

Climate change impact on grape ripening in Murfatlar vineyard

I.C. Ciobanu*, V. Artem and I. Dina

Research Station for Viticulture and Oenology Murfatlar, Romania

*Corresponding author email: stanciu_iulia_cristina@yahoo.com

ABSTRACT

Climate change is exerting a significant influence on viticulture, leading to altered phenological stages, shifts in grape ripening, and major challenges for maintaining wine typicity. This study evaluates the long-term impact of climate variability on grape maturity in the Murfatlar vineyard, southeastern Romania, one of the country's most representative wine regions. A comprehensive dataset was analyzed, integrating harvest initiation dates over two decades (2004–2024), grape composition at harvest for six cultivars across ten vintages (2015–2024), and berry ripening dynamics monitored during the last seven years (2017–2024). Results indicate a consistent advancement of harvest dates, with initiation occurring nearly three weeks earlier in 2024 compared to the early 2000s, at an average rate of 8.7 days per decade. Grape acidity displayed a steady decline across cultivars, reflecting the direct effect of higher temperatures on organic acid degradation. By contrast, sugar accumulation showed pronounced interannual variability without a clear upward trend, suggesting that heat and drought stress often limit carbohydrate assimilation despite accelerated ripening. The 2024 vintage further illustrated this decoupling: early and rapid sugar accumulation was followed by stagnation and dilution due to late-season rainfall, while berry weight decreased, with cultivar-specific responses. Overall, the findings highlight that the primary challenge for Murfatlar viticulture is not excessive sugar accumulation, but the accelerated loss of acidity, which compromises freshness and balance in wines. Adaptive strategies, including canopy and water management, optimized harvest timing, and innovative oenological practices, are therefore essential to safeguard grape quality and preserve the typicity of local cultivars under ongoing climate change.

Keywords: climate change, phenological shifts, grape ripening, Murfatlar, wine typicity

INTRODUCTION

Climate change is increasingly recognized as one of the main drivers shaping the future of viticulture and winemaking worldwide. Rising temperatures, altered rainfall patterns, and more frequent extreme weather events significantly affect vine growth, grape ripening, and ultimately wine quality (Jones *et al.*, 2005; Schultz, 2016). One of the most evident consequences is the shift in grapevine phenology, with earlier budburst, flowering, veraison and harvest dates recorded across many wine regions (Webb *et al.*, 2012; van Leeuwen and Destrac-Irvine, 2017). From an oenological perspective, these changes translate into accelerated sugar accumulation, reduced acidity, and altered aromatic potential of grapes (Mira de Orduña, 2010; Sadras and Moran, 2012). In some regions, varieties traditionally used for balanced wines now reach high sugar levels too early, before full phenolic or aromatic maturity. This imbalance poses a challenge for

winemakers seeking to preserve typicity and quality, while also adapting vineyard and cellar practices to new climatic realities (Hannah *et al.*, 2013).

In Romania, several studies have already documented the influence of climate change on grapevine phenology and fruit composition. Research carried out in different viticultural centers indicates earlier harvests, accelerated sugar accumulation, and a general decrease in grape acidity compared with historical averages (Irimia *et al.*, 2017). At Murfatlar, one of the most important wine-growing areas in southeastern Romania, recent investigations revealed that rising temperatures and reduced rainfall have led to shifts in the timing of key developmental stages, with earlier veraison and harvest, accompanied by higher sugar levels and lower acidity in grapes (Negraru *et al.*, 2022; Artem *et al.*, 2023). In this context, the present study analyzes a 10-year dataset (2015–2024) concerning sugar accumulation and titratable acidity (expressed in tartaric acid) in several grapevine varieties cultivated at Murfatlar. The objectives are threefold: (i) to evaluate interannual variability in grape sugar concentration and acidity at harvest; (ii) to analyze seasonal trends of sugar accumulation and berry weight for the period 2017–2024 in comparison with data from the 2024 vintage; and (iii) to assess the evolution of harvest starting dates over the past two decades.

MATERIALS AND METHODS

The study was conducted in the Murfatlar Viticultural Center, located in the southeastern part of Romania, one of the country's most representative wine regions. The area is characterized by a temperate-continental climate with strong maritime influences, hot and dry summers, and relatively mild winters. According to previous studies, Murfatlar is among the regions most affected by rising temperatures and declining precipitation in recent decades (Negraru *et al.*, 2022; Artem *et al.*, 2023). The dataset used for this research integrates three complementary components:

Harvest starting dates (2004–2024). The official dates marking the beginning of the harvest campaign were collected annually at the Murfatlar Research and Development Station for Viticulture and Oenology. Although these dates are often influenced by a combination of local subjective decisions, climatic variability, and economic factors, the long-term trend remains clear and illustrative for the impact of climate conditions on grape ripening.

