



THE INFLUENCE OF NOCTURNAL COOLING ON SUGAR CONCENTRATION STABILITY IN WINE GRAPE CULTIVARS

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Abstract: The research aim was to evaluate the influence of nighttime cooling on total soluble solids (TSS, °Brix) stability and berry morphological traits in six *Vitis vinifera* L. cultivars: 'Cabernet Sauvignon', 'Fetească Neagră', 'Merlot', 'Fetească Regală', 'Sauvignon Blanc', and 'Italian Riesling' cultivated in two Romanian vineyards (Recaș and Miniș-Măderat) for three consecutive growing seasons (2023-2025). Average nighttime temperature, daytime temperature range (DTR), and overnight cooling hours (<15°C) were connected with berry size, diameter, and skin-to-pulp ratio. Lower nocturnal parameters (2024), defined by less favorable night temperatures and longer cooling time, resulted in considerably smaller berries (1.10-1.35 g) and higher skin-to-pulp ratios (0.30-0.34), suggesting increased structural concentration and phenolic potential. Warmer nighttime temperatures (2025) increased berry size (up to 1.65 g) and lowered skin-to-pulp ratios (0.18-0.25), reflecting dilution effects. Under mild thermal circumstances, 2023 yielded intermediate reactions. Sugar concentration stability, measured as the standard deviation of total soluble solids, was highest during colder night, indicating less fluctuation in sugar accumulation. Local climate variations underlined the importance of climate change, with Recaş usually having lower temperatures during nights and better skin-to-pulp ratios than Miniș-Măderat. Red cultivars consistently had a larger skin contribution than white cultivars, even this difference decreased in warmer circumstances. Results show that nocturnal temperature is an essential determinant of grape composition and quality, which has significant implications for vineyard management and climate adaptation methods in temperate viticultural areas.

Introduction

Sugar accumulation and stability in grape berries (*Vitis vinifera* L.) are key factors influencing wine quality, including alcohol content, flavor, and sensory properties [11,16]. Nocturnal cooling regulates carbohydrate metabolism, berry ripening, and metabolite synthesis by reducing respiratory losses and enhancing glucose, fructose, anthocyanin, phenolic, and aroma compound accumulation [6,9,20,27]. Larger day-night temperature differences improve sugar stability and berry quality, whereas nocturnal warming may negatively affect grape composition [28,30].

This study evaluates the effects of nighttime cooling on sugar stability and berry quality in several wine grape cultivars. Temperature and berry composition parameters (sugars, acids, phenolics, anthocyanins, and aroma precursors) were analyzed to identify cultivar-specific responses and support viticultural management under changing climatic conditions.

Material and method

Study Sites and Experimental Design

The study was conducted during 2024-2025 in two vineyards from western Romania: Recaş and Miniș-Măderat. Both sites have temperate-continental climates but differ in nocturnal temperature conditions. Six grapevine cultivars (*Vitis vinifera* L.) were evaluated: 'Cabernet Sauvignon', 'Fetească Neagră', 'Merlot', 'Fetească Regală', 'Sauvignon Blanc', and 'Italian Riesling'. The experiment followed a randomized complete block design with three replicates per cultivar and 12 vines per plot. Standard vineyard practices were applied uniformly.

Climatic Monitoring

Automated weather stations recorded hourly air temperature, relative humidity, and solar radiation during 2024-2025. Nocturnal cooling was assessed using diurnal temperature range (DTR) and nighttime temperatures (21:00-06:00 h). Sensors placed above and within the canopy monitored ambient and cluster-zone temperatures. Analyses focused on the ripening period (July-September).

