The Impact of Climate Change on Vineyard Altitude

Rauf Asadullayev[1*], Khadija Mammadova[1], Khuraman Abasova[1], Aida Najafova[1], Magsud Gurbanov[2]

[1]Scientific Research Institute for Viticulture and Wine-making under the Ministry of Agriculture, Baku, Azerbaijan
[2]Institute of Botany of the National Academy of Sciences, Baku, Azerbaijan
asadullayevrauf@gmail.com

Abstract. As a result of abnormal heat – a manifestation of climate change – in recent years, the grapes reached maturity considerably earlier than usual; the process of changing the sugar/acidity ratio in early-ripening varieties slowed down significantly, while in late-ripening grapes, the rise in sugar content and reduction in acidity continued. According to the PRECIS model, from 2021 to 2050, the mean temperature in Azerbaijan is expected to rise by 1.5°C-1.6 °C, and precipitation by 0-20%, depending on location. Now, vineyards are located mainly at altitudes of 800-900 m above sea level, while the upper frontier of viticulture is around 1100-1300 m. Considering that every 100 m of elevation leads to a decrease in temperature by 0,6°C, it is possible to predict that climate warming will move the upper frontier of viticulture by 200-450 m by 2050. This shift will create favorable conditions for new vineyards in high-mountain areas located at 1400-1700 m above sea level, including in the East Zangezur economic region of Azerbaijan, which was recently returned to government control.

Keywords: Natural conditions, Viticulture, Climate Change

1. Introduction

The shape of the surface – its relief - heavily influences the ecological conditions of the area, especially in changes in meteorological conditions in close-to-surface air layers. The influence of the relief on the climate in the area is strong and comprises all meteorological factors: illumination, warmth, precipitation, winds, etc. In mountainous regions with complex climatic conditions, some characteristics are most subject to changes, e.g., isolation, temperature regime, and humidity regime [1,2].

Viticulture is among the activities most affected by climate change. The impact of climate change on grapes and, as a result, the wines is different and complex. On the one hand, earlier ripening allows grapes to enter the market earlier; however, the harvest period shortens almost twofold, which causes stress. Also, though the plants may adapt to the new climatic conditions, the temperature change first influences the quality of the grapes and their wine. The vegetation period in viticulture occurs when the sum of active temperatures ranges from 2500 to 3500°C. In the dormancy period, the grape plant can bear the temperature of - 12°, and some varieties – to -15 -20°. In the period of dormancy, the grape plant can withstand the temperature of -12° below zero, and certain grape varieties - up to -15 -20°. On launching the vineyards in areas

R. Rzayev et al. (eds.), *Proceedings of the International Conference on Current Problems in Engineering and Applied Sciences (ICCPEAS 2025)*, Advances in Engineering Research 299,
https://doi.org/10.2991/978-94-6239-668-5_62

located above 900 m, it should be taken into consideration that, compared to the zones below 800 m, the agro-climatic conditions change significantly: the vegetation period is shorter, the sum of active temperatures during active vegetation is lower, there are lower air temperatures, and more intensive frosts. Under such conditions, grape growing is possible with the right selection of early-ripening, frost-tolerant varieties [1,3].

In mountainous regions, due to the high intensity of the daytime solar radiation, there are significant differences between the air temperature in the close-to-surface layer and the temperature of the soil's upper layer, which should be considered in viticulture. In the highlands, there is quite a considerable decrease in soil temperature at night using radial emission. The altitude of a zone also affects an area's humidity: in the South Caucasus, precipitation increases by approximately 20% for every 100 m of elevation gained. In this connection, when evaluating the thermal resources and humidity in mountainous areas, appropriate amendments need to be made. The further south the location, the higher it is possible to cultivate the grapes. As altitude increases, climatic indicators such as the sum of active temperature and, in turn, the warm supply for different grape variety groups by ripening time, change considerably. Altitude plays an important role when choosing the grape assortment because, as one ascends higher in the mountains, reduced warmth means that the vegetation period necessary for full ripening of a definite variety increases [2,4].

