Marin Tomičić[1], Leonardo Ošo[1], Ivana Dminić Rojnić[1], Slavica Dudaš[1], Melita Zec Vojinović[1], Martina Peršić[1]

Original scientific paper

Morphometric characteristics of the leaf of 'Merlot' and 'Syrah' (*Vitis vinifera* L.) varieties in the vineyard of the Central Istria wine-growing region

Abstract
This study aimed to conduct a comparative morphometric and colorimetric analysis of 'Merlot' and 'Syrah' grapevine leaves to identify key distinguishing traits within the Central Istria wine-growing region. Quantitative International Organisation of Vine and Wine (OIV) descriptors for leaf morphometry and International Commission on Illumination (CIELAB) color values were analyzed on mature leaves of both varieties. Although the varieties showed high qualitative similarity, significant quantitative differences were found in distal vein lengths (N3, N4, N5), inter-vein angles (OIV 607, OIV 608), and the petiole sinus opening (OIV 618). Furthermore, colorimetric analysis revealed that the abaxial surface of 'Syrah' leaves was significantly lighter (higher L value) than that of 'Merlot', and Principal Component Analysis confirmed a complete separation between the two cultivars. Research established an objective set of descriptors for differentiating 'Merlot' and 'Syrah' in this specific terroir, demonstrating the utility of combining ampelometry and colorimetry for accurate varietal characterization.*
Keywords: *Merlot, Syrah, ampelography, ampelometry, colorimetry*

Introduction

Ampelography is the traditional science dedicated to the identification and classification of grapevine varieties (*Vitis vinifera* L.) based on their phenotypic characteristics. Although this practice has a long history, with detailed descriptions dating back to ancient Greek and Roman cultures, the term "ampelography" was first used by Phillip Jacob Sachs in 1661 (Dinu et al., 2021; Bodor-Pesti et al., 2023). The scientific approach to the discipline began in 1807 with Don Simón de Rojas Clemente, who published the first comprehensive ampelographic work on the varieties in the Spanish region of Andalusia (Tarailo and Vuksanović, 2018).

The development of ampelography as an independent discipline was largely driven by the practical need for reliable cultivar identification following the phylloxera epidemic, which devastated European vineyards and highlighted the confusion caused by the

*1 **Marin Tomičić**, mag. ing. hort, **Leonardo Ošo**, dr. sc. biotech. **Ivana Dminić Rojnić**, dr. sc. biotech. **Slavica Dudaš**, dr. sc. biotech. **Melita Zec Vojinović**, dr. sc. biotech. **Martina Peršić**, Veleučilište u Rijeci, Vukovarska 58, 51000 Rijeka, Hrvatska*

Correspondence author: *martina.persic@veleri.hr*

widespread use of synonyms for the same variety (Bodor-Pesti et al., 2023). In response to these challenges, the International Ampelographic Commission was established in 1873, beginning efforts to standardize variety descriptions and resolve nomenclature ambiguities (Tarailo and Vuksanović, 2018).

In Croatia, the ampelographic studies began in the early 19th century. The first comprehensive book on ampelography was compiled by Bulić in 1949, titled „Dalmatinska ampelografija" (*Dalmatian Ampelography*), and documented nearly 200 grapevine cultivars between 1887 and 1925 (Maletić et al., 2015).

Despite its historical significance, traditional ampelography faces several challenges. It is subjective method that heavily relies on skilled experts, and it is susceptible to environmental and genetic influences, which may introduce uncertainty (Carneiro et al., 2024), and some characteristics, like the color of young leaves or the juiciness and firmness of berry flesh, are particularly difficult for ampelographers to consistently distinguish. Furthermore, traditional ampelography may have limited accuracy for closely related varieties or clones, as minor genetic differences can result in subtle phenotypic variations that are hard to distinguish visually (Garcia-Munoz et al., 2011).

Ampelometry emerged to address these limitations of traditional ampelography by providing a quantitative and objective approach for characterizing grapevine varieties (Dinu et al., 2021). It involves measuring specific linear, angular, and shape-related traits of various plant organs to differentiate between varieties (Bodor-Pesti et al., 2023). Today, cultivar description is highly standardized through the efforts of the International Organisation of Vine and Wine (OIV), which maintains a list of nearly 150 qualitative and quantitative descriptors with detailed protocols for their assessment (OIV, 2009). The OIV Descriptor List includes many linear and angular ampelometric properties, such as vein lengths (OIV601-OIV604), sinus depths (OIV605-OIV606), and angles between veins (OIV607-OIV609). While leaves are the most frequently studied organ, ampelometry can also be applied to flowers, bunches, berries, and seeds (OIV, 2009; Bodor-Pesti et al., 2023).

Ampelometry, while offering a more quantitative and objective approach to grapevine variety characterization, still faces several limitations and challenges. Morphological characteristics, even when measured quantitatively, are significantly influenced by various environmental and agricultural factors, which can temporarily obscure typical varietal features (Kupe et al., 2021; Carneiro et al., 2024). These factors include: wheater phenomena like hailstorms (Garcia-Munoz et al., 2011), water status and irrigation (Gómez-del-Campo et al., 2003; Lepej et al., 2024;), canopy temperature (Migicovsky et al., 2024), viral infections, plant origin and propagation method, soil type, different years, bud-loads, number of shoots, vegetative load, and even row orientation (Bodor-Pesti et al., 2023). The variability introduced by these factors can make morphological descriptions less reliable and can further complicate accurate identification (Garcia-Munoz et al., 2003). This pronounced influence of environmental factors, collectively known as *terroir*, underscores the need for region-specific morphometric studies.

Today, morphometric analysis is often combined with molecular marker analysis, such as microsatellites (SSR), to provide a more thorough establishment of varietal identity. While molecular methods offer objective genetic profiles, morphometric data captures phenotypic traits not always evident through DNA alone, especially for somatic mutations or clonal evaluation (Popescu and Crespan, 2018).