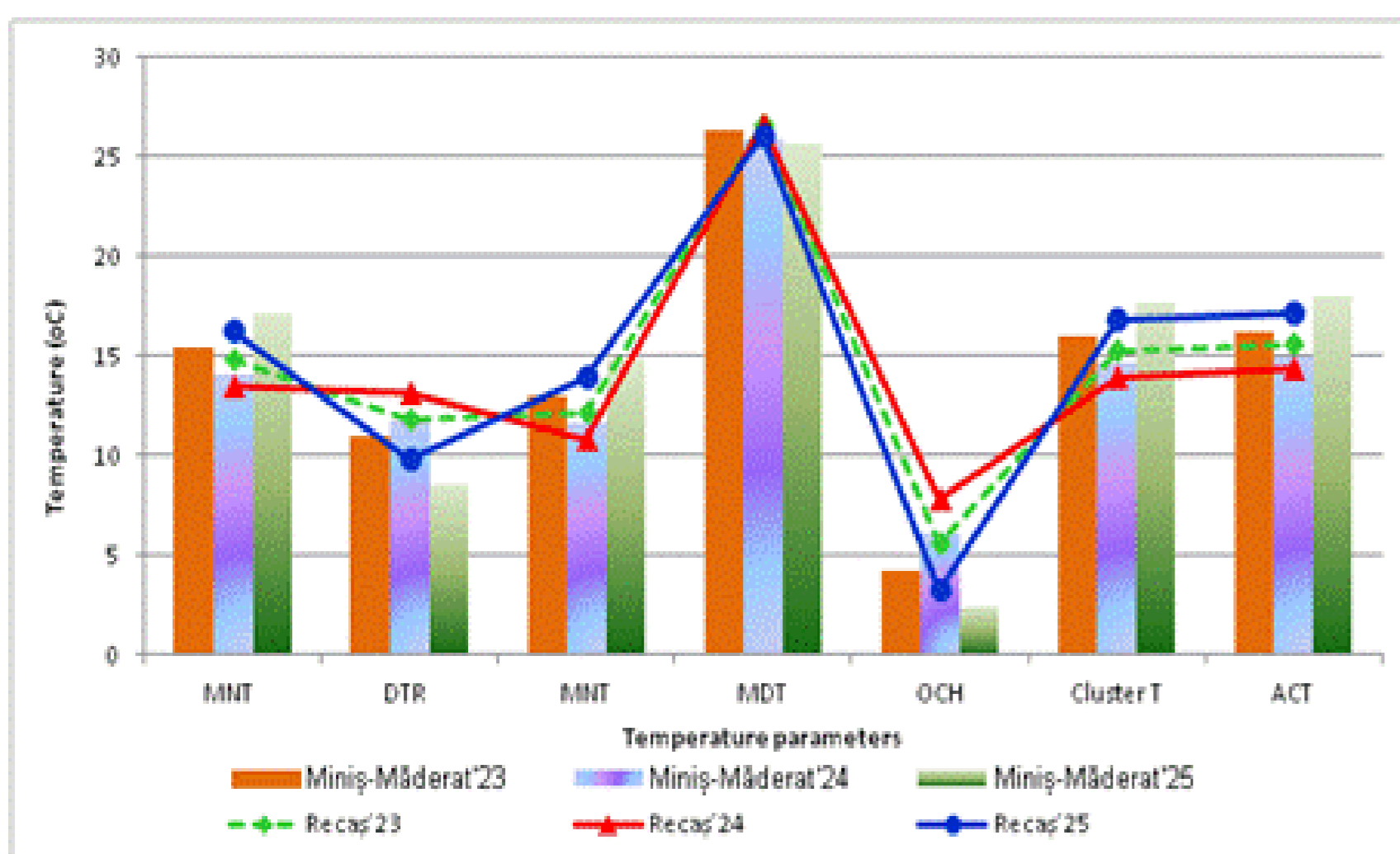


Figure 1. Temperature parameters during the veraison-ripening interval (June-September, 2023-2025), in Recaş and Miniș-Măderat vineyards (MNT - Mean Night Temp (°C) (21:00-06:00); DTR - diurnal temperature range; MDT - Mean Daytime Temperature (°C) (06:00-21:00); OCH - Overnight Cooling Hours (h, <15°C); Cluster T - Cluster Temp (°C); ACT - Above-Canopy Temp (°C))

Berry Sampling and Analysis

Berry samples were collected weekly from veraison to harvest. Approximately 100 berries per replicate were randomly sampled from different canopy positions. Total soluble solids (TSS, °Brix) were measured using a digital refractometer. Titratable acidity, pH, anthocyanins, phenolics, berry weight, and skin-to-pulp ratio were also determined using standard analytical methods. All measurements were performed in triplicate.

