



## PHYSICOCHEMICAL PARAMETERS OF WINES PRODUCED FROM INDIGENOUS AND INTRODUCED GRAPE (*VITIS VINIFERA* L.) CULTIVARS IN AZERBAIJAN

**M.A. HUSEYNOV<sup>1\*</sup>, S.A. MAMMADOVA<sup>1</sup>, S.F. RAHIMOVA<sup>1</sup>, M.H. MAHARRAMOVA<sup>1</sup>,  
 and V.S. SALIMOV<sup>2</sup>**

<sup>1</sup>Azerbaijan State University of Economics, UNEC, Baku, Azerbaijan

<sup>2</sup>Scientific Research Institute of Viticulture and Wine-making, Baku, Azerbaijan

\*Corresponding author's email: [movlud.huseynov@unec.edu.az](mailto:movlud.huseynov@unec.edu.az)

Email addresses of co-authors: [mammadova.saida.alim.2025@unec.edu.az](mailto:mammadova.saida.alim.2025@unec.edu.az), [samaya.rahimova@unec.edu.az](mailto:samaya.rahimova@unec.edu.az),  
[mehriban.maharramova@unec.edu.az](mailto:mehriban.maharramova@unec.edu.az), [vuqar.salimov@agro.gov.az](mailto:vuqar.salimov@agro.gov.az)

### SUMMARY

This study aimed to evaluate the ripening parameters of seven grape (*Vitis vinifera* L.) cultivars, Shiraz, Rkatsiteli, Sauvignon Blanc, Traminer, Cabernet Franc, Petit Verdot, and Bayanshira, cultivated in the mountain-marine zone of Aghbash Village, Shabran District, Azerbaijan. They sustained assessment through physicochemical properties of wines produced from these grape cultivars during 2024. In grape berries, determining the mass concentration of sugars, titratable acidity, and pH succeeded. In wine samples, ethanol volume fraction, residual sugar, titratable acidity, volatile acidity, extract content, total and free sulfur dioxide, total phenolic compounds, anthocyanins, and tannins underwent analysis. The results revealed the combined influence of mountains and marine factors significantly affects the grape's biochemical composition and wine quality parameters. The highest sugar concentration resulted in cultivars Cabernet Franc and Bayanshira (23.4 g/100 cm<sup>3</sup>), whereas the highest titratable acidity emerged in the cultivar Rkatsiteli (7.0 g/L). The pH values of the studied grape cultivars were within the optimal range. The physicochemical parameters of the wines complied with current regulatory requirements. The red wines exhibited the highest levels of total phenolics, anthocyanins, and tannins compared with white wines.

**Keywords:** Grape (*V. vinifera* L.) cultivars, grapes' biochemical composition, wines' physicochemical parameters, grape maturity, Caspian Sea, Greater Caucasus Mountains

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**Key findings:** The interaction of topographic factors, sea breezes, solar radiation, and temperature played a key role in shaping the sugar-acid balance of grapes (*V. vinifera* L.). The mountain-sea terroir of the Shabran Region developed favorable ecological conditions for the production of high-quality industrial grapes and wine products, confirming the potential for sustainable development of the industry in this region.

## INTRODUCTION

The geographical location of vineyards, including altitudes above sea level, proximity to water bodies, and soil mineral composition, were considerations as primary factors directly affecting the wine quality of grapes (*Vitis vinifera* L.) (Jones *et al.*, 2005; Asadullayev *et al.*, 2024). With larger water bodies slowly absorbing heat and releasing it gradually, the regions under maritime influence typically experience relatively cool summers and mild winters. Proximity to water bodies prevents sharp nocturnal temperature drops and subsequently promotes climatic stability. In viticulture and enology, the concept of terroir represents the integrated effects of geographical location, climate conditions, soil properties, and cultivation practices (Van-Leeuwen and Seguin, 2006; Musayeva *et al.*, 2026).

The vineyard placement on mountain slopes and near the sea considerably promotes varietal diversity and grape quality by maximizing solar radiation, topographic effects, and cooling marine winds. Persistent light winds improve the canopy aeration and reduce disease risks, thereby providing favorable viticultural conditions. Marine influence occurred to be most pronounced in vineyards located within several kilometers of the coastline (Jones *et al.*, 2005; Salimov *et al.*, 2025). The proximity of Shabran vineyards to the Caspian Sea enables the vineyards to benefit from the sea's moderating climatic effect and associated wind regimes. During early berry development in grapes, the synthesis of organic acids, minerals, amino acids, and phenolic precursors transpires, whereas ripening reveals characteristics of berry enlargement, acidity decline, sugar accumulation, pH increase, and aroma formation (Coombe and McCarthy, 2000; Keller, 2010). The concentrations of these compounds

determine the sensory and technological quality parameters of the grapes (Jackson, 2008).

