the winemaking process, the main determining factor is the composition of the grapes at harvest. Thus, significant research has been directed towards understanding the nature of flavonoids in grapevines and the factors influencing their biosynthesis. Emphasis has been placed on how this knowledge can be used to manipulate and regulate the composition of flavonoids in berries during harvest. However, the influence of soil and climatic conditions, including sunlight as the main energy source for photosynthesis, and their role in the accumulation of substances affecting grape productivity and quality require detailed study. The work does not reflect the differentiation of flavonoid groups, does not take into account the technological factors of winemaking, does not disclose the mechanisms of influence of the environment and agricultural technology, as well as does not take into account varietal specificity and nonlinear effects.

The authors of [15] indicate that the anthocyanin and phenolic compound profiles in the skin of *Vitis vinifera* Merlot berries from the Yakima Valley in Washington State were affected by sunlight exposure and temperature in 1999 and 2000. The sum of effective temperatures (base 10°C) accumulated between ripening and harvest was lower in 2000 than in 1999. The total monomeric anthocyanin concentration in skin was higher in 2000 than in 1999 under all treatments. Berry temperatures increased 13°C above ambient and shaded cluster temperatures when clusters were exposed to sunlight, regardless of north-south row orientation. However, maximum fruit temperatures were higher for clusters on the west side of the canopy because ambi-

ent temperatures were higher after 12:00 PM. West-facing cluster temperatures occasionally exceeded 40°C. East-facing bunches had higher anthocyanin concentrations than west-facing or shaded bunches. To separate the effects of light and temperature, west-facing bunches were cooled to the temperature of shaded bunches, and shaded bunches were warmed to the temperature of west-facing bunches. Sunlight exposure increased anthocyanin concentrations regardless of temperature in both years. In 1999 and 2000, cooling sun-facing bunches increased anthocyanin concentrations. Warming shaded bunches decreased anthocyanin concentrations in 1999 but had no effect during the cooler ripening period in 2000. Ultraviolet (UV) barriers had no effect on either bunch temperature or anthocyanin concentrations. The decrease in anthocyanin concentrations in berry skins from west-facing bunches was due to temperature, not UV radiation. Exposure to solar radiation increased the concentration of 3-glycosides quercetin, kaempferol, and myricetin. In 2000, the concentration of total flavanols in sunlit bushes, regardless of orientation, was almost 10 times higher than in shaded bushes. UV barriers significantly reduced the concentration of individual and total flavanols, while temperature had virtually no effect. It is claimed that with increasing altitude, the intensity of ultraviolet radiation increases, activating the synthesis of phenols and volatile compounds. However, questions remain unanswered regarding the integration of climatic, soil, and biochemical parameters, ultimately complicating the interpretation of the results due to a lack of comprehensive studies.

In the study, the influence of climatic differences between 1999 and 2000 is accounted for through temperature. However, it was important to consider factors such as vine water status, air humidity, and agricultural practices. These factors could have influenced anthocyanin accumulation. The higher anthocyanin concentration in the cooler 2000 may have been due not only to temperature but also to a combination of conditions. The study does not clarify its conclusions regarding the role of UV radiation. It is noted that UV barriers did not affect anthocyanins, but significantly reduced flavanol content. Therefore, it was important to discuss the possible interactions of UV radiation with temperature and water stress. It would have been useful to examine the intensity of UV radiation changes with temperature and the amplitude of diurnal fluctuations.

To obtain grapes with the desired productivity and quality, canopy management is particularly important, ensuring the effective use of climatic parameters. In coastal areas, uniformity of climatic factors is difficult to ensure, so studying the influence of terroir in marine conditions is especially important. All of this suggests the need for a comprehensive study on soil and climatic conditions affecting grapevine growth. Research lacks information on the influence of terroir on the nutrient content of introduced grape varieties adapted to specific growing conditions. Temperature changes and soil characteristics have been insufficiently studied in determining the formation and variability of grape and wine quality. Therefore, it is important to conduct a comprehensive assessment to establish the relationship between climatic factors, growing conditions, and the biochemical parameters of raw materials.

All of the above confirms the feasibility of conducting research on the influence of terroir on grape ripening dynamics and on the quality parameters of introduced grape varieties and the wines produced from them.

3. The aim and objectives of the study

The aim of our study is to identify patterns in the influence of terroir on the quality of introduced wine grape varieties. Studying the soil and climatic conditions of the Absheron Peninsula will help establish the relationship between grape ripening dynamics and the quality of the resulting wines. The resulting vineyards will contribute to the development of rural tourism and play an important role in ensuring the environmental and economic sustainability of the region.

To achieve this goal, the following objectives were set:

- to analyze the soil and climatic conditions of the Absheron Peninsula terroir;
- to analyze the quality characteristics of grape varieties grown on the Absheron Peninsula;
- to analyze the quality characteristics of wines produced from the studied grape varieties grown on the Absheron Peninsula.

4. The study materials and methods

4.1. The object and hypothesis of the study

Our study focuses on wines made from introduced grape varieties grown in the Absheron Peninsula.

The study's hypothesis assumes that the terroir of the Absheron Peninsula is favorable for the cultivation of introduced grape varieties. The soil and climate conditions of the area promote the accumulation of nutrients, which is reflected in the organoleptic properties of the wines produced from them. It is the balanced content of nutrients that creates the flavor and aroma of wines and makes them competitive in the international market.