Statistical Analysis

Data were analyzed using XLSTAT (2023.5.1). ANOVA and Tukey's test ($p < 0.05$) evaluated the effects of cultivar, location, and season. Principal component analysis (PCA) was used to identify cultivar responses and clustering patterns.

Conclusions

Nocturnal cooling significantly influenced grape berry composition by improving sugar stability, acidity retention, phenolic accumulation, and berry quality. 'Fetească Regală' and 'Italian Riesling' showed greater stability, while 'Fetească Neagră' and 'Merlot' were more sensitive to warmer nights. Cooler conditions also promoted smaller berries with higher skin-to-pulp ratios. The results emphasize the importance of diurnal temperature variation and vineyard microclimate for maintaining grape and wine quality under climate change.

Results and discussions

1. Climatic Conditions and Nocturnal Cooling (2023-2025)

The 2024 season showed the strongest nocturnal cooling, with the lowest night temperatures, highest diurnal temperature range (DTR), and longest cooling duration below 15 °C. In contrast, 2025 recorded the warmest nights, lowest DTR, and shortest cooling periods, while 2023 showed intermediate conditions. Cluster-zone temperatures were consistently lower than canopy temperatures, confirming the buffering effect of canopy structure on berry microclimate.

2. Berry Composition and Sugar Stability

Sugar accumulation and berry composition varied according to nocturnal thermal conditions. PCA explained 93.29% of total variability and showed strong positive correlations between sugars, anthocyanins, and phenolics. The 2024 season produced the most stable sugar accumulation, higher acidity, lower pH, and greater phenolic and anthocyanin contents, particularly in 'Cabernet Sauvignon' and 'Fetească Neagră' from Recaş. In contrast, 2025 showed greater sugar variability, reduced acidity, higher pH, and lower phenolic accumulation. Recaş consistently exhibited better sugar stability and phenolic preservation than Miniș-Măderat due to cooler nighttime conditions and higher DTR (Figures 2 and 3).