In grapes, the phenolics tended to be viable bioactive compounds for wine quality and human health (Teixeira *et al.*, 2013; Najafov *et al.*, 2026). During winemaking, the phenolic compounds' transformation into complex pigments stabilizes wine color and enhances aromatic properties (Waterhouse, 2002; Huseynov and Aghayev, 2024). Given the economic and nutritional values of grapes, numerous studies have focused on improving the biochemical composition of grapes and their processed products. However, this process is highly complex because of the interactions among important factors, such as climate, soil, cultivars, and cultivation practices, collectively forming the terroir effect. For the production of high-quality wine, environmental conditions should limit excessive vegetative growth and promote the balanced vine development through moderate water stress and low nitrogen availability (Van-Leeuwen *et al.*, 2009; Salimov *et al.*, 2025). However, the variability in terroir components significantly affects the cluster uniformity, ripening dynamics, and berry biochemical composition (Bramley *et al.*, 2011). Specific terroir conditions enable the vineyards to develop distinctive metabolite profiles (Robinson *et al.*, 2012; Teymurov *et al.*, 2026). Solar radiation is the primary energy source for photosynthesis and plays a crucial role in the accumulation of compounds affecting grape yield and quality traits (Downey *et al.*, 2006; Sadigov *et al.*, 2026a). Increasing altitude enhances UV radiation intensity and stimulates the synthesis of phenolic and volatile bioactive compounds (Spayd *et al.*, 2002; Shukurova *et al.*, 2026). Temperature accelerates vine phenology; however, excessively high temperatures may negatively alter the berry size and quality parameters. Wind increases evapotranspiration, thereby influencing berry

size and biochemical composition (Keller, 2010; Huseynov *et al.*, 2026).

Effective canopy management that optimizes the use of climatic parameters is essential for achieving the desired grape yield with better quality. This is because climatic homogeneity is difficult to maintain in mountainous terrain, and studying mountain-marine terroir conditions is particularly important. These vineyards also contribute to rural tourism development and support ecological, social, and economic sustainability in the region. The following study aimed to evaluate the effect of terroir on ripening parameters of seven grape cultivars—Shiraz, Rkatsiteli, Sauvignon Blanc, Traminer, Cabernet Franc, Petit Verdot, and Bayanshira—grown in Aghbash Village, Shabran District, Azerbaijan, and the physicochemical properties of wines produced from these grape cultivars.

## MATERIALS AND METHODS

### Description of the experimental vineyard

The study, conducted in 2024, was on seven

grape (*V. vinifera* L.) cultivars in the vineyard located in Aghbash Village, Shabran District, Azerbaijan. The vineyard sits on the southeastern slopes of the Greater Caucasus Mountains within the Samur-Davachi plain at a distance of up to 8 km from the coast of the Caspian Sea (41°08' N, 49°08' E). The elevation of the study area ranges from -27 to 200 meters above sea level (masl). For this research, the seven technical grape cultivars, Shiraz, Rkatsiteli, Sauvignon Blanc, Traminer, Cabernet Franc, Petit Verdot, and Bayanshira, grafted onto the CO4 rootstock were samples selected. All vines were 14 years old and planted within the same vineyard divided into four blocks (Figure 1).

### Climatic conditions

Monthly climatic data for 2024 are available in Table 1. Based on the 2024 records, the average monthly air temperature (°C), precipitation (mm), and sunshine duration (hours) were the data obtained from the Qubad Meteorological Station of the National Hydrometeorological Service, Ministry of Ecology and Natural Resources, Azerbaijan (AzStat, 2025).