Beside complementary role to molecular analysis, the importance of ampelometry lies in its accessibility because it does not require advanced technology or specialized equipment, it serves as a good preliminary technique for the identification of plant material, and it has the ability to differentiate between clones or varieties with minor genetic differences, where molecular markers are often ineffective (Garcia-Munoz et al., 2011; Popescu and Crespan, 2018).

The Central Istria wine-growing area is one of three wine-growing areas within the Croatia's Istria subregion, which itself is part of Croatia's Istria and Kvarner viticulture region. The Central Istria wine-growing area encompasses municipalities and towns such as Buzet, Barban, Cerovlje, Gračišće, Kanfanar, Karojba, Lanišće, Lupoglav, Motovun, Oprtalj, Pazin, Sveti Petar u Šumi, Svetvinčenat, Tinjan, and Žminj. The climate in Istria generally features mild and rainy autumns and springs, moderately cold winters, and dry, warm summers. The central hilly area, including Pazin, is less influenced by the Adriatic Sea compared to the western and southwestern parts of Istria, exhibiting more accentuated continental climatic characteristics. Soil types in Central Istria primarily consist of red soil (terra rossa), which is the most represented soil type (Sladonja et al., 2004; Šimunić et. al., 2021; Prša et al., 2023).

In 2010, Central Istria wine-growing area accounted for 1,126 hectares of vineyards, representing 16.72% of the total vineyard surface in Istria (Sladonja et al., 2004). Both 'Merlot' and 'Syrah' are recommended varieties for the Croatia's Istria subregion (Prša et al., 2023).

'Merlot' is one of the most important red grape variety in the wine industry globally. It has been cultivated for centuries in France, particularly around Bordeaux. Its genetic lineage traces back to 'Cabernet Franc' and 'Magdeleine Noire des Charentes' (Vujović et al., 2016). It was introduced to Istria (Poreč) in 1965, and it's a significant red grape variety in Istria (Fazinić and Benčić, 1998).

'Syrah', with common synonym 'Shiraz', is another red grape variety of French origin, genetically related to 'Pinot'. It is recognized as one of the world's top 30 red wine varieties (Anderson and Aryal, 2013) and is among the most common varieties globally according to the International Organisation of Vine and Wine (Carneiro et al., 2024). Although is cultivated on smaller scale than 'Merlot', it's important variety in Croatia and experimental vineyards have been established in northwestern Croatia by the Faculty of Agriculture from University of Zagreb to explore its potential for cultivation in the region (Osrečak et al., 2016).

While the general ampelographic profiles of 'Merlot' and 'Syrah' are well-documented, a quantitative morphometric analysis comparing these two major varieties within the specific *terroir* of Central Istria is currently lacking. This study aims to identify key distinguishing characteristics between 'Merlot' and 'Syrah' varieties by performing a comparative morphometric and colorimetric analysis of their leaves within the specific *terroir* of the Central Istria wine-growing region.

Materials and Methods

The research was conducted in a vineyard located at Buzet - Stari Grad, Croatia (coordinates 45°24'23.0"N 13°58'40.9"E), at an altitude of approximately 151 meters above sea level. The location belongs to the Central Istria wine-growing district, within the Croatia's Istria sub-region.

The vineyard contains six rows of grapevines, with a total of 450 vines, comprising the varieties 'Merlot' (four rows, 300 vines) and 'Syrah' (two rows, 150 vines). The spacing is 2.40×1.00 m, and the rows are oriented in a northwest-southeast direction. The vines are grafted on SO4 rootstock and trained to a double Guyot system, with the vine head positioned at approximately 60 cm. During winter pruning, a single six-bud cane and a renewal spur are retained on each side-branch.

For the analysis, 20 fully developed leaves were collected from each variety. Sampling was conducted by selecting leaves from the 5th to 7th node position on fruit-bearing shoots. To ensure the sample was representative, leaves were collected from every fifth vine within the central rows of the vineyard block.

Using a visual method, each collected leaf was assessed and characterized according to the following qualitative OIV descriptors: OIV 067 (Shape of blade), OIV 068 (Number of lobes), OIV 070 and 071 (Area of anthocyanin coloration of main veins on upper/lower side of blade), OIV 076 (Shape of teeth), OIV 077 (Size of teeth in relation to blade size), OIV 079 (Degree of opening/overlapping of petiole sinus), and OIV 080 (Shape of base of petiole sinus) (OIV, 2009).

Leaves were photographed against a neutral background that included a millimeter scale. Images were captured with a perpendicular camera projection under consistent lighting conditions to prevent perspective distortion. The Fiji image analysis software (version 2.17.0) was used to perform ampelometric measurements and determine the following quantitative OIV descriptors: OIV 601-604 (Length of veins N_1-N_4), OIV 605-606 (Length petiole sinus to upper/lower lateral leaf sinus), OIV 607-609 (Angles between N_1/N_2, N_2/N_3, and N_3/N_4 measured at the first ramification), OIV 610 (Angle between N_3 and the tangent between petiole point and the tooth tip of N_5), OIV 611 (Length of vein N_5), OIV 617 (length between the tooth tip of N_2 and the tooth tip of the first secondary vein of N_2), OIV 618 (Opening/overlapping of petiole sinus), and OIV 065 (Size of blade) (OIV, 2009).

Leaf color was measured on both the adaxial (upper) and abaxial (lower) surfaces using a Konica Minolta CR-10 Plus colorimeter (MinoltaCo., Osaka, Japan) with an 8 mm aperture. Two measurements were taken at random locations on each leaf surface. Color was quantified in the CIE L* a* b* color space, where L* denotes lightness, a* denotes the green-to-red axis, and b* denotes the blue-to-yellow axis (Dumas et al., 2003).

The data collected from the morphometric and colorimetric analyses were compiled, and statistical analyses were conducted using R statistical software (version 4.3.3). For the morphometric descriptors, comparisons between varieties were performed using Welch's two-sample t-test, while variability was assessed using the Coefficient of Variation (CV) and an F-test.