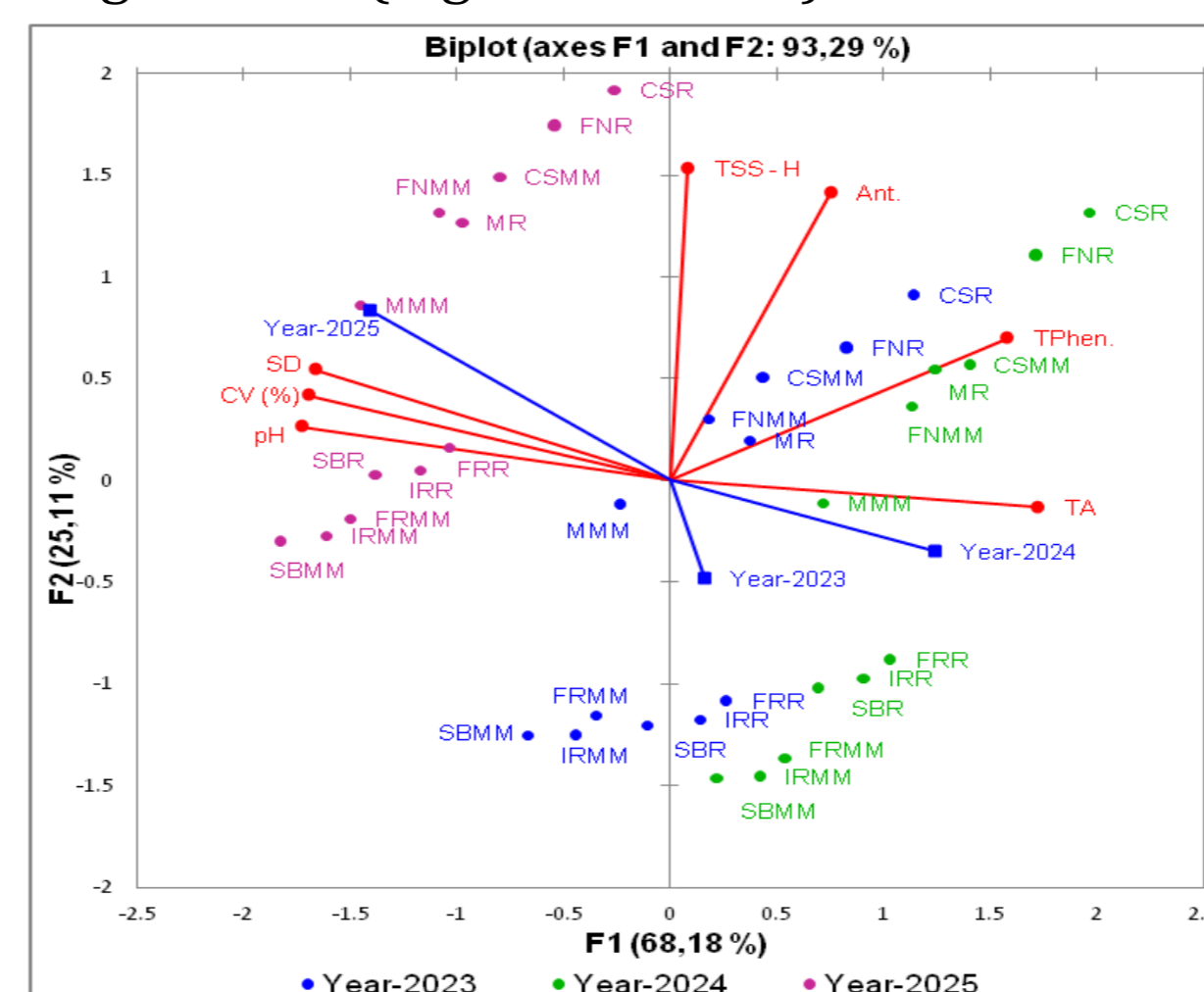


Figure 2. Average sugar concentration at harvest (°Brix) - TSS; Standard deviation (°Brix) - SD - Titratable Acidity (g/L) - TA; Anthocyanins (mg/L) - Ant; Total Phenolics (mg GAE/L) - Tphen.