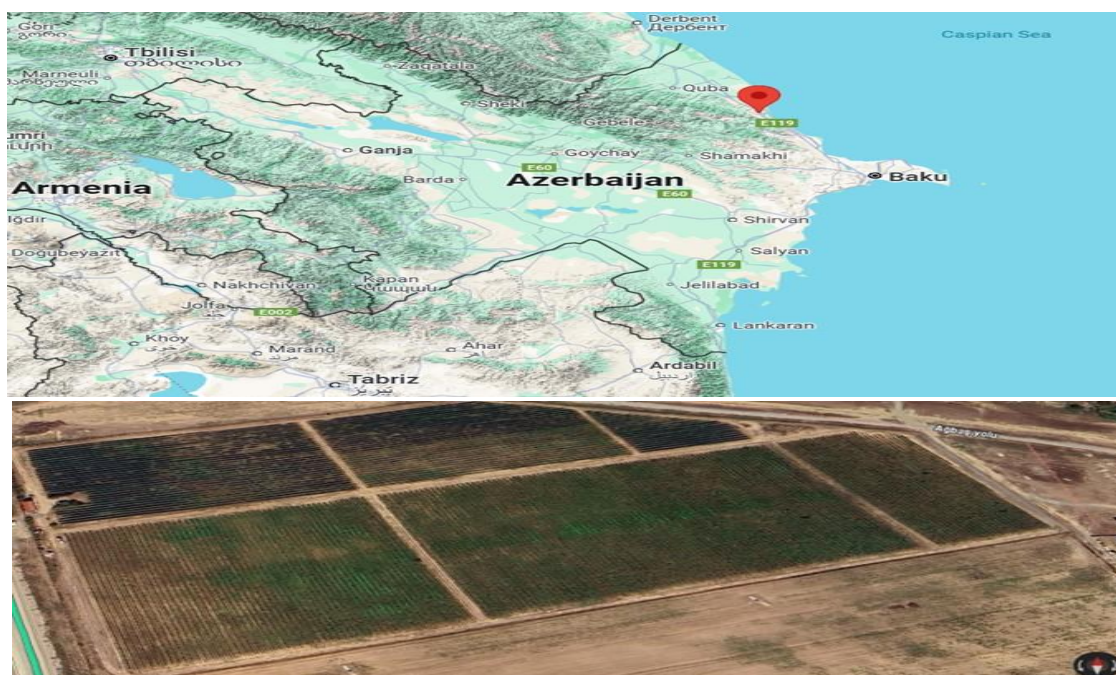


**Figure 1.** Geographical location of the vineyard under study on the map.

**Table 1.** Monthly climate data for the Year 2024.

| Months    | Average monthly air temperature (°C) | Amount of pericipitation (mm) | Continuation of sunlight (hour) |
|-----------|--------------------------------------|-------------------------------|---------------------------------|
| January   | 2.1                                  | 10.1                          | 107.7                           |
| February  | 3.1                                  | 16.2                          | 123.7                           |
| March     | 5.4                                  | 15.0                          | 80.4                            |
| April     | 16.0                                 | 1.9                           | 238.0                           |
| May       | 15.7                                 | 38.3                          | 161.8                           |
| June      | 25.7                                 | 20.7                          | 254.3                           |
| July      | 26.2                                 | 23.0                          | 241.3                           |
| August    | 25.7                                 | 0.3                           | 258.2                           |
| September | 25.6                                 | 7.8                           | 182.0                           |
| October   | 14.1                                 | 24.2                          | 147.0                           |
| November  | 8.2                                  | 35.1                          | 107.7                           |
| December  | 4.4                                  | 18.2                          | 97.7                            |

### Experimental sampling

In minimizing temperature effects and preserving characteristic quality, samples' collection proceeded on clear mornings between 05:00 am and 11:00 am, with absence of recent rainfall, heavy fog, and mist. The samples entailed placed into transparent airtight plastic bags (Ziploc type) measuring 30 cm × 15 cm. Each sample bag received labels with the appropriate identifier before transporting from the vineyard to the laboratory in a portable refrigerated container with ice. Sampling took place three days before harvest, according to the established methodology. The experimental design had five replications, following the protocol for the study of eno-chemical and eno-carpological characteristics of grapes (Huseynov *et al.*, 2025; Amanova *et al.*, 2026). Each replicate comprised 15 clusters. Fifteen berries collected from the middle third of each cluster resulted in 225 berries per replication.

### Juice extraction

During juice extraction, crushing berries used a mortar and sieve to prevent seed breakage, with the extracted juice transferred into 250 mL containers. The subsequent filtering of juice through sieves and funnels removed solid particles. The juice obtained from the berries underwent analysis for sugar concentration, titratable acidity (TA), and pH to monitor ripening.