It is assumed that introduced grape varieties (Shiraz, Rkatsiteli, Sauvignon Blanc, Traminer, Cabernet Sauvignon) have the ability to adapt to the soil and climate conditions of the Absheron Peninsula and ensure consistent harvest quality. It is assumed that marine terroir, including the influence of the Caspian Sea, wind conditions, humidity, and temperature factors, significantly influences grape ripening processes and the formation of their biochemical composition, including the accumulation of sugars, organic acids, and phenolic compounds. The applied agronomic and technological approaches to grape cultivation and processing are standard and do not distort the results of a comparative analysis of varieties.

It is also assumed that the chemical analysis methods employed are characterized by sufficient accuracy and reproducibility for an objective assessment of the quality parameters of grapes and wine. It is believed that the identified differences in the chemical composition and quality of wines are primarily due to varietal characteristics and terroir conditions under comparable technological production conditions. The results may be applicable to other regions with similar natural, climatic, and marine characteristics.

The study did not take into account possible microclimatic differences within individual vineyard sites, and growing conditions were considered uniform. A detailed analysis of the influence of micro zonation on the chemical composition of grapes was not conducted. Biotic factors, such as the influence of pests, diseases, and microbiota, as well as interannual climatic fluctuations, were not considered. Variability in climatic conditions across years was not included in the analysis; therefore, the interpretation of the results was carried out without considering the influence of weather factors during

individual growing seasons. The technological processes of grape processing and wine production were assumed to be standardized, without detailed variation of individual parameters (fermentation temperature, maceration duration, etc.). Furthermore, the interaction of individual terroir factors (topography, wind, temperature, humidity) was analyzed in a generalized manner, without separately assessing their quantitative contribution to the formation of grape and wine quality indicators.

4.2. Research methods

A terroir soil study was conducted in 2024 at a vineyard located on the Absheron Peninsula (40°27'49" N, 49°57'27" E), on the western coast of the Caspian Sea, within the territory of the Republic of Azerbaijan. The altitude ranged from 27 to 28 m above sea level. The introduced industrial grape varieties Shiraz, Rkatsiteli, Sauvignon Blanc, Traminer, and Cabernet Sauvignon were selected for the study (Fig. 1). The vineyard, which covers 117 hectares and is owned by a private company, is located in the village of Novkhani in the Absheron District. Shiraz, Rkatsiteli, Sauvignon Blanc, Traminer, and Cabernet Sauvignon are currently considered among the most significant introduced varieties used in the region's wine industry. The vines were planted in a 3.00 × 1.25 m pattern running north to south, parallel to the coast. Single-arm cordon training was used, with 6–8 buds per shoot. Yields were 6–8 tons per hectare. The vineyard is equipped with a trellis system and drip irrigation.

Grape harvest. To prevent temperature influence and to preserve characteristic quality, samples were collected on a clear day, without recent rain, dense fog, or smoke, in the morning hours between 05:00 and 11:00. Samples were placed in hermetically sealed (Ziploc type) transparent plastic bags measuring 30 × 15 cm. The sample bags were labeled with the appropriate identification names and transported from the vineyard to the laboratory in a portable cooler with ice for analysis. Sampling was carried out three days before harvest according to the methodology. The study was planned in five (5) replicates based on the work "Study of enochemical and enocarpological characteristics of grapes" [16]. Each replicate used 15 bunches [17]. Fifteen berries were selected from the middle third of each bunch, resulting in 225 berries used for each replicate. The juice obtained by pressing these berries was analyzed for sugar concentration, titratable acidity (TA), and pH to monitor ripeness.

A mortar and sieve were used to extract the juice to avoid damaging the seeds during crushing. The juice was poured into 250 ml containers and then filtered using sieves and funnels to remove solids.

The grapes were harvested at the technological maturity stage, with a density of 1.085–1.100 g/ml and transported to the processing plant under refrigeration. Processing took place in fermentation tanks with a refrigeration system. During the destemming and crushing process, the berries were sulfited using powdered potassium metabisulfite. Yeast (Laffort FX10) and yeast culture medium (Laffort Dynastart) were then added to the must, after which maceration and alcoholic fermentation began. During maceration, the "delestage" technique was used. The end of maceration was determined when the density of the must dropped below 1000, after which residual sugar was analyzed. Lactic acid bacteria (Laffort 450 Preac) and culture medium (Laffort PrePreac) were then added to the must, and malolactic fermentation began. The temperature was maintained at 22°C (±1°C). To monitor the progress of malolactic fermentation, malic acid and volatile acidity were measured regularly. Upon completion of malolactic fermentation, the wine was racked with aeration and resulfited.

To determine the timing of harvest, acidity, sugar content, and pH were determined. Sugar content and acidity were determined according to the OIV (International Organization of Vine and Wine) [18]. Titratable acidity was measured in g/L based on tartaric acid at a pH of 7 and a temperature of 20°C using the titration method. pH was measured with a pH meter, and total soluble sugars (°Brix) with a refractometer. In grape juice, the mass concentration of sugars was determined according to GOST 27198-87, titratable acids according to GOST 25550-82, and pH with a pH meter. In wine samples, the volume fraction of ethyl alcohol was determined according to GOST 32095-2013, residual sugar according to GOST 13192-73, mass concentration of titratable acids according to GOST 32114-2013, volatile acids according to GOST 32001-2012, extract according to GOST 32000-2012, and total and free sulfur content according to GOST 32115-2013.

The results reported in this study were evaluated using analysis of variance (ANOVA) using the Windows SPSS 22.0 Software statistical package. Results were evaluated with a 95% confidence interval.