The dynamics of the grape ripening are also heavily influenced by the area's altitude. Sugar content in the juice of the same grape variety drops by 0,8-1,0% per 100 m, and acidity rises by 0,9 g/l. Thus, the altitude might significantly affect the determination of the regional grape assortment and specialization of production. In the tropics, European varieties are grown at an altitude of 2000 m above sea level and even higher. In the Himalayas, grapes grow at a height of up to 2700 m. In hot countries, grapes grow at altitudes above 700 m and 1000 m; however, wild grape plants grow at an altitude of 1750-2000 m. Some vineyards in the South Caucasus are located at an altitude of 800 m and above. Generally, in a moderately warm climate, vineyards are located at an altitude of 400-600 m, and in a moderately cool climate, at 150-250 m. The hilly relief is more favourable for vineyards because of the protection it provides. On the slopes, especially the eastern and southeastern slopes, fungal diseases and rots develop less. The direction of mountains or hill ranges, for example, from the North to the South, or from the East to the West, affects the conditions of grape cultivation differently, creating various complexes of the main factors – warm, humidity, light, etc. – that determine the success of the growing, the quantity, and the quality of the yield [5,6].

The absolute height of a region greatly affects its temperature regime. The upper part above sea level, the lower part is the temperature. Ascending for 1 km can lower the temperature by 4-8°, which is equal to approaching the pole for 10° of latitude, or 1000 km. The size of the temperature gradient varies by region and time of year. For example, in the Caucasus, the drop per 100 m makes 0,5°, with seasonal hesitations from 0,4 to 0,6°. On average, it could be assumed that for every 100 m increase in altitude, the temperature drops by 0.6° [1].

Traditionally, the narrow strip between 35 and 50 parallels is considered optimal for viticulture. But with global warming, this changes. While wine-makers in the North benefit from new opportunities, those in the South can face the risks of drought and wildfires. Also, shifting to varieties adapted to climate change could break multi-centennial traditions and raise questions about how to cultivate the varieties that need irrigation [3,7].

Increasing viticulture altitude due to climate change allows growing grapes in areas previously considered unsuitable for cultivation. The influence of high altitude varies by grape variety. The higher altitudes generally lead to higher acidity and alcohol levels in wine, but don't change its colour. However, climate change directly impacts alcohol content, as the hotter vegetation period results in higher sugar conversion to alcohol [4,6]

Climate change has varied and complex effects on viticulture. On the one hand, earlier ripening allows grapes to enter the market earlier; however, with the yield period nearly halved, harvesting should be completed in a shorter timeframe. Also, while plants adapt to the new climatic conditions, rising temperatures affect the quality of the grapes and, therefore, the wines, and this influence could be negative as well. So, adaptation to climate change, scientifically based evaluation of the main impacting factors, and in-depth study of climate models and environmental influences are essential [8-12].

2. Natural conditions

The complex relief of the Republic of Azerbaijan, from the flat lowlands of the Kura-Araks basin, with an elevation of 28 m below sea level, to high-mountain plateaus at up to 4485 m above sea level, provides a wide diversity of climatic, soil, and other conditions. On the country's territory, almost all world climate types are present, excluding tropical and arid ones; more than 30 soil types, about 6000 plant species, etc. By the altitude zones, the territory of the republic, according to the height above sea level, could be divided into several orographic belts with the relevant percentages in the total square of the country (Fig.1):

below 0 m – 18%;
0-200 m – 24%;
200-500 m – 15,5%;
500-1000 m – 15,5%;
1000-1500 m – 12%;
1500-2000 m – 7,5%;
2000-2500 m – 4%;
2500-3000 m – 2,5%;
above 3000 m – 1%.

