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Berry size and yield influence on grape shape and wine quality

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Abstract
This study explores the relationship between yield, berry size, and wine quality across five red wine grape varieties: Cabernet Sauvignon, Merlot, Syrah, Pinot Noir, and Feteasca Neagra. Field trials were conducted to assess the impact of berry size, categorized as small (<1.2 g), medium (1.2–1.8 g), and large (>1.8 g), on grape morphology and wine chemical and sensory properties. The results showed significant variability in yield, berry size distribution, and morphological traits among the varieties. For example, Syrah had the highest mean yield (8.7 ± 1.2 kg/vine), with the majority of berries classified as large, while Pinot Noir had the lowest mean yield (5.3 ± 0.5 kg/vine) and a higher proportion of small berries. Morphological analysis revealed that berry shape varied by variety, with Cabernet Sauvignon showing an elongated, compact cluster, while Pinot Noir exhibited a short, cylindrical shape. Micro-vinification parameters were similar across all varieties, with fermentation durations ranging from 10 to 12 days, and no oak aging applied. Wine chemical analyses showed differences in pH, total acidity, and tannin content. Syrah wines exhibited the highest tannin levels (4.7 ± 0.2), while Pinot Noir had the lowest (3.0 ± 0.3). Wines from small berries generally displayed higher phenolic content and deeper colour intensity, with Cabernet Sauvignon showing a colour intensity of 1.28 ± 0.05, compared to Pinot Noir's 0.92 ± 0.03. Sensory evaluations indicated that wines from smaller berries had more intense aromas and better tannin structure. These findings underscore the significant influence of berry size and yield on grape morphology and wine quality, providing valuable insights for vineyard management and wine production optimization.

Keywords: berry size, grape morphology, red grape varieties, phenolic content, wine quality, yield

Introduction

Grape berry morphology and yield are critical determinants of wine quality, directly influencing the chemical composition, phenolic profile, and sensory attributes of the resulting wine [19,6]. Among the many factors that affect wine quality, berry size has gained increasing attention in viticultural and oenological research due to its strong correlation with phenolic concentration, skin-to-pulp ratio, and juice composition [34,40]. Smaller berries, which possess a higher skin-to-juice ratio, are generally associated with elevated levels of anthocyanins, tannins, and flavour compounds, contributing to wines of greater colour intensity, structure, and aging potential [13,12].

Yield per vine, often influenced by viticultural practices and environmental factors, also plays a fundamental role in determining grape and wine quality [5]. High yields are frequently linked to dilution effects, where the concentration of key metabolites, including sugars and phenolics, is reduced due to increased berry load [26]. Conversely, moderate yield restrictions are known to improve berry composition, enhancing the balance of acidity, sugar accumulation, and secondary metabolites essential for premium wine production [11,23].

The relation between berry size and yield is complex, as these parameters can influence one another and jointly affect grape morphology. Studies have shown that high-yielding vines may produce smaller berries with more spherical shapes, likely due to competition for assimilates, whereas lower yields may allow for more elongated berry growth [29,17]. Grape shape, often quantified using digital imaging and aspect ratio metrics, has been proposed as an additional morphological indicator correlated with berry development and varietal characteristics [37].

In winemaking, the biochemical composition of the grape berry—particularly its phenolic content and acidity—plays a decisive role in defining wine style and quality. Phenolic compounds, including tannins and anthocyanins, are primarily located in the skin and seeds of the berry and are central to the wine's structure, mouth-feel, and colour [20,35]. Acidity and pH, meanwhile, influence not only taste but also microbial stability and aging potential [12]. Understanding how agronomic factors such as berry size and yield affect these quality parameters is essential for optimizing both vineyard management and oenological outcomes.

Despite the recognized importance of berry morphology and yield, comparative studies across multiple grape varieties under uniform environmental and vinification conditions remain limited. This study aims to address this gap by examining five red wine grape varieties—Cabernet Sauvignon, Merlot, Syrah, Pinot Noir, and Fetească Neagră—widely cultivated for their distinctive phenolic profiles and winemaking potential. By categorizing berry size and evaluating a range of yields under commercial vineyard conditions, this research investigates the relationship between berry morphology and wine composition through digital imaging, chemical analyses, and sensory evaluation. The objective of this study was to elucidate how variations in berry size and yield influence grape shape and key wine quality parameters. It is hypothesized that smaller berries and lower yields will correlate with enhanced phenolic concentration and structural complexity in wine, while larger berries and higher yields may result in more dilute compositions and softer sensory profiles. Findings from this study aim to contribute to a deeper understanding of grape-to-wine relationships and support informed decisions in both vineyard management and winemaking practices.