### Winemaking procedure

Grapes reached harvesting at the physiological maturity with a must density of 1.084–1.100 g/mL before transporting to the processing facility under refrigerated conditions. Vinification continued in temperature-controlled fermentation tanks. During destemming and crushing, sulfitation used powdered potassium metabisulfite. The addition of yeast (Laffort FX10) and yeast nutrient (Laffort Dynastart) sought to initiate maceration and alcoholic fermentation. The 'pigeage' technique, applied during maceration, enabled completing maceration when the density decreased below the 1.000, after which, sugar analysis followed. Initiating malolactic fermentation ensued by adding bacteria (Laffort 450 Preac) and bacterial nutrient (Laffort PrePreac), with the temperature maintained at 22 °C ± 1 °C. Malolactic fermentation monitoring continued regularly by measuring the malic acid and volatile acidity. After completion of malolactic fermentation, wines underwent racking with aeration and subsequent sulfitation.

### Analytical evaluation

The grape parameters used to determine the harvest timing were sugar content, titratable acidity, and pH. The sugar content and acidity determination were according to OIV methods (Aurand, 2017). Titratable acidity measurement was by titration to pH 7 at 20 °C, expressed as

g/L tartaric acid. Determining total soluble solids (°Brix) used a refractometer. In grape cultivar juice, the detection of sugar concentration was according to GOST 27198-87, titratable acidity was according to GOST 25550-82, and pH used a pH meter. In wine samples, ethanol volume fraction determination was according to GOST 32095-2013, residual sugar according to GOST 13192-73, titratable acidity according to GOST 32114-2013, volatile acidity according to GOST 32001-2012, extract according to GOST 32000-2012, and total and free sulfur dioxide according to GOST 32115-2013.

### Statistical analysis

The recorded data based on various parameters, such as sugar concentration, titratable acidity, pH for ripening assessment of grape cultivars, and the physicochemical parameters of the wines, succeeded in their evaluation using one-way analysis of variance. The application of Tukey's post hoc test was at  $p < 0.05$  using IBM SPSS Statistics 27 software. A Pearson correlation matrix with a significance level of  $\alpha = 0.05$  also attained calculations for all parameters.

## RESULTS AND DISCUSSION

The results on the sugar concentration, titratable acidity, and pH values of the grape (*V. vinifera* L.) cultivars appear in Table 2, while the physicochemical parameters of the wine samples are available in Table 3. The grape cultivar Syrah was evident with the mass concentration of sugars (21.8 g/100 cm<sup>3</sup>), mass concentration of titratable acids (6.0 g/L), and the pH value of 3.28. According to a past study conducted by Salimov *et al.* (2022), the concentration of sugars in the cultivar Syrah berries across different regions of Azerbaijan ranged from 18.7 to 21.1 g/100 cm<sup>3</sup>, while titratable acidity varied between 5.27 and 7.06 g/L. In a study carried out under the conditions of Shamakhi and Absheron, the determined pH value of the cultivar Syrah was 3.48. In the presented study, the mass concentration of sugars in the cultivar Syrah corresponded to the

upper limit of previously obtained results, whereas the mass concentration of titratable acids and the pH value occurred to be relatively higher.

In the grape cultivar Rkatsiteli, the mass concentration of sugars was 21.8 g/100 cm<sup>3</sup>, the mass concentration of titratable acids was 7.0 g/L, and the pH value was 3.38. According to past research conducted in the Absheron Region, the concentration of sugars was 19.2 g/100 cm<sup>3</sup>, while titratable acidity was 6.5 g/L in the cultivar Rkatsiteli berries (Salimov *et al.*, 2022). In another conducted study, the mass concentration of sugars in the grape cultivar Rkatsiteli was 19.5 g/100 cm<sup>3</sup>, and titratable acidity was 5.63 g/L (Salimov *et al.*, 2022).

In the grape cultivar Sauvignon Blanc, the mass concentration of sugars was 19.1 g/100 cm<sup>3</sup>, the mass concentration of titratable acids was 6.3 g/L, and the pH value was 3.30. According to Salimov *et al.* (2022), the sugar concentration in the grape cultivar Sauvignon Blanc ranged from 19.2 to 22.6 g/100 cm<sup>3</sup>, while the mass concentration of titratable acids was 6.2 g/L. Moreover, in the previous study of Salimov *et al.* (2022), the soil and climatic conditions play a pivotal role in grape yield and quality parameters. The present results were also getting greater support from these past findings.