Grape quality at harvest (2015–2024). Six grapevine varieties cultivated in the Murfatlar vineyard were analyzed for sugar concentration (g/L) and titratable acidity (g/L tartaric acid) at harvest. These values were compared across vintages and against the 10-year average to highlight temporal patterns.

Berry ripening dynamics (2017–2024). Seasonal monitoring of sugar accumulation (g/L) and 100-berry weight (g) was performed for the same six varieties. Sampling was carried out weekly from veraison until harvest, following the standard protocol applied at the Murfatlar station. The year 2024 was compared with the 2017–2023 period to assess deviations from recent trends.

Data were processed using descriptive statistics and graphical analysis to identify long-term tendencies and inter-annual variability. Comparisons were made both within individual varieties and across the entire group, with emphasis on differences between 2024 and the multiannual averages.

RESULTS AND DISCUSSIONS

Harvest date trends

The evaluation of harvest initiation dates in the Murfatlar wine center over the past two decades (2004–2024) reveals a clear tendency towards earlier grape ripening (Figure 1). Between 2004–2010, harvest generally started between 10 and 20 September, whereas after

2015 several vintages show harvest initiation in late August. The earliest date was recorded in 2024 (22 August), representing an advancement of nearly three weeks compared to the early-2000s average. The linear regression fitted to the dataset confirms this shift, with a slope of $-0.87 \text{ days/year}^{-1}$ ($\approx 8.7 \text{ days per decade}^{-1}$) and a $R^2 = 0.553$, indicating a moderate but statistically meaningful trend. This progressive advancement is consistent with phenological responses to climate warming reported for many European wine regions (Jones et al., 2005; Hannah et al., 2013).

The local climatic context of Dobrogea further intensifies this effect. This region is characterized by hot, dry summers and pronounced inter-annual precipitation variability (Irimia et al., 2017; Negraru et al., 2022), that typically accelerate sugar accumulation, shorten ripening, and advance optimal harvest windows. Consequently, the advancement of harvest dates observed at Murfatlar reflects both broader global warming trends and the amplification influence of the regional terroir. This phenological compression may complicate the alignment between technological and phenolic maturity and could challenge the maintenance of varietal typicity.