5. Results of a study on the influence of cultivation terroir on the qualitative composition of grapes and wines

5.1. Analysis of soil and climatic conditions of the Absheron Peninsula terroir

Sandy and calcareous soils are predominantly found on the Absheron Peninsula. The location of the vineyard in Azerbaijan is shown in Fig. 1. A satellite image of the vineyard plots on the Absheron Peninsula is shown in Fig. 2. The soil analysis results are given in Tables 1, 2, and the irrigation water analysis in Table 3.

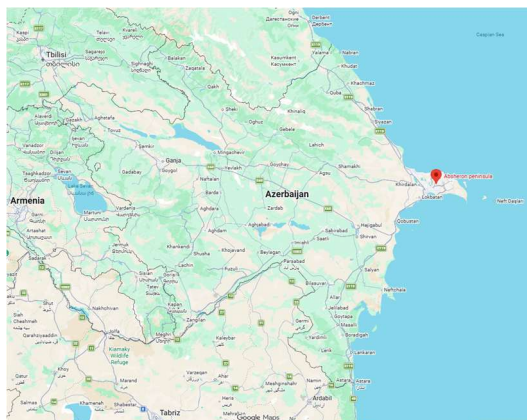
The results given in Table 1 indicate that the soil in the study area is slightly alkaline (pH 7.6), which is generally favorable for viticulture. However, a pH above the neutral range may limit the availability of certain micronutrients, particularly iron (Fe), zinc (Zn), and manganese (Mn), to plants. This phenomenon is typical of carbonate soils and corresponds to the soil and climatic conditions of the Absheron Peninsula.

Low electrical conductivity (EC = 0.46 mS/cm) indicates the absence of a risk of salinization, which ensures the normal functioning of the grape root system and the maintenance of water and nutrient balance. Low humus content (1.0%) indicates a low supply of organic matter in the soil, which may negatively affect its structure and water-holding capacity [19]. Macronutrient analysis reveals that nitrogen (113 mg/kg) and potassium (220 mg/kg) levels are sufficient for normal vegetative development. Increased potassium content plays an important role in sugar accumulation in berries and the development of the technological qualities of grapes [20]. High calcium concentrations (19,745 mg/kg) and carbonate content (CaCO₃ = 7.3%) confirm the carbonate nature of the soil.

According to Table 2, the soil is characterized by a high cation exchange capacity (CEC = 106 meq/100 g), indicating a high nutrient retention capacity. This is an important indicator of potential soil fertility [21].

The base saturation level shows a predominance of calcium (93.6%), exceeding optimal values and confirming the carbonate nature of the soil. However, the low magnesium (3.0%) and potassium (0.5%) contents may limit their availability to plants. These elements play a key role in photosynthesis, enzymatic activity, and carbohydrate transport.

The sodium content (2.9%) is within acceptable limits and does not pose a threat to soil structure. However, to optimize the cation balance, the use of fertilizers containing magnesium and potassium is recommended [22].



a



b

Fig. 1. Geographical location of the vineyard under study on the map:

a – map of Azerbaijan indicating the location of the vineyard; b – satellite image of vineyard plots on the Absheron Peninsula

Table 1

Analysis of soil composition of the vineyard experimental plot

Sample name	pH	EC, mS/cm	Humus, %	CaCO ₃ %	mg/kg														-	%	meq/100 g
					N	P	K	Ca	Mg	Na	Cl	SO ₄	Fe	B	Cu	Zn	Mn	Mo			
Soil	7.6	0.46	1.0	7.3	113	0.4	220	19745	381	705	70	214	8.6	1.2	0.4	0.4	15	<0.1	1.4	2.9	106
min	5.5	<4	1	<10	20	15	120	800	60	0	20	20	11	0.8	0.9	1.1	4	0.1	<13	<15	-
max	6.5		5		40	50	220	1200	120	60	150	40	16	2.0	1.2	3.0	8	0.3			-

Table 2

Table of soil saturation of the experimental plot

Sample name	Saturation										MeO			
	meq/100 g				meq/100 g	Saturation, %				Total, %	mg/kg			
	Ca	Mg	K	Na	CEC	Ca	Mg	K	Na		K ₂ O	CaO	MgO	Na
Soil	98.7	3.2	0.6	3.1	106	93.6	3.0	0.5	2.9	100	264	27643	632	705
Ideal saturation, %						60–85	10–20	2–5	1–4	–				

Table 3

Analysis of water for irrigation of the experimental plot

–	mS/cm	mg/l																
pH	EC	N-NO ₃	N-NH ₄	P-PO ₄	K	Ca	Mg	Na	S-SO ₄	Cl	HCO ₃	Si	Fe	B	Cu	Zn	Mn	Mo
7.2	0.42	1.2	0	0	10	41	13	20	33	3.4	122	–	44	0	0	0	0	0
mmol/L										μmol/l								
7.2	0.42	0.1	0	0	0.3	1.0	0.5	0.9	1.0	0.1	2.0	0	0.8	0	0	0	0	0

The results in Table 3 indicate that the pH of the irrigation water is 7.2, which is close to neutral and favorable for agricultural use. Low electrical conductivity (EC = 0.42 mS/cm) indicates no risk of salinization [23].

Low sodium (20 mg/L) and chloride (33 mg/L) concentrations indicate minimal risk of salt accumulation in the soil with long-term water use [24]. Sulfate and bicarbonate levels are within normal limits and do not significantly affect the soil’s pH balance.

The almost complete absence of trace elements (Fe, Zn, Cu, etc.) indicates the chemical purity of the water; however, this requires the additional application of these elements with fertilizers to ensure adequate plant nutrition [25].