The compositional parameters of the cultivar Sauvignon Blanc grown in a terroir located between mountains and the sea were more optimal. The results revealed that in addition to technological processes, soil and climatic conditions also play a considerable role in the formation of important components in the composition of produced wines. The grape cultivar Sauvignon Blanc showed a significant difference only in °Brix. The higher sugar concentration was in association with greater exposure to sunlight due to reduced shading, resulting in an increased photosynthetic activity. Previous studies reported the clusters exposed to sunlight possess higher levels of soluble solids and other berry constituents (Spayd *et al.*, 2002). However, the similarity in the pH values of the studied grape cultivars was consistent with the findings reported by Filippetti *et al.* (2013).

**Table 2.** Density of berry juice, mass concentration of sugars, titratable acidity (TA), and pH values in different grape cultivars.

| Parameters                                            | Grape cultivars |            |                 |          |                |              |            |
|-------------------------------------------------------|-----------------|------------|-----------------|----------|----------------|--------------|------------|
|                                                       | Syrah           | Rkatsiteli | Sauvignon blanc | Traminer | Cabernet Franc | Petit Verdot | Bayanshira |
| Density (g/mL)                                        | 1.092           | 1.092      | 1.084           | 1.090    | 1.098          | 1.091        | 1.098      |
| Mass concentration of sugars (g/100 cm <sup>3</sup> ) | 21.8            | 21.8       | 19.1            | 21.2     | 23.4           | 21.5         | 23.4       |
| Mass concentration of titratable acids (g/L)          | 6.0             | 7.0        | 6.3             | 6.0      | 5.2            | 5.0          | 6.0        |
| pH                                                    | 3.28            | 3.38       | 3.30            | 3.44     | 3.38           | 3.24         | 3.21       |

**Table 3.** Physicochemical parameters of the produced wine samples.

| Parameters                           | Grape cultivars |            |                 |          |                |              |            |          |
|--------------------------------------|-----------------|------------|-----------------|----------|----------------|--------------|------------|----------|
|                                      | Syrah           | Rkatsiteli | Sauvignon Blanc | Traminer | Cabernet Franc | Petit Verdot | Bayanshira | Standard |
| Ethyl alcohol content (%)            | 13.0            | 12.9       | 11.5            | 12.7     | 14.0           | 12.6         | 13.7       | 8.5–15.0 |
| Residual sugar (g/L)                 | 3.0             | 2.8        | 2.2             | 2.0      | 2.3            | 2.8          | 3.1        | < 4.0    |
| Titratable acidity (g/L)             | 5.4             | 6.2        | 5.6             | 5.8      | 5.0            | 4.5          | 5.3        | > 3.5    |
| Volatile acidity (g/L)               | 0.46            | 0.41       | 0.31            | 0.34     | 0.62           | 0.26         | 0.40       | < 1.0    |
| Extract content (g/L)                | 21.8            | 18.6       | 18.2            | 18.4     | 22.0           | 18.1         | 18.0       | > 16.0   |
| Total and free sulfur dioxide (mg/L) | 109/23          | 102/22     | 91/20           | 98/22    | 118/18         | 132/21       | 94/19      | < 200    |
| Total phenolic compounds (mg/L)      | 3134            | 357        | 287             | 887      | 2762           | 3728         | 381        | -        |
| Anthocyanins (mg/L)                  | 391             | -          | -               | 195      | 390            | 478          | -          | -        |
| Tannins (g/L)                        | 2.63            | 0.72       | 0.47            | 1.58     | 2.47           | 3.80         | 0.47       | -        |

In the grape cultivar Traminer, the values for mass concentration of sugars and titratable acids and the pH were 21.2 g/100 cm<sup>3</sup>, 6.0 g/L, and 3.44, respectively. According to the research conducted by Salimov *et al.* (2022) in the regions of Gabala and Shabran, the concentration of sugars ranged from 20.0 to 21.2 g/100 cm<sup>3</sup>, and the mass concentration of titratable acidity varied between 5.4 and 6.0 g/L. Meanwhile, the pH value was 3.40 in the grape cultivar Traminer berries. Based on the study results, the mass concentration of sugars and titratable acids and pH values were consistent with the values reported in previous studies.