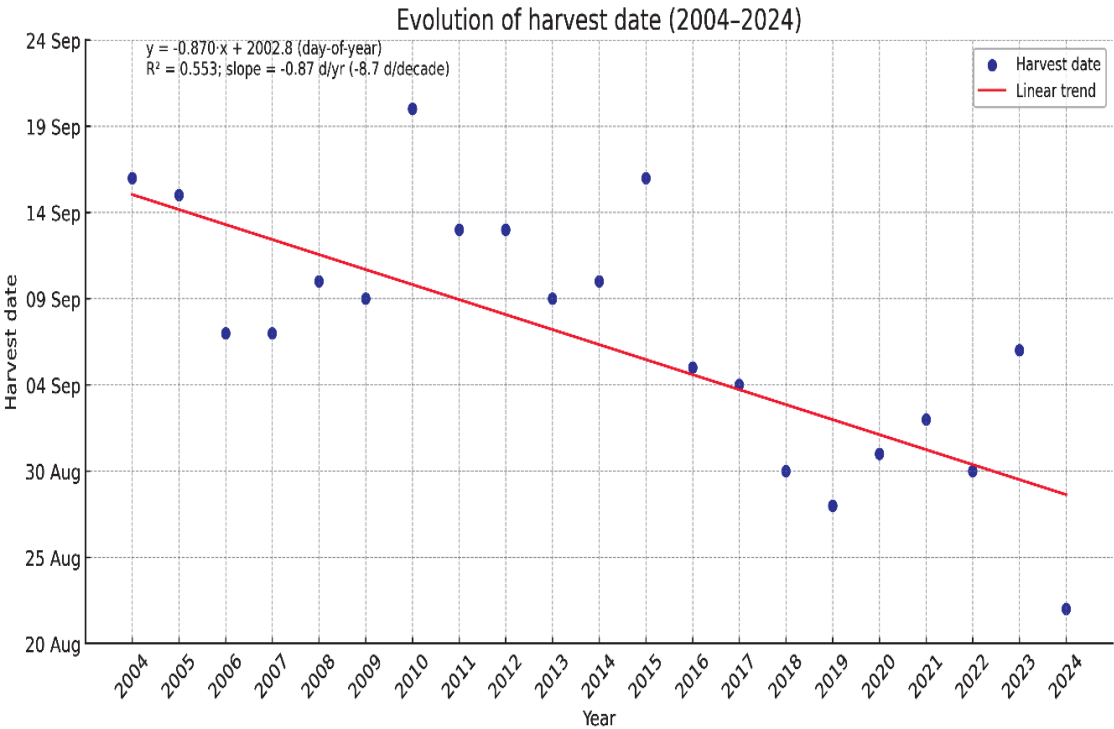


Figure 1. Evolution of harvest date in the Murfatlar wine center (2004–2024).

*Points show the observed harvest dates; the straight line indicates the linear trend ($y = -0.870 \cdot \text{year} + 2002.8$, $R^2 = 0.553$). Negative slope denotes a shift towards earlier harvests ($\approx 8.7 \text{ days per decade}$). The regression was fitted on day-of-year and displayed on a calendar-date axis.

Grape quality at harvest

The analysis of the 2015–2024 dataset revealed two distinct patterns regarding grape ripening in the Murfatlar vineyard (Figure 2). First, a consistent decline in titratable acidity was observed across cultivars, indicating a robust and directional response to climatic drivers.

Second, sugar accumulation showed high inter-annual variability without a clear upward trend, despite the widespread expectation that global warming would systematically increase sugar levels at harvest.