Overall, our results indicate that the soil and water conditions of the Absheron region are satisfactory for grape cultivation. However, to increase yield and product quality, it is necessary to implement agrochemical measures aimed at increasing the organic matter content in the soil, as well as optimizing the magnesium and potassium balance.

Monthly climate data for 2024 are given in Table 4. Average monthly air temperature (°C), precipitation (mm), and sunshine duration (hours) were obtained based on data from the National Hydrometeorology Service of the Ministry of Ecology and Natural Resources of the Republic of Azerbaijan. The data were recorded at the nearest weather station in Baku for 2024 [26]. The climate of the region is characterized as moderately warm and dry subtropical.

Table 4

Monthly climate data for 2024

Months	Average monthly air temperature (°C)	Amount of precipitation (mm)	Sunshine duration (hours)
January	5.6	45.7	115.3
February	6.6	25.2	143.1
March	8.1	36.2	141.6
April	16.8	9.1	268.5
May	17.5	32.9	227.1
June	26.7	12.4	324.7
July	29.0	15.2	278.9
August	27.7	1.3	314.5
September	23.1	0.0	245.1
October	16.7	53.8	145.7
November	11.4	37.6	101.6
December	7.5	69.9	74.1

In January 2024, heavy snowfall resulted in significant snow cover, ensuring high soil moisture and water supply for vegetation in the following period. Despite temperature peaks in early spring, temperatures and precipitation remained within long-term norms for the rest of the season. The summer was dry, allowing the growing season to proceed normally.

5. 2. Study of qualitative indicators of introduced grape varieties

Our study examined the qualitative indicators of grape varieties. The results of analysis of sugar concentration, titratable acidity, and pH values by variety are given in Table 5.

For the Shiraz grape variety, the mass fraction of sugars was 23.0 g/cm³, titratable acidity was 4.6 g/L, and the pH was 3.28. According to data [27] on various regions of Azerbaijan, the sugar concentration in Shiraz berries ranged from 18.7 to 21.1 g/cm³, and titratable acidity was 5.27 to 7.06 g/L.

The mass concentration of sugars in the Rkatsiteli grape variety was 23.3 g/100 ml, the mass concentration of titratable acids was 4.8 g/L, and the pH was 3.38. According to study [16], the sugar concentration in Rkatsiteli grapes under Absheron conditions was 19.6 g/100 ml, and the titratable acidity was 6.3–6.5 g/l. According to the results obtained in this study, the mass concentration of sugars was high, the mass concentration of titratable acids was at the upper limit of previously obtained results, and the pH was relatively low.

The mass concentration of sugars in Sauvignon Blanc grapes was 19.4 g/100 g, the mass concentration of titratable acids was 4.8 g/l, and the pH was 3.30.

The mass fraction of sugars in Traminer grapes was 21.7 g/100 cm³, the titratable acidity was 4.2 g/l, and the pH was 3.44. The Cabernet Sauvignon grape variety had a sugar mass concentration of 23.2 g/100 cm³, titratable acidity of 4.4 g/l, and a pH of 3.38.

The physiological characteristics of vines, including sugar accumulation, acidity, and pH, can be influenced by various factors, such as vine vigor, soil characteristics, water regime, and plant nutrition [28].

A comparative analysis of the studied varieties revealed the following: the highest mass concentration of sugars was recorded for the Rkatsiteli variety (23.3 g/100 cm³), while the lowest was recorded for the Sauvignon Blanc variety (19.4 g/100 cm³). The highest titratable acidity was recorded for the Sauvignon Blanc variety (4.8 g/L), while the lowest was recorded for the Traminer variety (4.2 g/L). The highest pH was recorded for the Traminer variety (3.44), and the lowest for the Shiraz variety (3.28).

Table 5

Qualitative indicators of the studied grape varieties

No.	Indicator	Shiraz	Rkatsiteli	Sauvignon Blanc	Traminer	Cabernet Sauvignon	D
1	Density, g/ml	1.096 ± 0.00	1.100 ± 0.00	1.085 ± 0.00	1.092 ± 0.00	1.098 ± 0.00	*
2	Sugar content, g/100 cm ³	23.0 ± 0.02	23.3 ± 0.01	19.4 ± 0.02	21.7 ± 0.02	23.2 ± 0.01	*
3	Titrateable acids, g/l	4.6 ± 0.01	4.4 ± 0.02	4.8 ± 0.01	4.2 ± 0.02	4.4 ± 0.02	*
4	pH	3.28 ± 0.01	3.38 ± 0.01	3.30 ± 0.01	3.44 ± 0.01	3.38 ± 0.01	*

Note: D – differences based on the results from ANOVA; * – differences are significant at a significance level of $p < 0.05$.

5.3. Investigating the quality indicators of wine samples

The results of our analysis of the quality indicators of wines produced from the studied grape varieties grown in the Absheron Peninsula are given in Table 6.

The volume fraction of ethyl alcohol in the wine samples obtained from the Shiraz grape variety was 13.55%, Rkatsiteli – 13.75%, Sauvignon Blanc – 11.43%, Traminer – 12.8%, and Cabernet Sauvignon – 13.66%. The values correspond to the established standard (8.5–15.0%) and vary depending on the sugar concentration in the juice of the respective grape varieties.

The residual sugar content was: 2.2 g/L for Shiraz, 2.9 g/L for Rkatsiteli, 2.6 g/L for Sauvignon Blanc, 3.0 g/L for Traminer, and 2.7 g/L for Cabernet Sauvignon. Residual sugar content is an important indicator of wine stability, reflecting the correctness of the technological process. All obtained values are below the maximum permissible level according to the standard (< 4.0 g/L).