The highest mass concentration of sugars resulted in the grape cultivar Cabernet Franc (23.4 g/100 cm<sup>3</sup>), whereas the lowest value was apparent in the cultivar Sauvignon Blanc (21.2 g/100 cm<sup>3</sup>). The highest titratable acidity appeared in the cultivar Rkatsiteli (7.0 g/L), while the lowest surfaced in the cultivar Cabernet Franc (5.2 g/L). Regarding pH values, the highest value was notable in the cultivar Traminer (3.44), while the lowest was in the cultivar Syrah (3.28). The higher °Brix values and lower titratable acidity levels in low-vigor vines may be due to the variations in berry weight and size at the ripening stage (Conde *et al.*, 2007). At full maturity, berry weight and

size of low- and medium-vigor vines were considerably the same (Bramley *et al.*, 2011; Gumbatov *et al.*, 2024). The tartaric and malic acids generally constitute most organic acids in grape berries and leaves.

Among the studied grape cultivars, Petit Verdot and Bayanshira demonstrated comparatively high berry juice density (1.091 and 1.098 g/mL, respectively). Bayanshira showed one of the highest sugar concentrations (23.4 g/100 cm<sup>3</sup>), indicating good technological maturity and potential for higher alcohol formation during fermentation. Petit Verdot also exhibited relatively high sugar accumulation (21.5 g/100 cm<sup>3</sup>) combined with the lowest titratable acidity (5.0 g/L), which could positively influence wine balance and sensory characteristics. The pH values of Petit Verdot (3.24) and Bayanshira (3.21) remained within the optimal range for grape processing and wine stability. These findings demonstrate the favorable biochemical characteristics of both cultivars and support their suitability for quality wine production.

With ripening, the metabolic origin of tartaric acid remains largely independent of oxidative sugar metabolism, whereas malic acid decreases during ripening, becoming converted into energy and sugars. The rate of catabolism enhanced with the rising temperature, simultaneously reducing acidity and enhancing sugar accumulation (Conde *et al.*, 2007; Sadigov *et al.*, 2026b). Based on the relationship between sugar concentration and acidity, the observed differences were considerably driven by the temperature effects during ripening, where higher temperatures in low-vigor vines accelerate maturation. This early ripening may also have an association with post-véraison water deficit conditions (Castellarin *et al.*, 2007; Huseynov *et al.*, 2026b; Huseynov *et al.*, 2026c).

Under mountain-marine terroir conditions, Madrasa grapes exhibited higher sugar concentration with comparable acidity, whereas Merlot grapes showed similar sugar levels with lower acidity. These results were not greatly analogous to previous studies (De-Oliveira *et al.*, 2019). Those studies reported that higher temperatures at lower elevations reduce the acidity through malic acid catabolism

while enhancing the sugar concentration. Therefore, in the presented study, temperature alone does not appear to explain the results, and the wind may have contributed to temperature regulation in the study area. The elevated sugar concentration in Madrasa grapes and the higher acidity in Cabernet Sauvignon grapes could refer to increased solar radiation boosting the photosynthetic activity. These results gained corroboration but are conflicting with findings previously reported by De-Oliveira *et al.* (2019).

The effect of in-row vine position within the vineyard on berry ripening also received evaluation. In Merlot, the significant differences were evident between outer-row and inner-row vines for titratable acidity and °Brix. Titratable acidity was higher in inner-row vines, whereas °Brix values were higher in outer-row vines. A nonsignificant difference was noticeable for pH between the inner and outer rows. In Cabernet Sauvignon, significant differences between inner and outer rows appeared for both the °Brix and pH. The differences in primary ecological parameters between inner and outer rows include solar radiation within the canopy, wind exposure, and humidity. Based on the canopy position, outer-row grapes were in higher exposure to solar radiation. Daytime berry temperature depends on the time of day and solar conditions. The optimal temperature for grape berry growth ranges between 25 °C and 30 °C (Hale and Buttrick, 1974; Kuliiev *et al.*, 2026; Mammadov *et al.*, 2026). Some studies also reported that sun-exposed berries occurred to be smaller than shaded berries (Crippen and Morrison, 1986). However, other studies revealed similar berry temperatures but greater berry weight and diameter in sun-exposed clusters, particularly due to light-mediated effects on early cell division and enlargement (Dokoozlian and Kliewer, 1996).