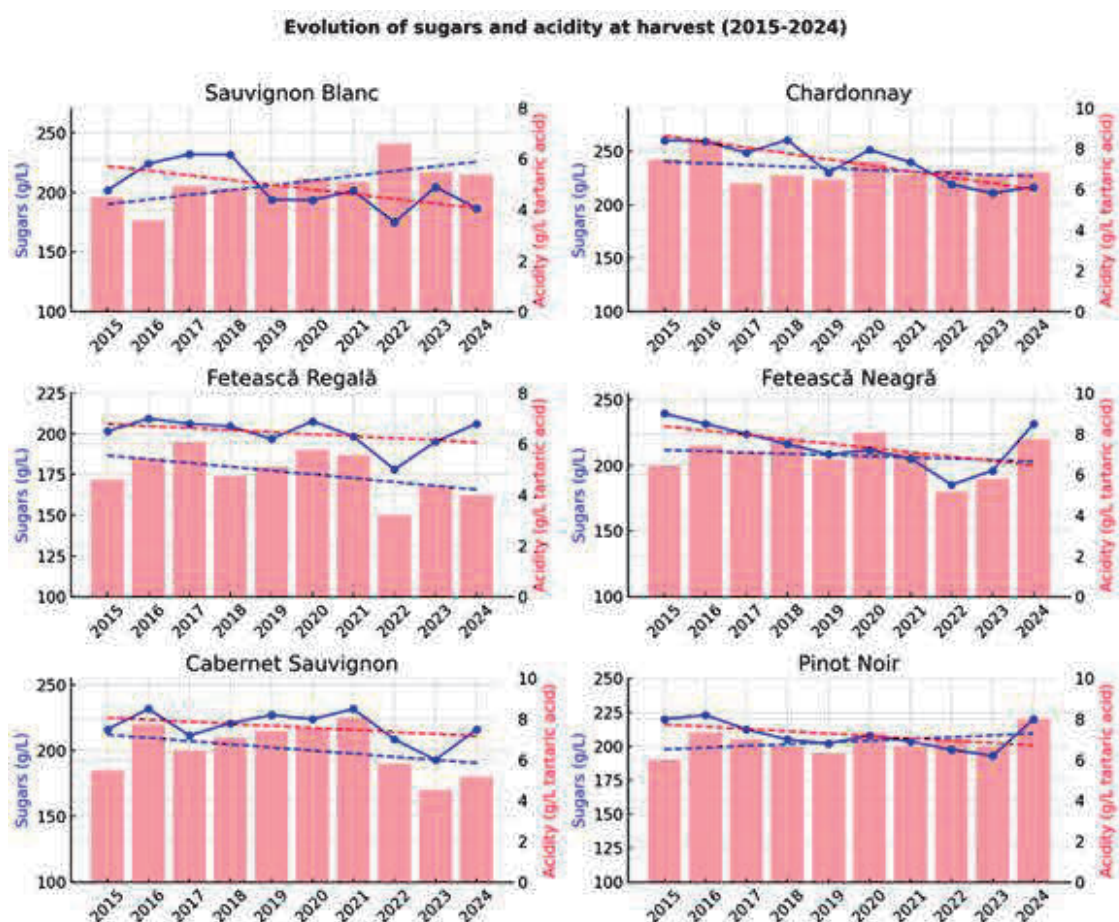


Figure 2. Sugars and acidity dynamics at harvest (2015-2024)

The decline in acidity is consistent with well-documented physiological mechanisms. Warmer ripening periods accelerate the respiration and degradation of organic acids, particularly malic acid, while water deficit can exacerbate this process by enhancing berry transpiration and reducing metabolic stability. As a result, grapes tend to reach harvest maturity at lower acidity, even when sugar accumulation does not substantially increase.

Such decoupling between technological ripeness (sugar concentration) and acid or phenolic balance has been increasingly reported in viticultural areas, especially in Mediterranean climates, where earlier harvests coincide with lower acidity but not necessarily higher sugar levels. This discrepancy arises because higher temperatures accelerate acid degradation, while heat- and drought-induced stomatal closure can limit sugar accumulation—resulting in high variability in sugar content despite significantly declining acid levels. This pattern has been documented in both experimental and survey-based studies of European viticulture under climate warming trends (Poni *et al.*, 2023).

This trend was also highlighted in Romanian vineyards, where higher temperatures and irregular precipitation regimes have led to an earlier onset of maturity and lower acid retention at harvest (Irimia *et al.*, 2017; Artem *et al.*, 2023; Bucur, 2019; Filimon, 2024).

In contrast, sugar levels did not display a systematic increase. Instead, they oscillated between years, reflecting strong vintage effects. Several factors may explain this apparent discrepancy. Under heat and drought stress, stomatal closure limits photosynthesis, reducing the assimilates available for sugar loading into berries. Furthermore, extreme climatic events—such as heatwaves or episodes of heavy rainfall—can either restrict sugar accumulation or dilute must composition. Additionally, biotic stressors (disease pressure)

and vineyard management decisions (harvest timing adjusted to preserve acidity) may also have contributed to maintaining sugars within a relatively stable range.

The regional context of Dobrogea further substantiates these findings. This area is characterized by hot and dry summers, with frequent droughts and irregular rainfall distribution. Climatic studies indicate a gradual warming trend coupled with increased frequency of extreme weather events, confirming the environmental pressures likely driving the observed shifts in grape composition (Negru et al., 2022; Irimia et al., 2017). Thus, the local terroir acts as both a magnifier of climatic variability and a determinant of grapevine metabolic response.

Taken together, these results suggest that the major challenge for Murfatlar viticulture is not excessive sugar accumulation, but the acidity decline. Practical implications include the need to adapt both viticultural and oenological strategies.

The decade-long data from Murfatlar underline a climate-driven decoupling of grape maturity parameters: acidity declines consistently, while sugars remain highly variable. This highlights the importance of integrated adaptation measures to preserve the typicity and competitiveness of local cultivars under ongoing climate change (Negru et al., 2022; Climate Change Summit Report, 2023).

In-season dynamics of 100-berry weight and sugar accumulation (2024 vs. multiannual average)

The monitoring of 100-berry weight in 2024 compared with the multiannual mean (Figure 3) reveals pronounced deviations associated with the specific climatic conditions of the year. The 2024 growing season was marked by severe drought during the berry growth phase, followed by episodes of heavy rainfall at the end of August and in early September. This sequence of climatic constraints strongly influenced both cell expansion and final berry size.