Pearson correlation matrices and a Principal Component Analysis (PCA) were used to explore relationships between variables and the overall morphological separation. For the colorimetric (CIELAB L*, a*, b*) data, a two-way Analysis of Variance (ANOVA) was used to test the main effects of variety, leaf surface, and their interaction. Where a significant interaction effect was detected, a Tukey's HSD post-hoc test was used for pairwise comparisons among the group means. A significance level of $p < 0.05$ was used for all statistical tests.

Results and Discussion

The analysis of qualitative OIV descriptors revealed a high degree of morphological similarity between the 'Syrah' and 'Merlot' varieties, although some intra-varietal variation was noted. The results of the visual assessment are summarized in Table 1.

Table 1. Ampelographic OIV Descriptors of Adult Leaves of 'Syrah' and 'Merlot' varieties / **Tablica 1.** Ampelografski OIV deskriptori lista sorata 'Syrah' i 'Merlot'

OIV descriptor	'Syrah'	'Merlot'
067 - Shape of blade	**2 - wedge-shaped (13)**; 3 - pentagonal (4); 4 – circular (3)	**2 - wedge-shaped (20)**;
068 - Number of lobes	**3 - five (17)**; 4 - seven (3)	2 – three (3) **3 - five (17)**;
070 - Area of anthocyanin coloration of main veins on upper side of blade	**1 - absent (20)**	**1 - absent (20)**
071 - Area of anthocyanin coloration of main veins on lower side of blade	**1 - absent (20)**	**1 - absent (20)**
076 - Shape of teeth	**3 - both sides convex (13)**; 4 - one side concave, one side convex (4) 5 - mixture between both sides straight (note 2) and both sides convex (note 3) (3)	2 - both sides straight (1); **3 - both sides convex (15)**; 4 - one side concave, one side convex (1); 5 - mixture between both sides straight (note 2) and both sides convex (note 3) (3)
077 - Size of teeth in relation to blade size	3 - small (5); **5 - medium (12)**; 7 - large (3)	**5 - medium (18)**; 7 - large (2)
079 - Degree of opening / overlapping of petiole sinus	**3 - open (20)**	**3 - open (20)**
080 - Shape of base of petiole sinus	**1 - U-shaped (20)**	**1 - U-shaped (20)**

**Numbers in parentheses indicate number of analyzed leaves per descriptor*
Source/Izvor: Authors/Autori

Both varieties predominantly exhibited a wedge-shaped blade. However, 'Merlot' had exclusively wedge-shaped blades (20 leaves), while 'Syrah' showed some variation, with 13 leaves classified as wedge-shaped, 4 as pentagonal, and 3 as circular. For both cultivars, the leaves were primarily five-lobed (17 for both 'Syrah' and 'Merlot'), but 'Merlot' had a subset of leaves with three lobes, whereas 'Syrah' had a subset with seven lobes.

An extremely high uniformity was observed for the trait of anthocyanin coloration on the main veins. For all 40 leaves analyzed across both varieties, coloration was completely absent on both the upper and lower surfaces of the blade.

The shape of the teeth was predominantly convex on both sides for both 'Syrah' (13 leaves) and 'Merlot' (15 leaves). The size of teeth in 'Merlot' was highly consistent, with 18 of 20 leaves classified as medium, while Syrah displayed a wider distribution of small, medium, and large teeth.

There was a complete correspondence between the two varieties regarding the petiole sinus. All analyzed leaves from both ‘Merlot’ and ‘Syrah’ had a U-shaped sinus. The degree of opening for the sinus was uniformly described as open for all leaves.

These results align with standard ampelographic descriptions. Key traits, including the shape and number of leaf lobes, the absence of anthocyanin coloration, tooth morphology, and the shape of the petiole sinuses are consistent with published literature, confirming previous research (OIV, 2009; INRAE & IFV, 2020a; INRAE & IFV, 2020b), although there are some differences. Some descriptive sources characterize the Merlot leaf as pentagonal (Vivai Rauscedo), while the Syrah leaves are described as circular (Vişan et al., 2019). These discrepancies may be the result of phenotypic plasticity, clone, or even from subjective description of the ampelographer.

A detailed comparison of the 14 morphometric descriptors revealed several statistically significant differences between the ‘Syrah’ and ‘Merlot’ varieties (Table 2).

Table 2. Comparison of morphometric characteristics of ‘Syrah’ and ‘Merlot’ leaves
Tablica 2. Usporedba morfometrijskih karakteristika sorata ‘Syrah’ i ‘Merlot’

OIV descriptor	‘Syrah’		‘Merlot’	
	Mean±SD	OIV Note	Mean±SD	OIV Note
OIV 601 - Length of vein N_1 (mm)	156.58±15.20 (ns)	7	148.92±20.04 (ns)	7
OIV 602 - Length of vein N_2 (mm)	131.51±10.68 (ns)	7	133.73±15.73 (ns)	7
OIV 603 - Length of vein N_3 (mm)	93.51±7.86 (*)	7	100.74±12.48 (*)	7
OIV 604 - Length of vein N_4 (mm)	58.04±6.38 (**)	9	66.75±12.52 (**)	9
OIV 611 - Length of vein N_5 (mm)	25.21±5.11 (***)	3	34.57±7.48 (***)	5
OIV 605 - Length petiole sinus to upper lateral leaf sinus (mm)	70.40±11.48 (ns)	5	67.90±13.43 (ns)	5
OIV 606 - Length petiole sinus to lower lateral leaf sinus (mm)	66.81±9.10 (ns)	5	70.83±12.02 (ns)	7
OIV 617 - Length between the tooth tip of N_2 and the tooth tip of the first secondary vein of N_2 (mm)	71.86±8.42 (ns)	9	68.34±11.54 (ns)	7
OIV 618 - Opening/overlapping of petiole sinus (mm)	27.73±5.54 (***)	1	36.65±7.44 (***)	1
OIV 607 - Angles between N_1/N_2 measured at the first ramification (°)	50.36±5.14 (**)	5	46.65±3.04 (**)	5
OIV 608 - Angles between N_2/N_3 measured at the first ramification (°)	47.74±3.53 (*)	5	50.37±3.53 (*)	5
OIV 609 - Angles between N_3/N_4 measured at the first ramification (°)	52.71±6.09 (ns)	5	56.23±7.49 (ns)	7
OIV 610 - Angle between N_3 and the tangent between petiole point and the tooth tip of N_5 (°)	63.21±7.20 (ns)	7	66.68±7.64 (ns)	7
OIV 065 - Size of blade (cm^2)	269.31±43.44 (ns)	5	283.13±71.19 (ns)	5