Differences in vine position between outer and inner rows also influenced the wind circulation around the vines. Vines in the less shaded outer rows sustained higher transpiration rates. Increased transpiration, particularly during early berry development when cells are sensitive, may stimulate dehydration and enhance stomatal conductance in berries. This process significantly affects the

berry composition and morphology. Such effects could also promote potassium accumulation in berries, leading to increased pH through membrane stabilization. In the presented study, the significant compositional differences in grapes likely resulted from the combined effects of temperature and wind. As reported in several studies, the lower acidity and higher sugar concentration in outer-row grapes were obviously temperature-related (Conde *et al.*, 2007; De-Oliveira *et al.*, 2019). Thus, the variations in sugar concentration can refer to differences in solar exposure.

The alcohol by volume (ABV) of the wines was 13.0% for the grape cultivar Syrah, 12.9% for Rkatsiteli, 11.5% for Sauvignon Blanc, 12.7% for Traminer, and 14.0% for the cultivar Cabernet Franc. These values fell within the standard range (8.5%–15.0%) and varied according to the sugar concentration of the grapes. Residual sugar was 3.0 g/L in the cultivar Syrah wine, 2.8 g/L in Rkatsiteli, 2.2 g/L in Sauvignon Blanc, 2.0 g/L in Traminer, and 2.3 g/L in the grape cultivar Cabernet Franc. Residual sugar was important for wine stability and revealed proper technological processing, and all values were below the maximum permitted level (< 4.0 g/L). Titratable acidity was 5.4 g/L in the grape cultivar Syrah wine, 6.2 g/L in Rkatsiteli, 5.6 g/L in Sauvignon Blanc, 5.8 g/L in Traminer, and 5.0 g/L in the cultivar Cabernet Franc, all complying with the standard requirement (> 3.5 g/L). Non-volatile aliphatic acids have become the natural acids of grapes and correspond to the total or titratable acidity of wine. The recommended active acidity of grape juice and wine was the pH 3.0–4.2, while titratable acidity (as tartaric acid) should range between 5 and 8 g/L (Nabiyev, 2010).

Volatile acidity was 0.46 g/L in the grape cultivar Syrah wine, 0.41 g/L in Rkatsiteli, 0.31 g/L in Sauvignon Blanc, 0.34 g/L in Traminer, and 0.62 g/L in the cultivar Cabernet Franc, and these values were within the acceptable range (< 1.0 g/L). Extract content was 21.8 g/L in the cultivar Syrah wine, 18.6 g/L in Rkatsiteli, 18.2 g/L in Sauvignon Blanc, 18.4 g/L in Traminer, and 22.0 g/L in the cultivar Cabernet Franc, meeting the standard

requirement (> 17.0 g/L). Total sulfur dioxide was 109 mg/L in the cultivar Syrah wine with 23 mg/L free SO<sub>2</sub>; in Rkatsiteli, the values were 102 and 22 mg/L; in Sauvignon Blanc, 91 and 20 mg/L; in Traminer, 98 and 22 mg/L; and in the cultivar Cabernet Franc, 118 and 18 mg/L. These values were also below the maximum permitted level (< 200 mg/L). Excess SO<sub>2</sub> in wine is unacceptable because elevated levels may negatively affect the human health (Nabiyev, 2010).

Total phenolic content was 3134 mg/L in the grape cultivar Syrah wine, 357 mg/L in Rkatsiteli, 287 mg/L in Sauvignon Blanc, 887 mg/L in Traminer, and 2762 mg/L in the cultivar Cabernet Franc (Figure 2). Phenolic compounds are natural components comprising aromatic rings bearing one or more hydroxyl groups. Polyphenol composition considerably depends on the grape cultivars, applied technological processes, yeast strains used in alcoholic fermentation, and the duration of skin contact during maceration. In red winemaking, all the grape components participate in fermentation; therefore, the total polyphenols appear to be higher in red wines than in white wines (Gutiérrez-Escobar *et al.*, 2021).

Anthocyanin content was 391 mg/L in the grape cultivar Syrah wine, 195 mg/L in Traminer, and 390 mg/L in the cultivar Cabernet Franc, whereas no anthocyanins were evident in wines produced from the white grape cultivars Rkatsiteli and Sauvignon Blanc. Color is one of the principal quality parameters of red wines and originates mainly from anthocyanins formed during vinification. Anthocyanins are water-soluble flavonoid pigments capable of producing red, purple, and blue hues depending on pH and, in some cases, complexing agents. These anthocyanins primarily exist in grape skins, except in teinturier cultivars, wherein they are present in both skins and pulp. During fermentation, particularly within the first one to two years of wine evolution, monomeric anthocyanins undergo various chemical reactions forming new pigment derivatives that play a crucial role in color stability (He *et al.*, 2012).