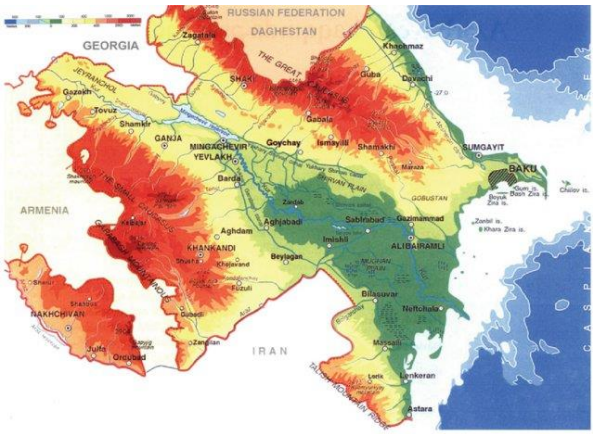

Fig. 1. Orographic map of Azerbaijan

Despite its diversity, the territory could be conditionally divided into two main parts, differing from each other by the altitude and character of the relief and by the agricultural methods, in particular: lowlands (height up to 200 m), which occupy 42% of the country territory, where the viticulture is possible only in the conditions of irrigation, and the rest, mountainous part (52%), with a system of rainfed and semi-rainfed viticulture [2,3].

As is known, each grape variety requires a specific amount of active temperatures measured as the total of average daily temperatures above 10° during the growing season, i.e., from bud break to full maturity. Naturally, with the wide orographic diversity of the country, natural factors, particularly multiannual sums of the active temperatures in different geographical locations that depend mainly on the height of the regions above sea level, sharply hesitate between 1000-1500 to 4000-4500 and more, annual precipitation sums from 150-180 (Baku, Alyat) to 1300-1500 (Lenkoran), the winds speed from 0,5 to 25 m/sec [3,7,13].

3. Impact of climate change

An increase in mean temperature by only 1-2°C could lead to considerable uncertainty in vineyards. Our studies on the dynamics of the change of chemical composition in the berries during the final stage of maturation showed that although regular processes occurred in all variants of the experiment - an increase in sugar content and a decrease in acidity, there was observed that the intensity of these processes in the season of 2021 was significantly lower than in 2020. This can be explained by extremely hot weather at the end of the summer season, which caused the grapes to reach full maturity much earlier than usual.

According to the scenario built on the PRECIS model, between 2021 and 2050, the mean temperature in Azerbaijan is expected to increase by 1,5°C-1,6°C, and precipitation could increase by 0-20% depending on the region. In a longer perspective (2071-2100), the mean temperature will increase by 5°C, and precipitation by 20-80% (by regions) compared to 1990 [14].

Table 1. Expected climatic changes (PRECIS model)

Period	Increase (compared to the period of 1961-1990)	
	Annual mean temperature, °C	Annual precipitation, %
2021-2050	1,5-1,6	10-20
2071-2100	2-7	20-80

Also, there is observed a tendency for the number of days with strong winds (more than 25 m/sec) to rise [8]. In our experiments on the evaluation of the grape storage ability in connection with SAT, we found that the grapes picked on SAT of 3300-3500°C are most suitable for long-term storage; however, some results fell out of the general background (Fig.2).