The mass concentration of titrateable acids was: 4.2 g/L for Shiraz, 4.07 g/L for Rkatsiteli, 4.22 g/L for Sauvignon Blanc, 3.8 g/L for Traminer, and 4.03 g/L for Cabernet Sauvignon, which meets the regulatory requirements (> 3.5 g/L). Non-volatile aliphatic acids are considered natural grape acids. These acids also include total or titrateable acids in wine.

The mass concentration of volatile acids was: 0.33 g/L for Shiraz, 0.52 g/L for Rkatsiteli, 0.36 g/L for Sauvignon Blanc, 0.59 g/L for Traminer, and 0.47 g/L for Cabernet Sauvignon, which meets the standard (< 1.0 g/L). During the fermentation of grape juice, the amount of volatile acids increases. Acetic acid accounts for the majority (80–90%) of volatile acids in wine. Compared to grape juice, the concentration of acetic acid in wine is 20–50 times higher. This is due to fermentation conditions and temperature, the choice of cultured yeast, and other technological factors. Furthermore, improper storage of

table wines can lead to oxidation of ethanol, producing acetic acid. To produce wine with low volatile acid content, the fermentation process must be strictly controlled [29].

The extractive content was: 26.9 g/l for Shiraz wine, 21.5 g/l for Rkatsiteli, 19.8 g/l for Sauvignon Blanc, 25.2 g/l for Traminer, and 28.4 g/l for Cabernet Sauvignon, which meets the standard (>17.0 g/l). To obtain high-quality wine, it is necessary to use fully ripened technical grapes. Ripe grapes contain more glucose and fructose and less colloidal compounds, such as cellulose and pectin. Wines with a high alcohol yield and an increased extractive content are obtained from such grapes. Therefore, during winemaking, special attention must be paid to the sugar content of the grapes and their degree of ripeness [30].

The total sulfur content in Shiraz wine was 93.8 mg/l, and the free sulfur content was 42.5 mg/l; in Rkatsiteli – 98.5 mg/L and 41.1 mg/L, respectively; in Sauvignon Blanc – 93.7 mg/L and 41.4 mg/L; in Traminer – 96.9 mg/L and 41.8 mg/L; in Cabernet Sauvignon – 94.4 mg/L and 41.6 mg/L. All indicators comply with the established standard (< 200 mg/L).

The total content of phenolic compounds in wines produced from the Shiraz variety was 1764 mg/L, in Rkatsiteli – 335 mg/L, in Sauvignon Blanc – 191 mg/L, in Traminer and Cabernet Sauvignon – 755 mg/L and 1862 mg/L, respectively.

The anthocyanin concentration in Shiraz wine was 314 mg/L, compared to 121 mg/L for Traminer and 320 mg/L for Cabernet Sauvignon. No anthocyanins were detected in wines made from white grape varieties (Rkatsiteli and Sauvignon Blanc). Color is a key quality indicator for red wines and is primarily determined by anthocyanins formed during vinification.

The tannin content in Shiraz wine was 2.20 g/L, compared to 0.35 g/L for Rkatsiteli, 0.38 g/L for Sauvignon Blanc, 1.48 g/L for Traminer, and 1.93 g/L for Cabernet Sauvignon (Fig. 2).

Table 6

Quality indicators of wine samples by variety

Indicator	Shiraz	Rkatsiteli	Sauvignon Blanc	Traminer	Cabernet Sauvignon	Norm	D
Ethyl alcohol content, %	13.55 ± 0.00	13.75 ± 0.00	11.43 ± 0.00	12.8 ± 0.00	13.66 ± 0.00	8.5–15.0	*
Residual sugar, g/L	2.2 ± 0.1	2.9 ± 0.1	2.6 ± 0.1	3.0 ± 0.1	2.7 ± 0.1	< 4.0	*
Titrateable acid concentration, g/L	4.2 ± 0.01	4.07 ± 0.02	4.22 ± 0.01	3.8 ± 0.02	4.03 ± 0.02	> 3.5	*
Volatile acid concentration, g/L	0.33 ± 0.02	0.52 ± 0.01	0.36 ± 0.02	0.59 ± 0.01	0.47 ± 0.01	< 1.0	N.S
Extract, g/L	26.9 ± 0.3	21.5 ± 0.4	19.8 ± 0.4	25.2 ± 0.3	28.4 ± 0.3	> 16.0	*
Total and free sulfur, mg/L	93.8 ± 1.4/42.5 ± 1.2	98.5 ± 1.9/41.1 ± 3.4	93.7 ± 1.9/41.4 ± 1.2	96.9 ± 1.9/41.8 ± 1.2	94.4 ± 1.4/41.6 ± 1.2	< 200	N.S
Total phenolic content, mg/L	1764 ± 76.1	335 ± 31.1	191 ± 31.1	755 ± 33.0	1862 ± 76.1	–	*
Anthocyanins, mg/L	314 ± 6.3	–	–	121 ± 2.5	320 ± 2.4	–	**
Tannins, g/L	2.20 ± 0.1	0.35 ± 0.1	0.38 ± 0.1	1.48 ± 0.1	1.93 ± 0.1	–	*

Note: D – status of difference according to the analysis of variance; * – indicates the significance of the difference at the level of $P < 0.05$, ** – significance at the level of $p < 0.01$, N.S – insignificance at the level of $p > 0.05$.