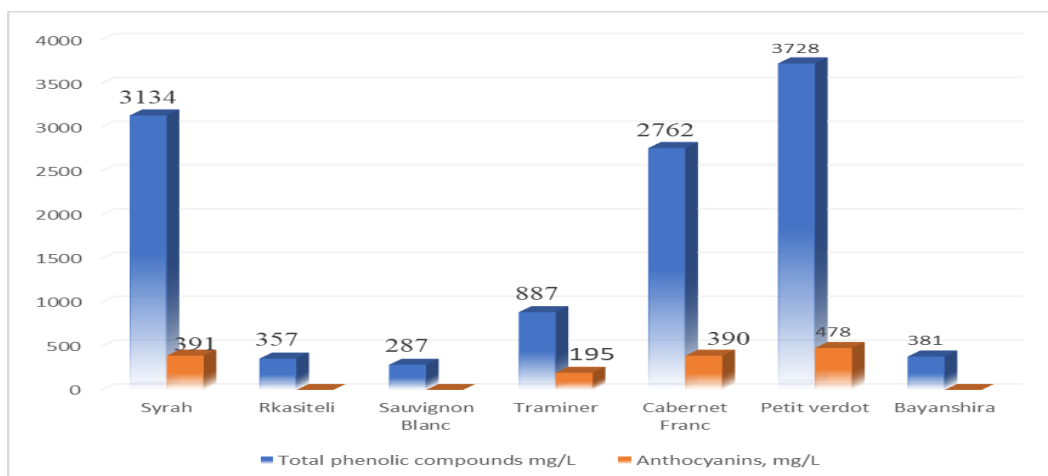


**Figure 2.** Total content of phenolic compounds (mg/L) and anthocyanins (mg/L) in the analyzed wine samples.

Among the investigated wine samples, Petit Verdot and Bayanshira demonstrated favorable physicochemical characteristics. Bayanshira wine exhibited relatively high ethyl alcohol content (13.7%) and residual sugar concentration (3.1 g/L), indicating good grape maturity and efficient fermentation performance. Petit Verdot wine expressed characteristics of comparatively low titratable acidity (4.5 g/L) and volatile acidity (0.26 g/L), which could positively affect wine balance and microbiological stability. In addition, Petit Verdot showed the highest concentrations of total phenolic compounds (3728 mg/L), anthocyanins (478 mg/L), and tannins (3.80 g/L) among all investigated cultivars, suggesting strong antioxidant potential, intense color formation, and enhanced structural properties of the wine. The physicochemical parameters of both cultivars were within the acceptable standard ranges, confirming their suitability for high-quality wine production.

Tannin content was 2.63 g/L in the grape cultivar Syrah wine, 0.72 g/L in Rkatsiteli, 0.47 g/L in Sauvignon Blanc, 1.58 g/L in Traminer, and 2.47 g/L in the cultivar Cabernet Franc. Wine tannins are the natural polyphenolic compounds derived mainly from grape skins and seeds. Tannins play a crucial role in the structure, sensory profile, and aging potential of red wines. Their concentration and composition vary, depending on the grape cultivars, ripeness

level, and fermentation conditions. Tannins also influence the color stability and resistance to oxidation. During fermentation and maturation, tannins react with other polyphenols and proteins, enriching the wine's sensory profile. A balanced tannin structure was essential for the long-term aging capacity and quality development of premium red wines (Cheynier *et al.*, 2006).

## CONCLUSIONS

Based on the research findings, the study determined that the mountain-marine terroir of the Shabran Region exerts a significant influence on the grape (*V. vinifera* L.) development and on the physicochemical properties of the wines produced. Significant differences were evident among the grape cultivars for the sugar concentration, titratable acidity, and pH, and these values were within optimal ranges. The volumetric fractions of ethyl alcohol, acidity, extract, and sulfur compounds in the wines complied with established standards. Higher levels of phenolic compounds, anthocyanins, and tannins succeeded in their identification in red wines (obtained from cultivars Syrah and Cabernet Franc), which contributed to improved structural expression and color stability. The combined effects of topographic factors, marine winds, solar

radiation, and temperature played a crucial role in the formation of the sugar-acid ratio in grapes.

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