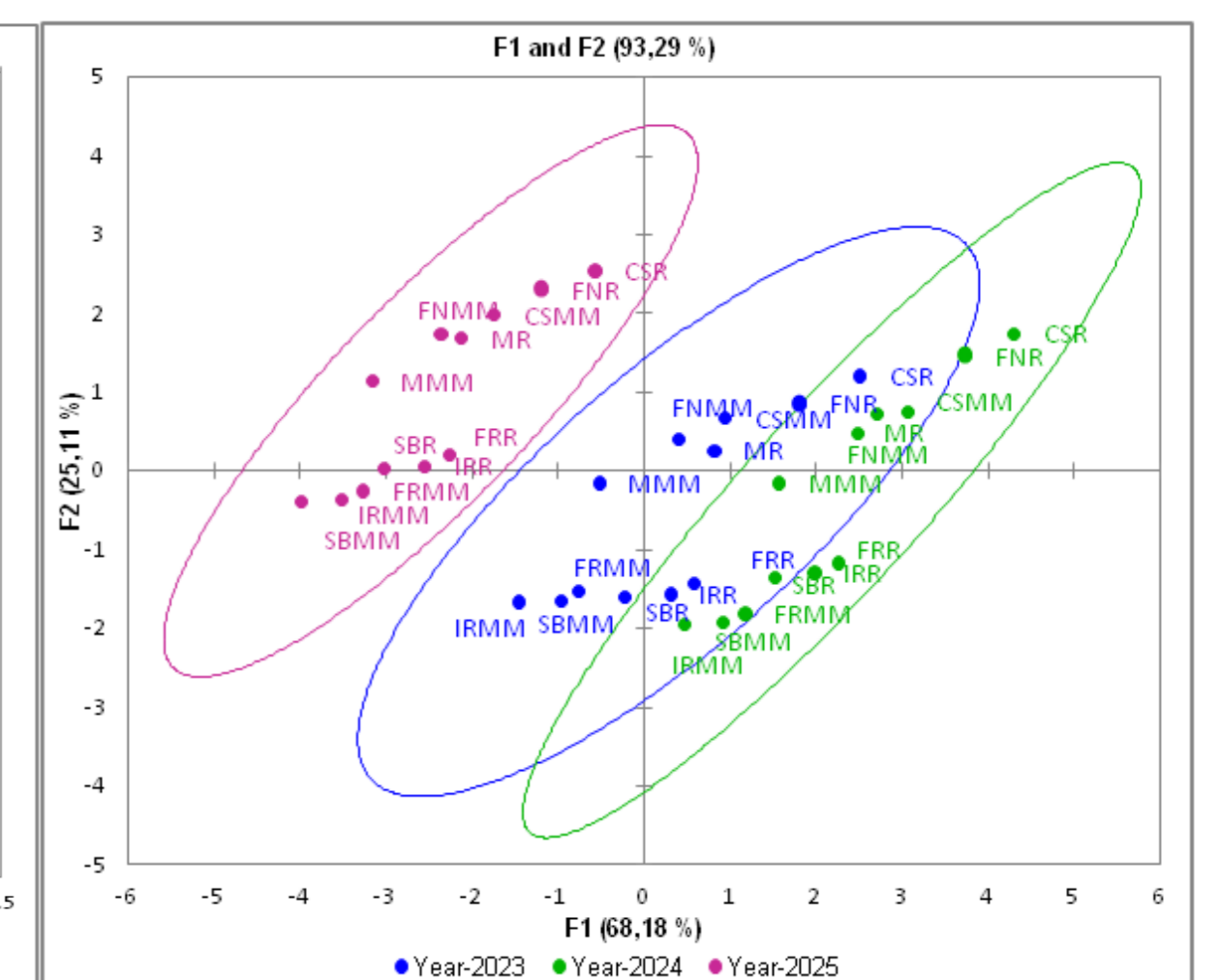


Figure 3. Principal Component Analysis (PCA) for cultivars reaction across growing seasons 2023-2025 ['Cabernet Sauvignon' (CS), 'Fetească Neagră' (FN), 'Merlot' (M), 'Fetească Regală' (FR), 'Sauvignon Blanc' (SB) and 'Italian Riesling' (IR); Recaş (R), Miniș-Măderat (MM)]

3. Berry Morphology

Berry morphology was strongly influenced by nocturnal temperature conditions. Cooler nights in 2024 reduced berry size and increased skin-to-pulp ratio, especially in red cultivars from Recaş, favoring phenolic accumulation. Warmer nighttime conditions in 2025 promoted larger berries and lower skin-to-pulp ratios, particularly in white cultivars. Across all seasons, red cultivars showed naturally higher skin-to-pulp ratios than white cultivars. Recaş generally produced smaller berries with thicker skins, indicating more favorable conditions for high-quality red wine production (Figures 4 and 5).