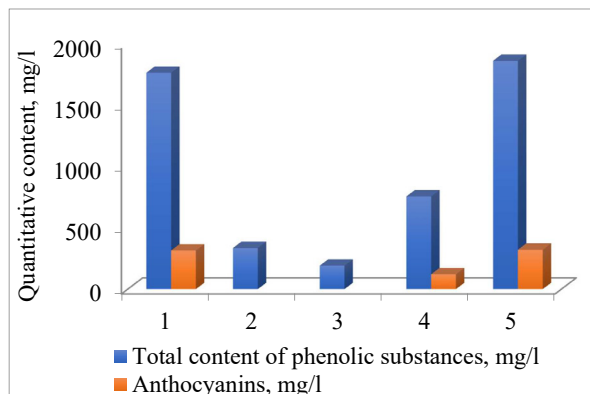


Fig. 2. Total content of phenolic substances and anthocyanins in the prepared wine samples: 1 – Shiraz; 2 – Rkatsiteli; 3 – Sauvignon Blanc; 4 – Traminer; 5 – Cabernet Sauvignon

Tannins are natural polyphenolic compounds formed primarily from the skins and seeds of grapes. In high-quality red wines, a balanced tannin structure is essential for long-lasting shelf life and flavor development [29].

6. Discussion of results based on studying the influence of growing terroir on the quality of grapes and wines.

Overall, our results indicate that the soil and water conditions of the Absheron region are satisfactory for grape cultivation (Table 1). However, to improve yield and product quality, it is necessary to implement agrochemical measures aimed at increasing the organic matter content in the soil and optimizing the magnesium and potassium balance (Table 2).

An analysis of the climatic conditions in 2024 (Table 4) revealed that they generally met the biological requirements of grapes and contributed to their normal growth and development. The presence of snow cover during the winter ensured sufficient moisture accumulation in the soil, which had a positive effect on plant water availability at the beginning of the growing season (Table 3).

The temperature regime in the spring, despite short-term fluctuations, was generally within the long-term norm and did not have a significant negative impact on plant development. The dry summer conditions typical for the region facilitated optimal berry ripening processes, including sugar accumulation and the development of quality indicators for the harvest (Table 5).

Thus, climatic conditions in 2024 can be assessed as favorable for grape cultivation. They ensured stable progression through all phases of the growing cycle and created the preconditions for producing high-quality grapes (Table 4).

According to the results reported in this study, the mass concentration of sugars was high, the mass concentration of titratable acids was at the upper limit of previously obtained results, and the pH value was relatively low (Table 5).

For the Shiraz grape variety, the mass fraction of sugars was 23.0 g/cm³, titratable acidity was 4.6 g/l, and the pH value was 3.28 (Table 5). According to data from [26], from various regions of Azerbaijan, the sugar concentration in Shiraz berries ranged from 18.7 to 21.1 g/cm³, and titratable acidity was 5.27 to 7.06 g/l. In study [16], conducted in Shamakhi and Absheron, the pH value of the Shiraz variety was 3.48. In this study, the mass fraction of sugars in the Shiraz variety corresponds to the upper limit

of previously obtained data, while titratable acidity values were at a higher level.

The mass concentration of sugars in the Rkatsiteli grape variety was 23.3 g/100 ml, the mass concentration of titratable acids was 4.8 g/l, and the pH was 3.38 (Table 5). According to study [28], the concentration of sugars in berries of the Rkatsiteli grape variety under the conditions of Absheron was 19.6 g/100 ml, and the titratable acidity was 6.3–6.5 g/l. According to our results from this study, the mass concentration of sugars was high, the mass concentration of titratable acids was at the upper limit of previously obtained results, and the pH was relatively low.

The sugar concentration in Sauvignon Blanc grapes was 19.4 g/100 g, the titratable acid concentration was 4.8 g/L, and the pH was 3.30. According to paper [16], the sugar concentration in Sauvignon Blanc grapes ranged from 19.2 to 22.6 g/100 g, and the titratable acid concentration was 6.2 g/L. According to the results, soil and climatic conditions play an important role in grape quality. Our results are also consistent with this (Table 5). It was found that the compositional parameters of Sauvignon Blanc grapes grown on seashore terroir are more optimal. This indicates that, in addition to technological processes, soil and climatic conditions also play an important role in the optimal formation of important components in wine composition. The Traminer grape variety had a sugar content of 21.7 g/100 cm³, titratable acidity of 4.2 g/L, and a pH of 3.44 (Table 5).

Some studies emphasize that growing grapes at high altitudes significantly influences solar radiation levels, temperature, and other environmental factors in the growing zone [28]. Higher altitudes are generally associated with more intense solar radiation, lower temperatures and humidity, and greater differences between day and night temperatures, creating extreme growing conditions. All of these factors have a significant impact on the chemical composition of grapes [29].

In studies conducted in various regions of Azerbaijan, the sugar content of the Cabernet Sauvignon variety ranged from 21.1–21.5 g/100 cm³, titratable acidity from 4.5–4.8 g/L, and pH was 2.92 [16]. Compared with these data, the Cabernet Sauvignon variety in the present study had a significantly higher sugar content, while its acidity and pH were higher than previously recorded values (Table 5).

Vine physiological characteristics, including sugar, acid, and pH accumulation, can be influenced by various factors, such as vine vigor, soil characteristics, water regime, and plant nutrition [27].

A comparative analysis of the studied varieties revealed that the highest sugar content was recorded in the Rkatsiteli variety (23.3 g/100 cm³). The lowest value was recorded for the Sauvignon Blanc variety (19.4 g/100 cm³). The highest titratable acidity was observed for Sauvignon Blanc (4.8 g/L), and the lowest for Traminer (4.2 g/L). The highest pH was recorded for Traminer (3.44), and the lowest for Shiraz (3.28) (Table 5).