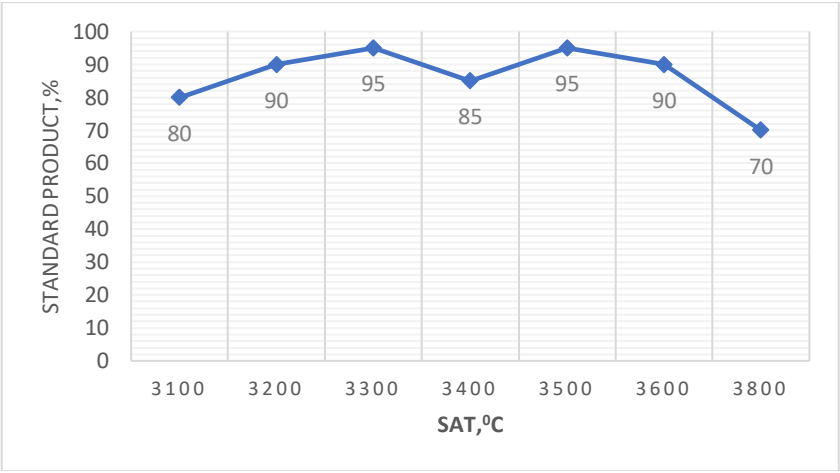

Figure 2. Output of standard products depending on SAT

Having thoroughly analyzed the available data, we concluded that these deviations were caused by strong winds preceding the harvest. This is almost the only negative factor for table viticulture on the Absheron peninsula, which is very rich in local grape varieties [15,16].

Another exciting outcome of the PRECIS model is the difference between precipitation and total evaporation sizes. This indicator notably decreases in the country's territory during the scenario period. With a 20-80% increase in precipitation, evaporation is expected to rise even more. As a result, the water supply could fall by 0,2-0,5 mm per day, leading to a sharp increase in irrigation demands. Although these areas are rainfed ones, it is possible to use innovative irrigation technologies by conducting the necessary measures for the preservation of the atmospheric humidity collected in the soil during the months with large amounts of precipitation, building basins for collecting the atmospheric precipitation for easy watering of the vineyards, if necessary, in the future.

From this point of view, climate change, though causing some difficulties, will also create new opportunities for developing viticulture in the mountainous areas. Nowadays, vineyards are often established at altitudes of 800-900 m above sea level, while the upper limit of viticulture lies at 1100-1300 m. Taking into account that an increase in height for each 100 m leads to a decrease of temperature by 0,6°C, it is possible that by 2050 the upcoming warming of the climate will lift the upper frontier of viticulture by 200-450 m; thus, the favourable conditions for viticulture are expected at the height of 1400-1700 m above sea level.

For example, the highland areas of the East Zangezur economic region are at an altitude of 900-1200 m above sea level and even higher. The sum of active temperatures reaches 3200-3300°C; annual precipitation is 430-595 mm; main soil types are grey-chestnut with a granular-nut structure, clayey-granular, skeletal. Nevertheless, back in the '60s of the 20th century, some wine (Madrasa, Pinot group, Riesling) and table grape varieties (Ag Khalili, Qara shany, Kahraba, Pearl of Csaba (Csabagyöngye), White Chasselas) [3,16] were cultivated in this region.

Due to the increase in rainfall, there is an expected rise in production (4-5% by 2050 in rainfed vineyards). An increase in temperature will also positively affect the quality of the must. These changes are expected to boost the sugar content in berries by 2-3%, and increase their acidity by about 1%. These conditions would be

favourable for producing high-quality table, semi-sweet, and dessert wines, and less fit for sparkling and light table wines.

4. Conclusion

The findings of this study highlight that climate change is a critical factor influencing viticulture in Azerbaijan, significantly affecting grape development, composition, and overall production conditions. Rising temperatures are accelerating ripening processes and altering the balance between sugar and acidity, which has direct implications for yield quality and wine characteristics. At the same time, climate projections suggest a notable upward shift in suitable viticulture zones by 200–450 m by 2050, creating new opportunities for vineyard expansion in higher-altitude regions. However, these positive prospects are accompanied by challenges such as increased evapotranspiration, greater irrigation demands, and heightened exposure to climatic variability. Addressing these changes will require the adoption of adaptive management practices, careful selection of grape varieties, and the application of scientifically grounded approaches to ensure the long-term sustainability of the viticulture sector..

Acknowledgements. The authors extend their thanks to the staff of the Azerbaijani Scientific Research Institute of Viticulture and Wine-making for the facilities provided.

Disclosure of Interests. The authors have no competing interests.