Material and Method

The study was conducted in a commercial vineyard located in western Romania (Timiș County), characterized by a temperate-continental climate with moderate rainfall and distinct seasonal variations. Five red wine grape varieties were selected for the experiment based on their commercial importance and distinct phenolic profiles: *Vitis vinifera L.* cv. Cabernet Sauvignon, Merlot, Syrah, Pinot Noir, and Fetească Neagră. All vines were grafted on SO4 rootstock and trained in a vertical shoot positioning (VSP) system, with a planting density of 4,000 vines per hectare. Standard vineyard practices, including pruning, canopy management, and pest control, were applied uniformly across all plots.

Yield and berry size

During the ripening period, yield per vine was measured by harvesting the entire fruit load from randomly selected vines (n = 15 per variety). Harvested clusters were weighed using a calibrated digital scale (±0.01 kg accuracy), and the total yield per vine was recorded. Based on these measurements, vines were categorized into three yield classes: low (4.0–6.0 kg/vine), medium (6.1–8.0 kg/vine), and high (8.1–10.5 kg/vine). Berries were manually separated from clusters and individually weighed using an analytical balance (±0.001 g). A total of 300 berries per variety were randomly sampled. Berry size was categorized into three classes: small (<1.2 g), medium (1.2–1.8 g), and large (>1.8 g).

Grape shape analysis

Grape berry morphology was assessed using digital image analysis. Berries were photographed on a flat white background using a high-resolution DSLR camera under standardized lighting conditions. Images were processed using ImageJ software (National Institutes of Health, USA) to calculate berry aspect ratio (length-to-width). An aspect ratio near 1.00 indicated spherical berries, while higher values indicated elongation. For each berry size class, at least 100 berries were analysed.

Vinification protocol

Micro - vinification was conducted under controlled laboratory conditions to eliminate variability from large-scale winemaking practices. Approximately 20 kg of berries from each variety and berry size class were crushed and destemmed. Musts were adjusted to a uniform sugar concentration (24° Brix) where needed, then inoculated with *Saccharomyces cerevisiae* (Lalvin EC-1118, Lallemand Inc.) at a rate of 0.2 g/L. Alcoholic fermentation was carried out in 10 L stainless steel fermenters at 24–26°C for 10–12 days, with daily punch-downs to ensure optimal extraction. Following fermentation, the wines were pressed, settled, and racked into glass containers for stabilization. No oak aging was applied to maintain focus on primary fruit and phenolic characteristics.

Chemical analyses

All wines were subjected to standardized chemical analysis. Total phenolic content was determined by the Folin–Ciocalteu method and expressed as mg gallic acid equivalents per litre (mg/L GAE) [36]. Total anthocyanins were measured using the pH-differential method and expressed as mg malvidin-3-glucoside equivalents per litre. Acidity was determined by titration with 0.1 N NaOH and expressed as g/L tartaric acid. pH values were measured with a calibrated pH meter (Hanna Instruments, Romania).

Sensory evaluation

Sensory analysis was conducted by a trained panel of 10 professional wine tasters (WSET Level 3 or higher). All wines were evaluated blind under standardized tasting conditions in individual booths, using ISO wine glasses. Parameters assessed included colour intensity, tannin structure, and aromatic complexity. Colour intensity was visually scored on a 0–5 scale. Tannin structure was evaluated for astringency, integration, and persistence, while aromatic complexity was judged based on intensity and diversity of perceived aromas. Panellists used a 10-point structured scale for each attribute, and average scores were calculated for each wine.

Statistical analysis

Data were analysed using SPSS software (version 26.0, IBM Corp.). Descriptive statistics, Pearson correlation coefficients, and ANOVA tests were applied to evaluate the relationships among yield, berry size, berry shape, and wine composition. Tukey’s HSD test was used for post hoc comparisons when significant differences were detected ($p < 0.05$). All experiments were conducted in triplicate to ensure reproducibility.