*P-values were determined by Welch’s two-sample t-test. Significance codes: ns $p \geq 0.05$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Source/Izvor: Authors/Autori*

Notably, several key descriptors, including the overall blade size (OIV 065) and the lengths of the main veins (OIV 601 and OIV 602), did not show a significant difference between the two varieties, which suggests that simple size metrics are insufficient for firmly distinguishing between 'Syrah' and 'Merlot'. Most of the linear ampelometric features like vein lengths are significantly influenced by the year-to-year effect, which is why ampelometry often rely on ratios and angles to normalize for size variations caused by environmental factors or leaf age, thereby capturing the more genetically conserved aspects of leaf shape (Bodor-Pesti et al., 2023)

Veins N_3, N_4, and N_5 define the structure of the proximal and petiolar lobes. 'Merlot' consistently showed longer distal veins, indicating deeper sinuses and more pronounced lower lobes compared to 'Syrah'. The pronounced significant difference ($p < 0.001$) in vein N_5 length highlights it as a primary distinguishing characteristic. This is consistent with genetic studies that have identified quantitative trait loci on several chromosomes that control lobedness and sinus depth, indicating a strong genetic basis for these traits (Demmings et al., 2019).

'Syrah' leaves displayed a wider angle between the main and upper lateral veins (OIV 607), while 'Merlot' showed a wider angle between the upper and lower lateral veins (OIV 608). These angular differences impact the orientation of the primary lobes and the overall leaf contour. The stability of angular traits compared to linear measurements, which can be more susceptible to environmental influences like water stress, has been noted in previous research (Martí et al., 2006: Lepej et al., 2024). This suggests that OIV 607 and OIV 608 could serve as stable and reliable descriptors for differentiating these two varieties across different *terroirs* and seasons.

To compare the morphological consistency of the two varieties, the relative variability of each descriptor was calculated using the Coefficient of Variation (CV), with statistical significance assessed by an F-test (Figure 1). The analysis revealed significant differences in the variability of several key traits. Across both varieties, angular measurements proved to be the most stable traits, exhibiting the lowest CV values. In particular, the angle between veins N_2/N_3 (OIV 608) and N_1/N_2 (OIV 607) showed low relative variability. This high consistency suggests that these angles are stable and reliable traits within each variety.

Furthermore, these angles proved to be strong descriptors for distinguishing between the varieties, as the mean values for both the angle between N_1/N_2 (OIV 607) and N_2/N_3 (OIV 608) were statistically significant (Table 2). The stability of these traits, combined with their significant inter-variety differences, makes these angular descriptors highly reliable for ampelographic determination between these two varieties. 'Merlot' leaves generally showed greater variability than 'Syrah' across a range of characteristics, most notably in the overall blade size (OIV 065) and the length of vein N_4 (OIV 604). 'Syrah' variety displayed significantly higher variability in a shape-related trait, the angle between veins N_1/N_2 (OIV 607). For the majority of the other descriptors, the two varieties displayed a comparable level of morphological consistency, with no significant differences in their CV values. These results suggest that the two varieties differ not only in their average leaf measurements but also in their developmental stability for specific size and shape characteristics.

To investigate the internal relationships between morphometric traits, correlation matrices showing only statistically significant ($p<0.05$) correlations were generated for each variety. While both 'Syrah' (Figure 2) and 'Merlot' (Figure 3) showed the expected pattern of strong positive correlations among size-related descriptors like vein lengths, the correlation analysis revealed fundamental differences in the morphological integration of the two varieties.

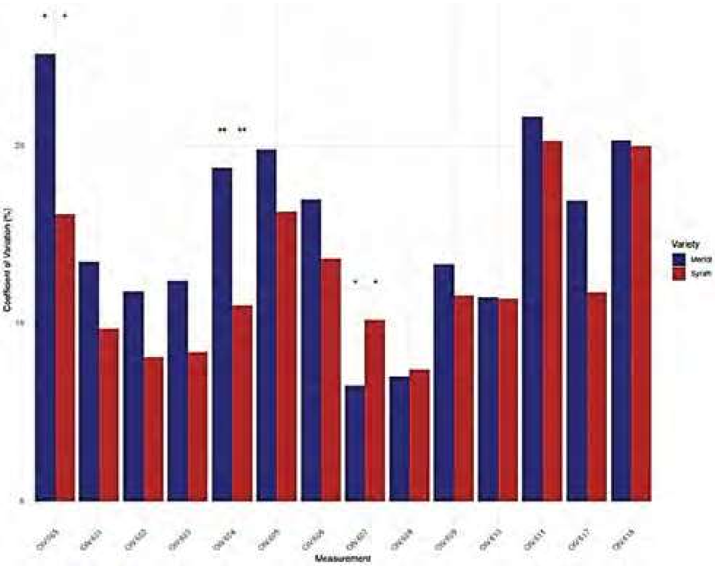

Figure 1. Comparison of relative variability between 'Merlot' and 'Syrah' varieties
Slika 1. Usporedba relativne varijabilnosti između sorata 'Merlot' i 'Syrah'
Source/Izvor: Authors/Autori