References

1. P.P.Blagonravov: Choosing the site for launching a vineyard and selecting the varieties. Moscow (1958)
2. Regional Climate Change Impacts Study for the South Caucasus Region, pp.2-4, 37-43 Tbilisi (2011) https://eiec.gov.ge/Ge/Documents/ViewFile/526#:~:text=As%20the%20South%20Caucasus%20is,preventive%20public%20health%20measures%20(e.g.)
3. F.D.Novruzov: Agrobiological resources of Azerbaijan SSR. Leningrad (1975)
4. L.Mercenaro, A.F.de Oliveira, M.Cocco, G.Nieddu: Yield and grape quality of three red grapevine cultivars (*Vitis vinifera* L.) in relation to altimetry. BIO Web Conf., 13 (2019). https://doi.org/10.1051/bioconf/20191302002
5. E.V.Kushnereva, T.I.Guguchkina, M.I.Pankin, N.M.Ageyeva: Changes in sugar and organic acids concentration during the process of maturation of the grape berry /News of the High Schools. Food technology, **1**, p.34-36. (2012). https://doi.org/03.06.2019/ISSN:0579-3009
6. R.Asadullayev, Kh.Abasova, Kh.Mammadova, V.Shukurova: Annual differences in the change of chemical composition during maturation. Viti. Wine **59**. pp.7-9 Odesa, (2022). https://www.viticulture-winemaking.org.ua/wp-content/uploads/2024/03/Visnyk-vynogradarstva-i-vynorobstva-1.pdf
7. R.Safaraliyev: Azerbaijan. Country report (ADRC) (2015). https://www.adrc.asia/countryreport/AZE/2014/AZE_CR2014B.pdf
8. Jones, G.V., White, M.A., Cooper, O.R. et al.: Climate Change and Global Wine Quality. Climatic Change 73, pp.319–343 (2005). https://doi.org/10.1007/s10584-005-4704-2
9. G.V.Jones, R.E.Davis, Climate Influences on Grapevine Phenology, Grape Composition, and Wine Production and Quality for Bordeaux, France. Am J Enol Vitic. 51. pp.249-261 (2000) https://doi.org/10.5344/ajev.2000.51.3.249

10. Schultze, S.R., Sabbatini, P. & Luo, L.: Effects of a warming trend on cool climate viticulture in Michigan, USA. Springer Plus, **5**, 1119 (2016). https://doi.org/10.1186/s40064-016-2777-1
11. C. van Leeuwen, P.Darriet: The Impact of Climate Change on Viticulture and Wine Quality. Journal of Wine Economics, **11**(01):150-167. (2016). DOI: 10.1017/jwe.2015.21
12. P.Aigrain, F.Brugière, E.Duchêne et al., Adaptation to climate change: Interest of a prospective approach. BIO Web Conf., 7, 03015. (2016). DOI: https://doi.org/10.1051/bioconf/20160703015
13. V.S.Salimov, M.T.Musayev, R.A.Asadullayev: Ampelographic characteristics of Azerbaijani local grape varieties. Vitis, **54,** 121–123. (2015). https://doi.org/10.5073/vitis.2015.54.special-issue.121-123
14. Climate scenarios for assessment of vulnerability to climate change in the agricultural sector. Report of the Ministry of Ecology and Natural Resources of the Republic of Azerbaijan. Baku (2018)
15. R.Asadullayev, Kh.Mammadova, T.Musayev: Influence of the local climatic specifics on storage ability of grape varieties in the conditions of the Absheron peninsula. Book of abstracts. - 42nd Congress of Vine and Wine, 17th General Assembly of the OIV. Book of abstracts, p.40. Geneva, Switzerland (2019). Book of abstracts 978-285-038-0105.pdf
16. V.Salimov: Ampelographic screening of the grapes. Baku (2019). https://www.researchgate.net/publication/377701284_Uzumun_ampeloqrafiq_skrininqi