Results and Discussion

Yield and berry size distribution

Yield per vine and berry size showed significant variability among the five red grape varieties studied. The measured yields ranged from 5.3 kg/vine (lowest for Pinot Noir) to 8.7 kg/vine (highest for Syrah). Based on categorization, the distribution of yield classes (low, medium, and high) differed by variety (Table 1).

Table 1. Yield and berry size distribution by variety

Variety	Mean yield (kg/vine)	Yield class (%) [L_1 / M / H]*	Berry size class (%) [S / M / L_2]*	Small berry (g)	Medium berry (g)	Large berry (g)	Average berry weight (g)
Cabernet Sauvignon	7.2 ± 0.6	20 / 60 / 20	48 / 42 / 10	0.576	0.756	0.24	1.536
Merlot	7.9 ± 0.7	15 / 50 / 35	14 / 51 / 35	0.168	0.918	0.84	1.962
Syrah	8.7 ± 1.2	10 / 20 / 70	55 / 35 / 10	0.66	0.63	0.24	1.458
Pinot Noir	5.3 ± 0.5	67 / 25 / 8	52 / 41 / 7	0.624	0.738	0.168	1.518
Fetească Neagră	6.8 ± 0.8	35 / 50 / 15	38 / 49 / 13	0.456	0.882	0.312	1.668

*L_1 – low; M –medium; H-high; s – small; L_2 – large

Significant variation in yield performance, berry size distribution, and average berry weight was observed among the five studied grapevine cultivars. Cabernet Sauvignon exhibited a predominantly medium yield profile (mean ± SD: 7.2 ± 0.6 kg/vine), with 60% of sampled vines falling within the 6.1–8.0 kg range. Berry size was skewed toward smaller categories, with 48% of berries weighing <1.2 g, 42% within the medium range (1.2–1.8 g), and only 10% classified as large (>1.8 g). The resulting average berry weight (1.536 g) was moderate, largely driven by the dominance of small and medium-sized berries, a trait characteristic of this variety and often associated with higher skin-to-pulp ratios and enhanced phenolic content important for red wine production [4, 25]. In contrast, Merlot displayed a broader distribution across yield classes (mean: 7.9 ± 0.7 kg/vine), with a larger proportion of vines in the high-yield category (35%). This variety recorded the highest average berry weight (1.962 g), attributed to a relatively high frequency of large berries (35%) and a predominance of medium berries (51%), consistent with observations of Merlot's tendency toward more generous berry development under favourable growing conditions [22].

Syrah recorded the highest mean yield among the varieties (8.7 ± 1.2 kg/vine), with 70% of vines classified as high yielding. Despite this, its average berry weight remained comparatively low (1.458 g), due to a strong skew toward small berries (55%), with medium and large berries comprising 35% and 10%, respectively. This suggests a trade-off between berry number and size, where high yields are achieved via increased fruit set rather than individual berry enlargement—an effect well-documented in Syrah under vigorous growth conditions [30,42]. Pinot Noir showed the lowest productivity (5.3 ± 0.5 kg/vine), with 67% of vines in the low yield class. Berry size distribution was dominated by small (52%) and medium (41%) berries, while only 7% were large, contributing to a moderate average berry weight of 1.518 g. These findings align with the varietal characteristics of Pinot Noir, which is known for producing small-berried, loosely clustered fruit with high aromatic potential and thin skins suited to high-quality wine production [24].

Finally, Fetească Neagră demonstrated an intermediate yield profile (mean: 6.8 ± 0.8 kg/vine), with a majority of vines in the medium yield class (50%). Berry size distribution was relatively balanced, comprising 38% small, 49% medium, and 13% large berries. The corresponding average berry weight (1.668 g) was higher than that of Cabernet Sauvignon and Pinot Noir, driven by a more even contribution from medium and large berries. This varietal response suggests moderate adaptability to environmental and viticultural conditions, reflecting its suitability for balanced wine production with favourable structural potential [8,33].