The correlation matrix for 'Syrah' showed the strongest relationships among the angular measurements. A very strong positive correlation was found between the angle of N_2/N_3 (OIV 608) and N_3/N_4 (OIV 609), with a coefficient of r=0.88. Similarly, the angle between N3/N4 (OIV 609) and the angle related to vein N5 (OIV 610) were also strongly correlated (r=0.70). Additionally, the two linear measurements defining the leaf - the distance from the petiole sinus to the upper (OIV 605) and lower (OIV 606) lateral sinuses - were strongly correlated (r=0.62). This suggests a highly integrated and predictable angular geometry in the 'Syrah' leaf. On the contrary, the relationship between overall blade size (OIV 065) and other traits was only moderate, with the strongest connection being to the opening of the petiole sinus (OIV 618). Chitwood et al. (2014) identified distinct constellations of traits in grape leaves, separating those related to lobing and serration from those describing the angular placement of lobes. The structure observed in 'Syrah' appears to be dominated by this latter constellation, indicating that its leaf shape is governed by a development that prioritizes geometric proportions.

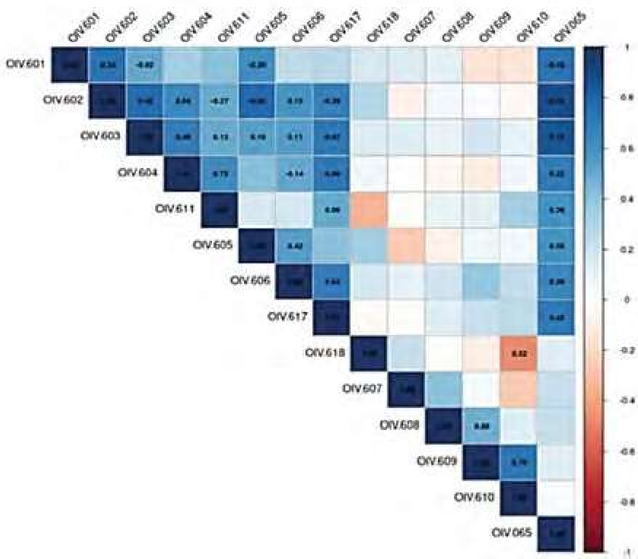

Figure 2. Correlation matrix for 'Syrah' variety
Slika 1. Korelacijska matrica za sortu 'Syrah'
Source/Izvor: Authors/Autori

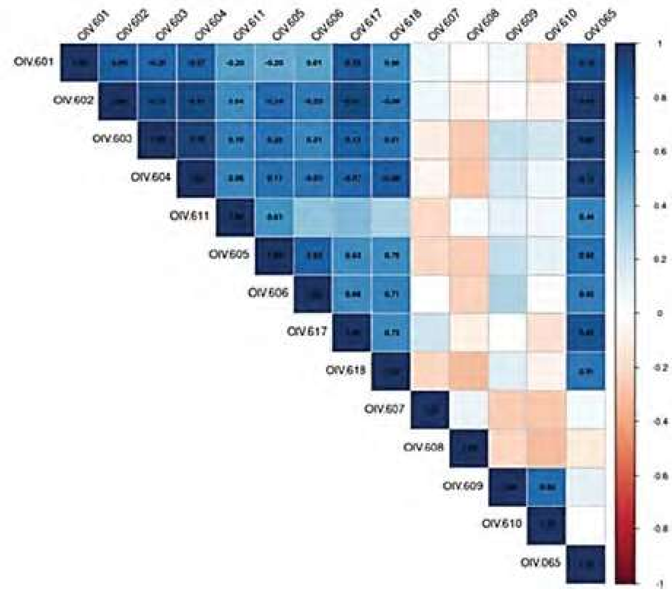

Figure 3. Correlation matrix for 'Merlot' variety
Slika 3. Korelacijska matrica za sortu 'Merlot'
Source/Izvor: Authors/Autori

The 'Merlot' variety showed a different and more integrated correlation structure, heavily influenced by overall size. The strongest correlation was between blade size (OIV 065) and the opening of the petiole sinus (OIV 618), with a coefficient of r=0.91. This indicates that as a 'Merlot' leaf gets larger, its petiole sinus widens in a highly predictable manner. Furthermore, blade size in 'Merlot' was also strongly correlated with several other linear traits, including the distances to the lateral sinuses (OIV 605 and OIV 606) and the tooth distance on vein N_2 (OIV 617). Strong relationships were also observed between adjacent vein lengths, such as N_3 (OIV 603) and N_4 (OIV 604) with r=0.78, and between the measurements of the leaf base (OIV 605 and OIV 606) with r=0.83. These results indicate that as a 'Merlot' leaf grows, its shape scales in a highly predictable manner. This observation is directly supported by the findings of Gutiérrez-Gamboa et al. (2021), who reported in their multivariate analysis that 'Merlot' was positively related to most leaf morphometric parameters, including area and length, distinguishing it from other cultivars like 'Chardonnay'.