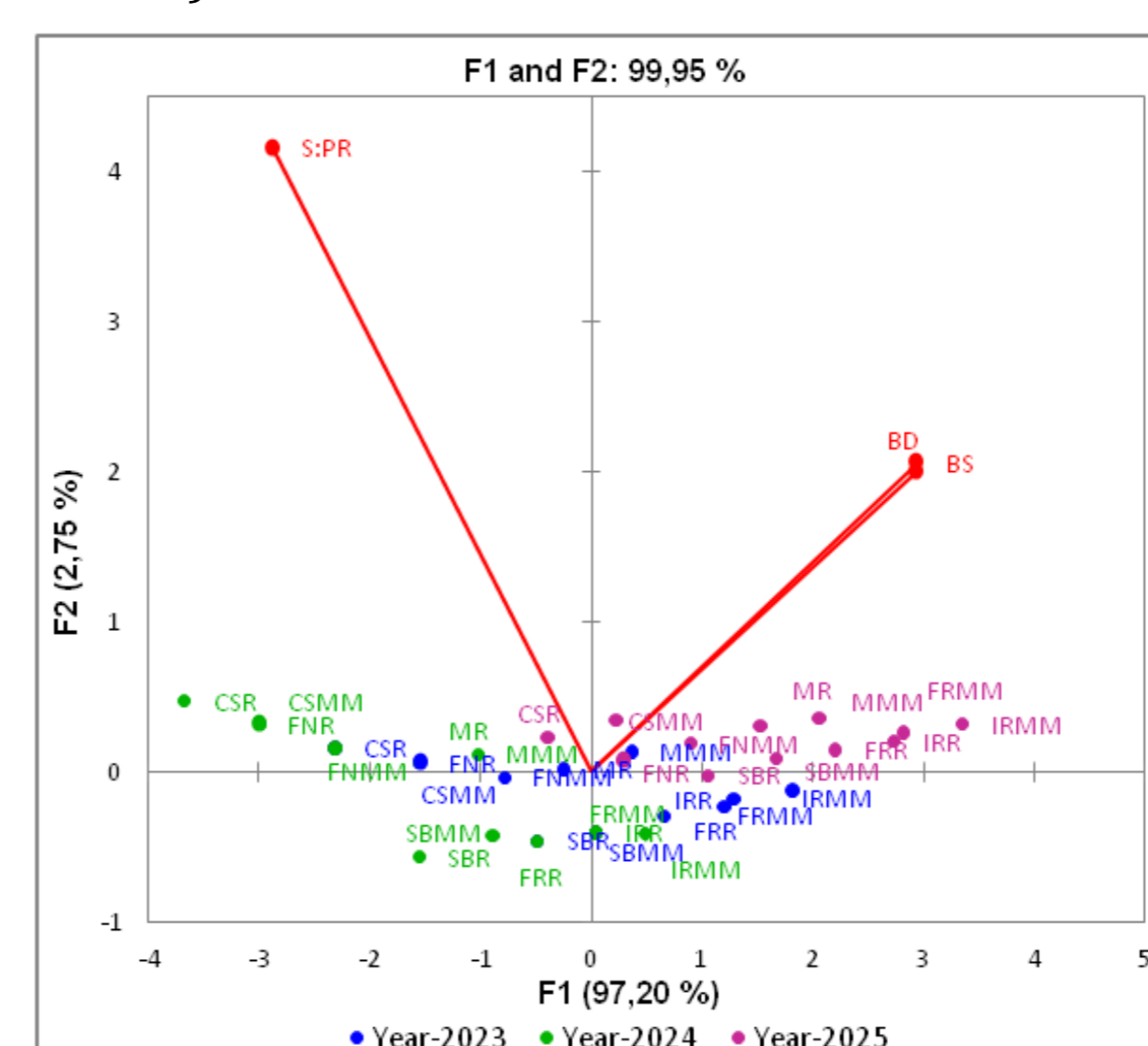


Figure 4. PCA diagram for berry size (BS), berry diameter (BD), and skin-to-pulp ratio (S:PR) reaction to changes in night temperature and cooling time in 'Cabernet Sauvignon' (CS), 'Fetească Neagră' (FN), 'Merlot' (M), 'Fetească Regală' (FR), 'Sauvignon Blanc' (SB) and 'Italian Riesling' (IR) in Recaş (R), Miniș-Măderat (MM) vineyards (2023-2025)