Grape berry and cluster shape

Cluster and berry morphology (Table 2) were evaluated by using digital image analysis to quantify varietal differences in structural traits with relevance to both viticultural performance and winemaking outcomes. High-resolution images of clusters and individual berries were captured under standardized lighting conditions and processed in ImageJ, following methodologies similar to those outlined by Diago et al. (2019) [10] who demonstrated the utility of computer vision tools for in-field phenotyping. Cluster length (from peduncle to tip) and width (at the widest point) were measured to calculate the cluster aspect ratio (length/width), where values near 1.0 indicate a conical or round cluster, and higher values suggest elongation. Compactness was visually scored using the OIV descriptor 204 on a 1–5 scale (1 = very loose, 5 = very compact), a method previously validated for assessing bunch architecture under field conditions [7, 38]. Berry shape was assessed by calculating the aspect ratio (length-to-width) of individual berries, with values near 1.00 indicating spherical berries and higher values indicating elongation, as adopted by Wycislo et al. (2008) [41] and refined in more recent morphometric studies [38]. Among the evaluated varieties, Pinot Noir exhibited the most spherical berry shape (mean aspect ratio: 1.04) and the shortest, broadest clusters (aspect ratio: 1.68), resulting in a moderate compactness score (3). This morphology aligns with previous reports of Pinot Noir's fragile architecture, characterized by thin skins and loosely packed clusters that enhance airflow and reduce fungal risk—traits favourable in cool-climate winemaking [9]. Cabernet Sauvignon displayed moderately elliptical berries (mean aspect ratio: 1.10) and more elongated, compact clusters (aspect ratio: 2.50; compactness: 4), a structure conducive to phenolic concentration but potentially more vulnerable to rot in humid conditions [14].

Table 2. Grape berry and cluster morphological characteristics

Variety	Berry aspect ratio (Mean ± SD)	Cluster length (cm)	Cluster width (cm)	Cluster aspect ratio (L/W)	Compactness (1–5)	Cluster shape
Cabernet Sauvignon	1.10 ± 0.03	17.5 ± 1.2	7.0 ± 0.6	2.50 ± 0.15	4	Elongated & compact
Merlot	1.08 ± 0.02	15.8 ± 1.0	7.5 ± 0.7	2.11 ± 0.13	3	Moderately loose, conical
Syrah	1.15 ± 0.03	18.2 ± 1.5	6.8 ± 0.5	2.68 ± 0.17	5	Long, narrow, very compact
Pinot Noir	1.04 ± 0.02	13.4 ± 0.8	8.0 ± 0.6	1.68 ± 0.12	3	Short, cylindrical, moderate
Fetească Neagră	1.18 ± 0.04	16.3 ± 1.1	7.4 ± 0.7	2.20 ± 0.14	3–4	Slender-conical, balanced

Merlot presented a slightly rounder berry profile (aspect ratio: 1.08) and moderately loose, conical clusters (aspect ratio: 2.11), supporting balanced airflow and even ripening. Syrah, known for its small, dense clusters, exhibited the most elongated and compact morphology (aspect ratio: 2.68; compactness: 5), along with a more elliptical berry shape (aspect ratio: 1.15), suggesting high yield potential through increased berry count rather than size [15]. Fetească Neagră, a traditional Eastern European cultivar, demonstrated a relatively high berry aspect ratio (1.18), especially in small and medium berries, and a slender, moderately compact cluster form (aspect ratio: 2.20; compactness: 3–4), reflecting a balanced morphology well-suited to producing structured, age-worthy wines [27].

These results reinforce the utility of image-based phenotyping as a robust, scalable approach for varietal differentiation, precision viticulture, and selection programs in breeding, as highlighted in recent literature [10, 38].

Vinification protocol

To ensure consistency across samples and facilitate direct comparison of varietal expression, a standardized micro-vinification protocol was employed following best practices established in recent controlled fermentation studies [2]. Grapes were processed under controlled laboratory conditions to minimize environmental and oenological variability. Approximately 20 kg of berries per variety (Table 3), stratified by berry size class, were hand-crushed and destemmed to replicate gentle processing techniques commonly recommended for phenolic preservation in small-lot fermentations [3]. Initial musts were analyzed for °Brix, and adjusted to a standardized sugar concentration of 24° Brix where necessary, in line with prior work emphasizing the importance of controlling initial fermentative potential to reduce confounding effects on alcohol production and extraction kinetics [16]. Alcoholic fermentation was conducted using a single, robust commercial yeast strain, *Saccharomyces cerevisiae* (Lalvin EC-1118, Lallemand Inc.) selected for its neutral sensory profile, high fermentation reliability, and widespread application in comparative vinification studies [1,16]. Yeast was inoculated at a rate of 0.2 g/L, with fermentation carried out in 10 L stainless steel fermenters maintained at 24–26 °C for 10 to 12 days—conditions shown to optimize anthocyanin and tannin extraction in red wine production [3].