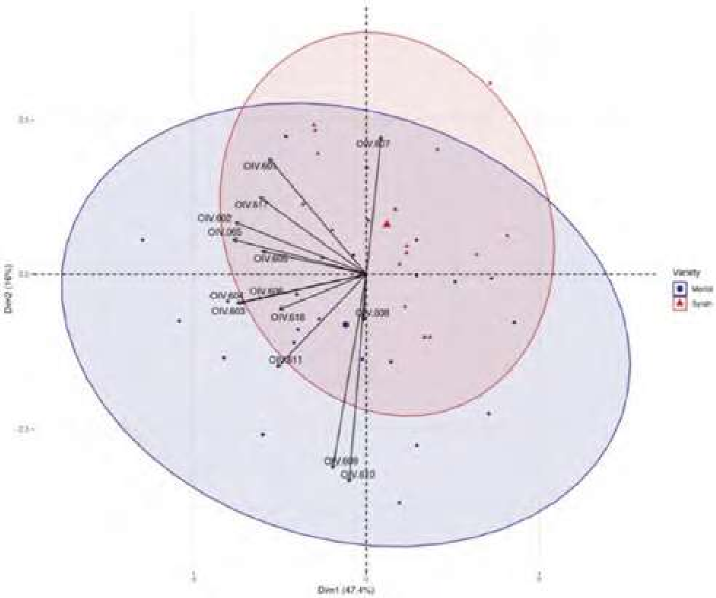

Figure 4. Principal Component Analysis (PCA) biplot of 'Syrah' and 'Merlot' leaves based on 14 morphometric descriptors
Slika 4. Biplot analize glavnih komponenti (PCA) listova sorata 'Syrah' i 'Merlot' na temelju 14 morfometrijskih deskriptora
Source/Izvor: Authors/Autori

A Principal Component Analysis (PCA) was performed to visualize the overall morphological separation between the two varieties based on all 14 descriptors. The resulting biplot shows a clear and complete separation between the 'Syrah' and 'Merlot' clusters (Figure 4).

Principal Component 1 (Dim1), which explained 47.4% of the variance, clearly represents the primary axis of differentiation related to leaf size and the development of the upper lobes. The variables with the strongest negative loadings on this axis include the overall blade size (OIV 065), the opening of the petiole sinus (OIV 618), and the lengths of the distal veins N_3, N_4, and N_5 (OIV 603, 604, and 611). This axis effectively separates the larger 'Merlot' leaves with more elongated distal parts from the smaller 'Syrah' leaves.

Principal Component 2 (Dim2) accounted for an additional 16% of the variance and is primarily driven by angular measurements. The strongest positive loading on this axis corresponds to the angle between veins N_1/N_2 (OIV 607), while the angles in the upper part of the leaf (OIV 609 and OIV 610) load negatively. PCA highlights the morphological divergence between two varieties. 'Merlot' is primarily characterized by its greater overall size and associated linear measurements, while 'Syrah' is defined by a distinct angular geometry at the leaf base.

The colorimetric analysis of the leaves provided an understanding of the subtle differences between the two varieties, revealing that color is not a simple discriminatory marker in this case. The primary determinant of leaf color was the surface being measured, with the adaxial (upper) and abaxial (lower) surfaces being significantly different in lightness (L*), red-greenness (a*), and yellow-blueness (b*) across both varieties.

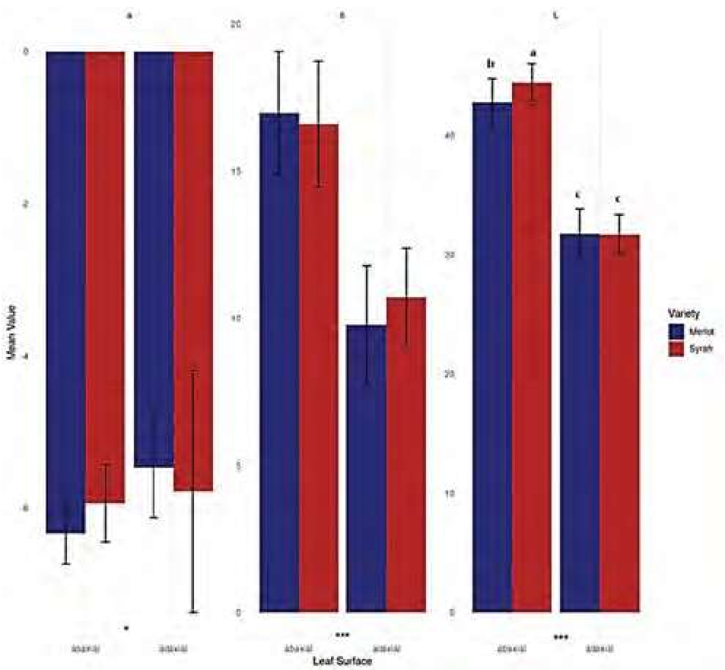

Figure 5. Mean colorimetric values of 'Merlot' and 'Syrah' varieties by leaf surface / **Slika 5.** Srednje kolorimetrijske vrijednosti sorata 'Merlot' i 'Syrah' prema strani lista
Source/Izvor: Authors/Autori

Error bars represent standard deviation, asterisks denote a significant difference (Two-way ANOVA) * $p < 0.05$, *** $p < 0.001$., bars with different letters in the L* panel are significantly different (Tukey HSD, $p < 0.05$)

The analysis revealed a highly significant interaction between variety and leaf surface for the lightness (L*) coordinate ($p < 0.001$). A subsequent Tukey HSD test showed that while the adaxial surfaces of both 'Syrah' and 'Merlot' were similarly dark, their abaxial surfaces differed significantly. Specifically, the abaxial surface of 'Syrah' was significantly lighter than that of 'Merlot'. This distinction can serve as a colorimetric marker for separating the two varieties. The darker color of the adaxial surface is most probably a consequence of the higher concentration of chlorophyll in the dense palisade tissue of the leaf, which is specialized for absorbing sunlight for photosynthesis. The abaxial surface is lighter due to the spongy parenchyma, which has more air spaces and trichomes that scatter the light (Dubravec, 1993). The density of trichomes could potentially explain the difference between abaxial surface. Trichomes are known to increase light reflectance and serve as a key feature in ampelographic descriptions. A study by Güler et al. (2024) specifically found that 'Syrah' exhibits a high proportion of trichomes (16.29%). The high density of light-scattering trichomes on the 'Syrah' leaf underside could provide a direct anatomical explanation for its higher L* value compared to 'Merlot'.