When considering higher °Brix values and lower titratable acidity in grapes with low growth vigor, differences in berry weight and size may be due to the degree of ripeness [17]. At maximum grape ripeness, berry weight and size will be similar for grapes with low and medium growth vigor. When considering higher °Brix values and lower titratable acidity in grapes with low growth vigor, differences in berry weight and size may be due to the degree of ripeness [30]. When grapes reach maximum maturity, the weight and size of berries in low and medium vigor grapes will be similar [13].

Tartaric and malic acids typically comprise the majority of all organic acids found in grape berries and leaves (Table 6). As ripening progresses, tartaric acid maintains its metabolic source outside of oxidative sugar metabolism, while malic acid declines, being converted to energy and sugars. Catabolism increases with increasing temperature, while sugar accumulation increases and acidity decreases [29]. Based on the relationship between sugar concentration and acidity, differences in these parameters during ripening may be due to temperature effects, with higher temperatures promoting earlier ripening in grapes with low vigor [28].

Grapevine development involves changes in its shape. The type of development can lead to differences in total leaf area and the percentage of leaf area well illuminated by light. Consequently, the ability of grapevines to efficiently photosynthesize depends on the development system and the accompanying light microclimate of their leaves. In addition to altering the foliar light microclimate, training can influence many other variables, such as fruit bud differentiation, cluster light exposure, vine water status, and leaf transpiration. Modifying vine training systems to achieve a balance between vigor and yield has led to the development of split-canopy systems, which can simultaneously increase yield and improve fruit composition by optimizing the foliar light microclimate. Consequently, many training systems have been identified as having the potential to improve wine quality through a combination of improved foliar and fruit microclimates [22]. Such early ripening, especially after the onset of veraison, can be caused by water stress [14].

Projected climate changes in European wine regions in the coming decades could significantly alter both the range and distribution of currently cultivated grape varieties. Changes observed in recent years support these predictions. In particular, shifts in precipitation patterns will affect most European regions, increasing the risk of drought, with the effects most dramatic in the Iberian Peninsula under this scenario. Tillage practices may need to be adapted to account for changes in soil moisture and organic matter decomposition rates. While increased CO₂ concentration alone could increase grape yields and water use efficiency, more comprehensive studies predict yield reductions when considering increased temperatures and changes in solar radiation. Within the context of these changes in solar radiation, UVB levels are likely to continue to increase and have a direct impact on grape composition. This suggests that flavor development will be enhanced through changes in secondary metabolites such as flavonoids, amino acids, and carotenoids [14].

Some studies have shown that berries exposed to sunlight were smaller in size compared to those developed in the shade. Berry temperatures in sun and shade were similar, and berries exposed to light had a larger weight and diameter, especially during the early growth stage, which is associated with the effect of light on cell division and growth [15]. Differences in grape position between outer and inner rows also caused differences in air circulation around the berries. Berries in the outer rows, which have less shade, are subject to higher transpiration. Increased transpiration, especially during the early sensitive stage of berry cell development, stimulates dehydration and leads to increased stomatal permeability. This significantly affects berry composition and morphology. Such changes, by stimulating the accumulation of potassium cations to stabilize membranes, can lead to an increase in pH. This study suggests that significant differences in grape composition could be due to the combined effects

of temperature and wind. Also, as noted by various authors, the reduced acidity and increased sugar concentration in grapes from outer rows are clearly related to temperature exposure [16]. Therefore, differences in sugar concentration can be explained by differences in sunlight exposure [17]. At the same time, differences in pH between grapes from outer and inner rows may be a response to wind exposure. Our study also examined the physicochemical properties of wine samples obtained from various grape varieties.

The study results showed that the quality characteristics of the wines met the established standard (8.5–15.0%) and varied depending on the sugar concentration in the juice of the respective grape varieties (Table 6).

Residual sugar content is an important indicator of wine stability, reflecting the correctness of the technological process. All obtained values were below the maximum permissible level according to the standard (< 4.0 g/L). The mass concentration of titratable acids complied with regulatory requirements (> 3.5 g/L).

The total acid content of wine is determined by titration, which is why it is also called titratable acidity. Organic acids have a significant impact on the quality of grape juice and wine. In grape juice and wine, active acidity ranges from pH 3.0–4.2, while titratable acidity (calculated as tartaric acid) should be 5–8 g/L. Organic acids, undergoing various biochemical transformations both during grape juice fermentation and in subsequent winemaking stages, contribute to the enrichment of the resulting product with nutrients. These acids play a key role in the formation of wine's color, flavor, and aroma, participating in grape metabolism, fermentation, and wine production. The mass concentration of volatile acids was within the standard (< 1.0 g/L) (Table 6). Wine extractivity is an important indicator; studies showed that the extractive content complied with the standard (> 17.0 g/L) (Table 6).

Excessive levels of sulfur dioxide (SO₂) in food products, including wine, have a negative impact on human health. When exceeded, sulfur dioxide can convert to sulfurous acid and then sulfuric acid, causing the destruction of anthocyanins (pigment substances) and wine discoloration. Sulfur dioxide can be formed both during fermentation by certain yeasts and when it is artificially added to juice or wine. It has also been established that certain wine yeasts can naturally produce up to 50 mg/L or more of SO₂ during fermentation. Sulfur dioxide is widely used in the wine industry as an antiseptic and antioxidant at various stages of wine production [22].