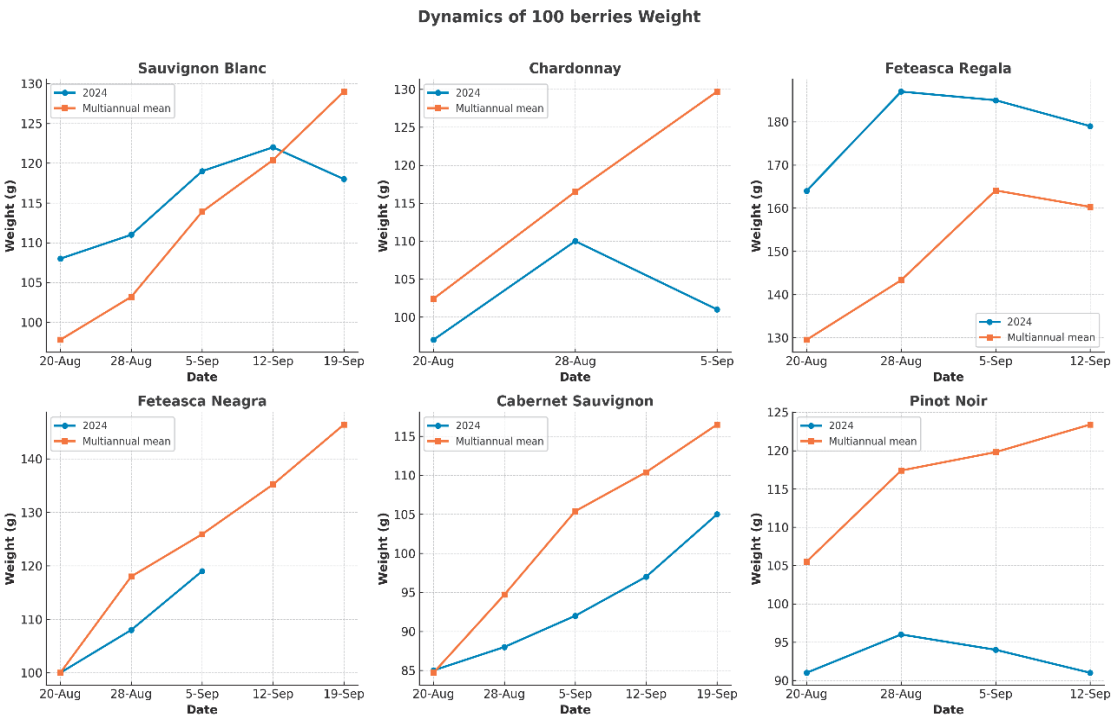


Figure 3. Comparison of 100-berry weight between the 2024 harvest and the multiannual average

In terms of berry weight, most cultivars ('Sauvignon Blanc', 'Chardonnay', 'Cabernet Sauvignon', 'Fetească Neagră') showed lower values than the multiannual mean, with an earlier and more evident decrease towards full maturity. 'Fetească Regală' was the only variety that exceeded the long-term reference, maintaining larger berries for a longer period and showing resilience to climatic stress. 'Pinot Noir' registered the widest gap compared to the multiannual average, with persistently lower values and a steeper decline after veraison, which illustrates its particular sensitivity to climatic extremes.

Monitoring the dynamics of sugar accumulation in 2024, compared with the multiannual mean (Figure 4), indicates pronounced deviations driven by the atypical climatic pattern of the season. All cultivars entered the ripening phase with sugar levels higher than the long-term reference, reflecting the accelerated onset of maturation under the high temperatures recorded during July and early August. However, the progression of sugar accumulation shifted markedly in late August, when reduced sunshine hours and substantial rainfall events slowed down the ripening process and, in some varieties, led to a stagnation of sugar concentration. Among the cultivars evaluated, 'Pinot Noir' consistently maintained higher sugar levels than the multiannual mean across all sampling dates, confirming its sensitivity to thermal conditions and its tendency toward rapid technological maturation during warm seasons. 'Sauvignon Blanc' initially displayed a strong advantage over the long-term reference but was unable to sustain accumulation under the cooler, wetter conditions of early September, resulting in final values below the multiannual average. 'Chardonnay', 'Fetească Regală', and 'Cabernet Sauvignon' also showed signs of stagnation or slight declines in the final stages of ripening, illustrating the combined effects of excess precipitation, reduced radiation and physiological limitations imposed by the climatic anomalies of 2024.