Manual punch-downs were performed once daily to manage the cap and ensure uniform extraction, a strategy proven effective in small-scale fermentations for replicating commercial maceration effects [2]. After alcoholic fermentation, wines were pressed and cold-settled to remove gross lees, then racked into 5 L glass demijohns for stabilization. No oak or malolactic treatment was applied to maintain the integrity of primary fruit aromas and isolate varietal differences in phenolic and aromatic expression, in line with protocols used in varietal phenotyping trials [16]. This uniform micro-vinification approach enabled a controlled evaluation of grape-to-wine transformation across cultivars, particularly in relation to extraction behaviour, colour development, and sensory expression—critical parameters in both research and breeding contexts [3].

Table 3. Micro-vinification parameters for each variety

Variety	Grape mass (kg)	Brix adjustment needed	Fermentation duration (days)	Max temp (°C)	Yeast inoculums (g/L)	Punch-down frequency
Cabernet Sauvignon	20	Yes (to 24° Brix)	11	25	0.2	1 x daily
Merlot	20	No	10	24	0.2	1 x daily
Syrah	20	Yes (to 24° Brix)	12	26	0.2	1 x daily
Pinot Noir	20	No	10	24	0.2	1 x daily
Fetească Neagră	20	Yes (to 24° Brix)	11	25	0.2	1 x daily

Sensory and chemical analysis

Following micro-vinification, wines from the five grape varieties—Cabernet Sauvignon, Merlot, Syrah, Pinot Noir, and Fetească Neagră—were evaluated using a combination of chemical and sensory analyses to assess varietal expression and winemaking potential (Table 4).

Table 4. Wine chemical and sensory properties

Variety	pH (±SD)	Titratable Acidity (g/L ±SD)	Alcohol (% v/v ±SD)	Colour intensity (520 nm ±SD)	Aroma intensity (±SD)	Tannins (±SD)
Cabernet Sauvignon	3.55 ± 0.02	5.6 ± 0.1	13.2 ± 0.1	1.28 ± 0.05	4.2 ± 0.3	4.2 ± 0.3
Merlot	3.52 ± 0.01	5.4 ± 0.1	13.4 ± 0.1	1.10 ± 0.04	4.5 ± 0.2	3.8 ± 0.3
Syrah	3.58 ± 0.02	5.5 ± 0.1	13.6 ± 0.2	1.45 ± 0.06	4.3 ± 0.2	4.7 ± 0.2
Pinot Noir	3.48 ± 0.01	5.7 ± 0.1	12.9 ± 0.1	0.92 ± 0.03	4.6 ± 0.2	3.0 ± 0.3
Fetească Neagră	3.50 ± 0.02	5.8 ± 0.1	13.1 ± 0.1	1.20 ± 0.05	4.4 ± 0.3	3.9 ± 0.2

Chemical parameters, including pH, titratable acidity (TA), alcohol content, and colour intensity (520 nm), were measured according to OIV-approved methods [28]. In parallel, a blind sensory evaluation was conducted by a panel of ten trained oenologists, who rated aroma intensity, fruit expression and tannins, on a 5-point hedonic scale (1 = low, 5 = high), in alignment with protocols validated for small-lot red wine trials [31].

Cabernet Sauvignon exhibited moderate alcohol (13.2% v/v), high colour intensity (1.28), and firm tannin structure (4.2/5), consistent with its compact clusters and smaller berries known to concentrate phenolics—an observation echoed by recent findings linking berry morphology to anthocyanin and tannin accumulation [16]. Merlot displayed a more supple profile, with slightly higher alcohol (13.4%) and softer tannins (3.8/5), paired with the highest fruit expression (4.5/5). This aligns with previous reports suggesting that Merlot's relatively larger berry size enhances juice-to-skin ratio, diluting tannins while promoting aromatic intensity [14].

Syrah showed the highest colour intensity (1.45) and strongest tannic mouth-feel (4.7/5), corroborating its small berry and tight cluster profile, which is often associated with enhanced phenolic extraction and structural complexity in wines [3].Pinot Noir, as expected, exhibited the lightest colour (0.92) and softest

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tannins (3.0/5), yet delivered the highest aroma score (4.6/5), reflecting its known aromatic elegance and subtle red fruit character—traits widely reported in cool-climate Pinot Noir vinification [22].