Common phenolic compounds are natural components that are aromatic structures containing one or more hydroxyl groups. Polyphenol content depends significantly on a number of factors, including grape variety, the processing methods used, the type of yeast used during alcoholic fermentation, and the duration of contact between the must and the solid parts of the grapes during maceration. It should be noted that in the production of red wines, all parts of the berry are involved in the fermentation process. Therefore, the total polyphenol content in red wines is generally higher than in white wines (Fig. 2). The total phenolic content in wines produced from the Shiraz grape variety was 1764 mg/L, in Rkatsiteli – 335 mg/L, in Sauvignon Blanc – 191 mg/L, and in Traminer and Cabernet Sauvignon – 755 mg/L and 1862 mg/L, respectively (Table 6).

Anthocyanins are water-soluble flavonoid pigments that, depending on pH and, in some cases, the presence of complexing compounds, can impart red, purple, or blue hues to wine. Typically, anthocyanins are localized primarily in the

grape skin; the exception is the so-called “teinturier” varieties, in which pigments are present in both the skin and the pulp. During fermentation, particularly during the first two years of aging, monomeric anthocyanins undergo various chemical transformations, resulting in the formation of new anthocyanin pigments, which play an important role in stabilizing the wine’s color. Research has shown that anthocyanins are present in wines made from red grape varieties, and Cabernet Sauvignon has a higher concentration than other varieties (Table 6).

Tannins play a key role in the structure, flavor, and aging potential of red wine. Their concentration and composition depend on the grape variety, ripeness, and fermentation conditions. Tannins also influence the color stability and oxidation resistance of wine. During fermentation and subsequent aging, they react with other polyphenols and proteins, contributing to a more complex and harmonious flavor profile. A balanced tannin structure is essential for producing high-quality red wines with long-term shelf life. The tannin content of Shiraz wine was 2.20 g/L, Rkatsiteli 0.35 g/L, Sauvignon Blanc 0.38 g/L, Traminer 1.48 g/L, and Cabernet Sauvignon 1.93 g/L (Table 6).

Sugar concentration, titratable acidity, pH, and physicochemical parameters of the wine were assessed using one-way analysis of variance (ANOVA); significance was considered significant at $p < 0.05$. Tukey’s post-hoc test was used to analyze differences between groups using IBM SPSS version 27 software. A Pearson correlation matrix was also calculated with a significance level of $\alpha = 0.05$ for all parameters.

The limitations of our study include the fact that the research was conducted in a single vineyard and therefore may not reflect data for the entire region. Furthermore, the low organic matter content of the soil necessitates additional costs for agronomic interventions. All of this necessitates correction of the results.

Disadvantages include the fact that the studies reflect annual indicators; there are no long-term observations, and no possibility of comparing annual results. However, this could be addressed by expanding the study area and increasing the number of grape varieties and wine types.

The research’s prospects stem from the precise timing of harvesting and the refinement of raw material processing technologies. Challenges include the need for comprehensive consideration of climatic factors, algorithmic modeling of ripening dynamics, as well as testing the resilience of varieties to changing conditions.

7. Conclusions

1. The slightly alkaline soil, low electrical conductivity, and absence of salinity create favorable conditions for plant growth and development. Adequate levels of essential macronutrients, particularly potassium, contribute to yield formation and improved berry quality. However, factors limiting potential soil productivity have been identified. These include low humus content, an imbalance in cation composition with calcium dominance, and the limited availability of certain micronutrients (Fe, Zn, Mn) under elevated pH conditions. Furthermore, despite favorable physicochemical properties, irrigation water contains virtually no micronutrients, requiring their supplementation. Our study established that the marine terroir of the Absheron Peninsula significantly influences grape ripening and the physicochemical characteristics of the wines produced. The interaction of topographic factors, sea winds, solar radiation, and temperature played

a key role in shaping the sugar-acid balance of the grapes. Climate conditions in 2024 can be considered favorable for grape cultivation. They ensured stable progression through all phases of the growing cycle and created the conditions for producing high-quality grapes.

2. The mass concentration of sugars, titratable acidity, and pH values of the varieties in the imported grapes were within optimal limits. The volume fraction of ethyl alcohol, acidity, extract, and sulfur compounds in the resulting wines met established standards. The red wines (Shiraz and Cabernet Sauvignon) had higher levels of phenolic compounds, anthocyanins, and tannins, indicating a more pronounced structure and color stability.

3. Since time immemorial, only table grape varieties have been grown on the Absheron Peninsula. However, our research has shown that the maritime terroir creates favorable conditions for growing high-quality wine grapes. Introduced grape varieties easily adapt to these conditions, producing high-quality, competitive wines. All this will strengthen the sustainability of the wine industry in the region.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

Use of artificial intelligence

Model and version: Microsoft Copilot (based on GPT-4).

Usage areas: individual sentences in the Discussion section (Chapter 6), as well as grammar checking and source search for the literature review.

Tasks performed: grammar, spelling, and punctuation checking; open source keyword search. No original data, hypotheses, or conclusions were generated using AI.

Results verification: All texts and retrieved sources were manually reviewed by the authors for factual accuracy, terminological correctness, and compliance with journal standards.

Impact on conclusions: the use of AI did not influence the scientific results and conclusions of the study as it was limited to technical support (grammatical correctness and literature search).

Authors’ contributions

Movlud Huseynov: Formal analysis, Writing – original draft, Investigation; **Afet Gasimova:** Conceptualization, Methodology, Writing – review & editing; **Vugar Salimov:** Project administration, Visualization, Validation;

Garay Mirzayev: Project administration, Visualization, Validation; **Gultakin Gasimova:** Methodology, Resources, Investigation; **Umida Majnunlu:** Resources, Data Curation, Investigation.

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