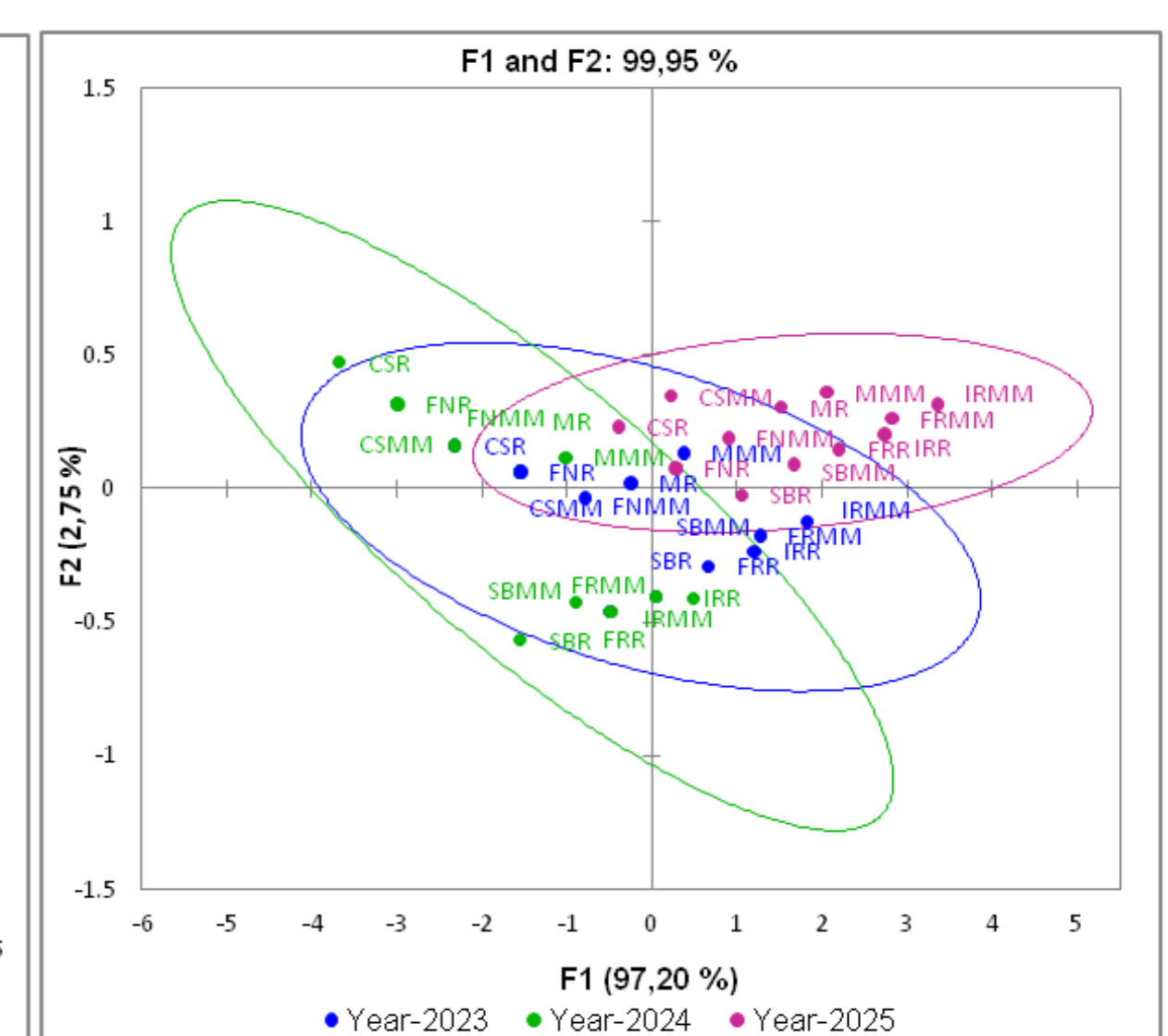


Figure 5. Principal Component Analysis (PCA) for berry characteristics and cultivars reaction across growing seasons 2023-2025. ['Cabernet Sauvignon' (CS), 'Fetească Neagră' (FN), 'Merlot' (M), 'Fetească Regală' (FR), 'Sauvignon Blanc' (SB) and 'Italian Riesling' (IR); Recaş (R), Miniș-Măderat (MM)]