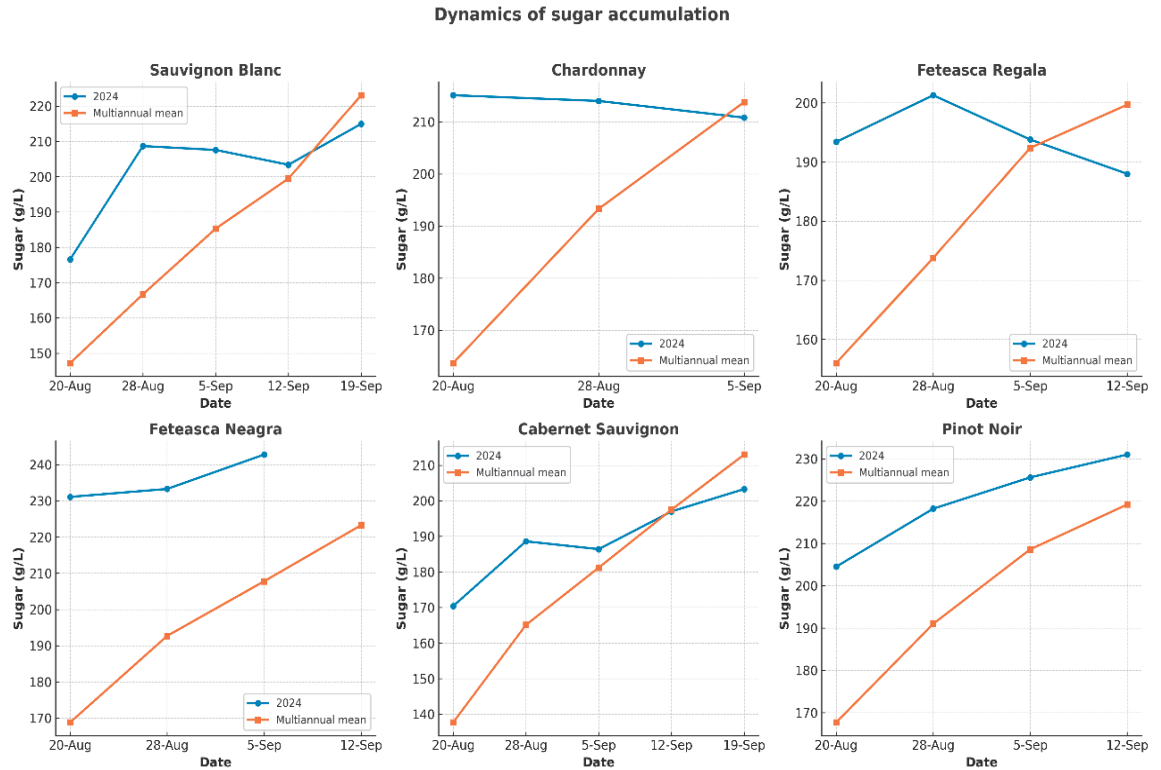


Figure 4. Dynamics of sugar accumulation – comparison between 2024 harvest vs. multiannual average

Taken together, the 2024 vintage shows a markedly atypical ripening dynamic across all cultivars.

An initial phase of accelerated sugar accumulation is observed between 20 and 28 August, followed by a marked reduction in accumulation rate during early-mid September (5–12 September), a period characterized by lower solar radiation and high rainfall.

This shift resulted in cultivar-specific responses. '*Sauvignon Blanc*', '*Fetească Regală*', and '*Cabernet Sauvignon*' exhibited an early-season sugar advantage that was subsequently attenuated, leading to final sugar concentrations on 12–19 September that converged with or dropped below the multiannual mean. Conversely, '*Pinot Noir*' maintained higher sugar levels throughout the September measurements, despite reduced berry mass, indicating a partial decoupling between sugar accumulation and berry growth under late-season climatic constraints.

CONCLUSIONS

The two-decade monitoring of grape ripening at Murfatlar highlights clear climate-driven shifts. Harvest initiation has advanced by nearly three weeks since the early 2000s, reflecting accelerated ripening under warmer and drier conditions. Acidity levels showed a steady decline, whereas sugar accumulation displayed strong inter-annual variability, lacking a consistent increasing trend.

The detailed assessment of the 2024 vintage illustrates how extreme weather shapes grape composition: drought during berry growth limited berry size, while abundant rainfall in late August led to stagnation or dilution of sugars. These combined effects underline the growing risk of decoupling between technological and phenolic ripeness, as well as the challenge of maintaining freshness and balance in local cultivars.

From a practical perspective, the results emphasize the importance of adaptive strategies in both the vineyard and winery. Measures such as optimized canopy and water management, precise harvest timing, and innovative oenological practices are critical to preserve the typicity and competitiveness of Murfatlar wines under ongoing climate change.

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