The significant, though less pronounced, interaction for the a* value suggests subtle differences in the green pigmentation or surface texture between the varieties. However, the violation of the homogeneity of variances for this variable (Levene's test, $p = 0.042$) suggests that the variability in greenness differs between the groups, making it a less stable marker than lightness. For both varieties, the adaxial surface was less intensely green (i.e., had a less negative a* value) than the abaxial surface. This effect was more pronounced in the 'Syrah' variety, indicating a subtle difference in its green pigmentation or surface characteristics.

For the b* coordinate, representing the blue-yellow axis, no significant interaction effect was detected. Instead, a consistent main effect of the leaf surface was observed. For both 'Syrah' and 'Merlot', the abaxial surface was significantly more yellow than the adaxial surface. This uniform pattern suggests it is likely related to anatomical features common to both cultivars.

Conclusion

This study established a set of quantitative descriptors to differentiate 'Merlot' and 'Syrah' grapevine varieties within the specific terroir of Central Istria. Although visually similar, a combined ampelometric and colorimetric analysis revealed that the varieties can be reliably separated based on significant differences in distal vein lengths (particularly N_5), key inter-vein angles (OIV 607 and OIV 608), and the significantly higher lightness (L*) of the abaxial leaf surface in 'Syrah'. Principal Component Analysis confirmed a complete morphological separation, effectively distinguishing the varieties based on size-related traits for 'Merlot' and a distinct angular geometry for 'Syrah'. These findings provide an objective and reproducible baseline for varietal identification, highlighting the value of quantitative techniques for understanding phenotypic expression in this key Croatian wine region.

References

Anderson, K, Aryal, N.R. (2013). *Which Winegrape Varieties are Grown Where? A Global Empirical Picture, University of Adelaide Press, Adelaide, https://doi.org/10.20851/winegrapes*

Bodor-Pesti, P., Taranyi, D., Deák, T., Nyitrainé Sárdy, D.Á., Varga, Z. (2023). *A review of ampelometry: morphometric characterization of the grape (Vitis spp.) Leaf. Plants, 12(3), p.452. https://doi.org/10.3390/plants12030452*

Carneiro, G.A., Cunha, A., Aubry, T.J. and Sousa, J. (2024). *Advancing Grapevine Variety Identification: A Systematic Review of Deep Learning and Machine Learning Approaches. AgriEngineering, 6(4), pp.4851-4888. https://doi.org/10.3390/ agriengineering6040277*

Chitwood, D.H., Ranjan, A., Martinez, C.C., Headland, L.R., Thiem, T., Kumar, R., Covington, M.F., Hatcher, T., Naylor, D.T., Zimmerman, S., Downs, N. (2014). *A modern ampelography: a genetic basis for leaf shape and venation patterning in grape. Plant physiology, 164(1), pp.259-272. https://doi.org/10.1104/pp.113.229708*

Demmings, E.M., Williams, B.R., Lee, C-R., Barba, P., Yang, S., Hwang, C-F., Reisch, B.I., Chitwood, D.H., Londo, J.P. (2019). *Quantitative Trait Locus Analysis of Leaf Morphology Indicates Conserved Shape Loci in Grapevine. Front. Plant Sci. 10:1373. https://doi.org/ 10.3389/fpls.2019.01373*

Dinu, D.G., Bianchi, D., Mamasakhlisashvili, L., Quarta, C., Brancadoro, L., Maghradze, D., Cardinale, M., Rustioni, L. (2021). *Effects of genotype and environmental conditions on grapevine (Vitis vinifera L.) shoot morphology. Vitis, 60(2), pp.85-91. https://dx.doi.org/10.5073/vitis.2021.60.85-91*

Dubravec, K., Botanika. (1993). *Udžbenici Sveučilišta u Zagrebu, Zagreb*

Dumas, Y., Dadomo, M., Di Lucca, G., Grolier, P. (2003). *Effects of environmental factors and agricultural techniques on antioxidantcontent of tomatoes. Journal of the Science of Food and Agriculture, 83(5), 369-382. https://doi.org/10.1002/jsfa.1370*

Fazinić, M., Benčić, M. (1998). *Merlot crni. Agronomski glasnik: Glasilo Hrvatskog agronomskog društva, 60(5-6), 269-281.*

Garcia-Munoz, S., Munoz-Organero, G., de Andrés, M.T., Cabello, F. (2011). *Ampelography-an old technique with future uses: The case of minor varieties of Vitis vinifera L. from The Balearic Islands. Oeno One, 45(3), pp.125-137. https://doi.org/10.20870/oeno-one.2011.45.3.1497*

Gómez-del-Campo, M., Ruiz, C., Baeza, P., Lissarrague, J.R. (2003). *Drought adaptation strategies of four grapevine cultivars (Vitis vinifera L.): modification of the properties of the leaf area. OENO One, 37(3), pp.131-143. https://doi.org/10.20870/oeno-one.2003.37.3.950*

Gutiérrez-Gamboa, G., Torres-Huerta, N., Araya-Alman, M., Verdugo-Vasquez, N., Moreno-Simunovic, Y., Valdés-Gómez, H., Acevedo-Opazo, C. (2021). *Leaf morpho-colorimetric characterization of different grapevine varieties through changes on plant water status. Horticulturae, 7(9), p.315. https://doi.org/10.3390/horticulturae7090315*

INRAE & IFV (2020a) *Syrah N. https://www.plantgrape.fr/en/varieties/fruit-varieties /267 (22.9.2025).*

INRAE & IFV (2020b) *Merlot N. https://www.plantgrape.fr/en/varieties/fruit-varieties/164 (22.9.2025).*

Kupe, M., Sayinci, B., Demir, B., Ercisli, S., Aslan, K.A., Gundesli, M.A., Baron, M., Sochor, J. (2021). *Multivariate analysis approaches for dimension and shape discrimination of vitis vinifera varieties. Plants, 10(8), p.1528. https://doi.org/10.3390/plants10081528*

Lepej, P., Taranyi, D., Rakun, J., Nagy, B., Steckl, S., Lukácsy, G., Mikóczy, N., Nyitrainé Sárdy, D.Á., Bodor-Pesti, P. (2024). *The Effect of Irrigation on the Vineyard Canopy and Individual Leaf Morphology Evaluated with Proximal Sensing, Colorimetry, and Traditional Morphometry. Horticulturae, 10(7). https://doi.org/10.3390/horticulturae10070716*

Vişan, L., Tamba-Berehoiu, R.M, Popa, C., Dănăilă-Guidea, S., Dobrinoiu, R.V. (2019). *SYRAH -GRAPEVINE AND WINE-A CRITICAL REVIEW. Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, Vol. 19, Issue 1*

Maletić, E., Pejić, I., Kontić, J.K., Zdunić, D., Preiner, D., Šimon, S., Andabaka, Ž., Mihaljević, M.Ž., Bubola, M., Marković, Z., Stupić, D. (2015). *Ampelographic and genetic characterization of Croatian grapevine varieties. Vitis-Journal of Grapevine Research, 54, pp.93-98.*

Martí, C., Casanova, J., Montaner, C., Badia, D. (2006). *Ampelometric study of mature leaves from two indigenous Vitis cultivars grown in Somontano de Barbastro. Journal of Wine Research, 17(3), pp.185-194. https://doi.org/10.1080/09571260701286635*

Migicovsky, Z., Swift, J.F., Helget, Z., Klein, L.L., Ly, A., Maimaitiyiming, M., Woodhouse, K., Fennell, A., Kwasniewski, M., Miller, A.J., Chitwood, D.H. (2024). *Grapevine leaf size influences canopy temperature. OENO one, 58(2). https://doi.org/10.20870/oeno-one.2024.58.2.7735*

OIV. (2009). *OIV descriptor list for grape varieties and Vitis species (2nd ed.) Organisation Internationale de la Vigne et du Vin, Paris, France*

Osrečak, M., Kozina, B., Štambuk, P., Karoglan, M. (2016). *Biološka i agronomska svojstva cv. Syrah (Vitis vinifera L.) u uvjetima Zagrebačkog vinogorja. Glasnik zaštite bilja, 39(6), 58-61.*

Popescu, C.F., Crespan, M. (2018). *Combining microsatellite markers and ampelography for better management of Romanian grapevine germplasm collections. Notulae Scientia Biologicae, 10(2), pp.193-198. https://doi.org/10.15835/nsb10210297*

Prša, I., Rašić, D., Petric, I. V., Rakić, V., Telišman Prtenjak, M., Omazić, B., Karoglan, M., Preiner, D., Karoglan Kontić, J., Crnković, B., Karačić, D., Kristek, I., Ileš, M. (2023). *Prilagodba vinogradarskog sektora u Hrvatskoj klimatskim promjenama [Elaborat]. Hrvatska agencija za poljoprivredu i hranu; Sveučilište u Zagrebu, Prirodoslovno-matematički fakultet; Sveučilište u Zagrebu, Agronomski fakultet; Sveučilište Josipa Jurja Strossmayera u Osijeku, Ekonomski fakultet u Osijeku.*

Sladonja, B., Peršurić, Đ., Milotić, A., Ilak Peršurić, A. S. (2004). *Viticultural sites and their valorisation in Istra (Croatia). Joint International Conference on Viticultural Zoning. Isle Trautmann (ur.) Cape Town: SASEV South African Society for Enology and Viticulture (pp. 26-27).*

Šimunić, I., Likso, T., Husnjak, S., Bubalo Kovačić, M. (2021). *Analysis of climate elements in central and western Istria for the purpose of determining irrigation requirements of agricultural crops. Agriculturae Conspectus Scientificus, 86(3), 225-233.*

Tarailo, R. and Vuksanović, P. (2018). *Ampelografija. URL: https://ovinu.info/ ampelografija/*

Vivai Rauscedo (n.d.) Merlot. https://vivairauscedo.com/contributi/en/schede/merlot.pdf (22.9.2025)

Vujović, D., Žunić, D., Pejin, B., Popović-Djordjević, J. (2016). *Ampelographic description of cluster, berry and seed of Merlot cultivar (Vitis vinifera L.): And its selected clones. Journal of Agricultural Sciences (Belgrade), 61(1), 45-55. https://doi.org/10.2298/jas1601045v*

Prispjelo/Received: 3.9.2025. ***Prihvaćeno/Accepted: 15.10.2025.***

Izvorni znantsveni rad

Morfometrijske karakteristike lista sorata 'Merlot' i 'Syrah' (Vitis vinifera L.) u vinogradu vinogorja Centralna Istra

Sažetak

*Cilj ovog istraživanja bio je provesti usporednu morfometrijsku i kolorimetrijsku analizu lista sorata vinove loze 'Merlot' i 'Syrah' kako bi se utvrdile ključne razlikovne karakteristike unutar vinogorja Centralna Istra. Analizirani su kvantitativni OIV deskriptori za morfometriju lista i CIE L*a* b* vrijednosti boje na zrelim listovima obiju sorata. Iako su sorte pokazale visoku kvalitativnu sličnost, utvrđene su značajne kvantitativne razlike u duljinama distalnih lisnih žila (N3, N4, N5), kutovima između žila (OIV 607, OIV 608) te u otvorenosti sinusa peteljke (OIV 618). Kolorimetrijska analiza otkrila je da je abaksijalna strana lista sorte 'Syrah' značajno svjetlija (viša L* vrijednost) od sorte 'Merlot', a analiza glavnih komponenti potvrdila je potpunu odvojenost dvije sorte. Ovo istraživanje uspostavilo je objektivan skup deskriptora za razlikovanje sorata 'Merlot' i 'Syrah' u ovom specifičnom terroiru, pokazujući korisnost kombiniranja ampelometrije i kolorimetrije za preciznu karakterizaciju sorata.*

Ključne riječi: *Merlot, Syrah, ampelografija, ampelometrija, kolorimetrija*