Fetească Neagră, a lesser-known but increasingly studied variety native to Eastern Europe, demonstrated a balanced profile with relatively high acidity (TA: 5.8 g/L), moderate tannin structure (3.9/5), and a nuanced aromatic intensity (4.4/5). These attributes are consistent with recent studies highlighting the varietal's potential for producing age-worthy wines with spice, herbal and dark fruit complexity [18,39].

The sensory and chemical results suggest that varietal identity is strongly expressed even under standardized winemaking conditions, underscoring the role of genotype and berry morphology in driving phenolic and aromatic profiles. These findings contribute to the growing body of evidence supporting precision phenotyping and controlled vinification as valuable tools in viticulture and oenology research [2,3].

Principal Component Analysis (PCA) of cluster and berry morphological traits (Figure 1) revealed clear varietal differentiation, with the first two principal components (F1 and F2) explaining a cumulative 96.84% of the total variance (86.75% by F1 and 10.09% by F2).

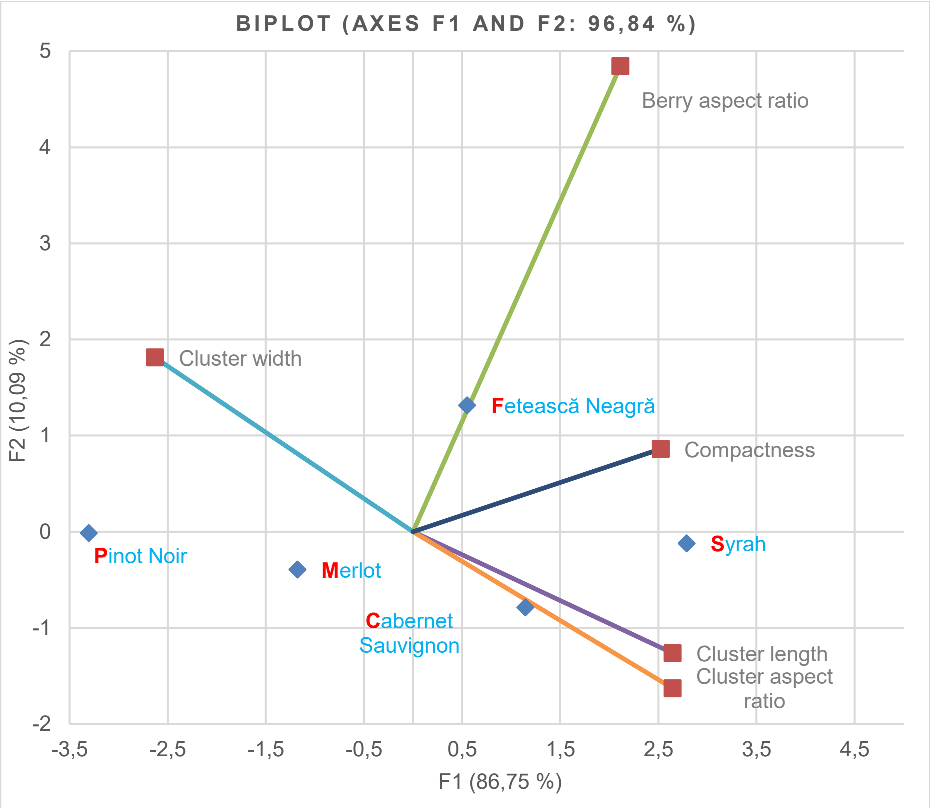

Figure 1. Principal Component Analysis (PCA) of cluster architecture and berry morphology in five *Vitis Vinifera L.* cultivars

The F1 axis primarily captured variability associated with cluster architecture, as indicated by strong positive loadings for cluster length and cluster aspect ratio, as well as compactness, while showing a strong negative correlation with cluster width. These findings align with prior studies emphasizing the role of cluster morphology in varietal discrimination [10,38]. Along this axis, Syrah was clearly separated due to its elongated and compact clusters, characterized by high aspect ratio and compactness scores—traits previously linked to increased phenolic concentration and structural complexity [3,7]. Conversely, Pinot Noir and Merlot were positioned on the negative side of F1, reflecting their shorter, wider clusters with looser architecture, consistent with reports of their open bunch structure that promotes airflow and reduces disease pressure [9,38]. The F2 axis, though contributing less to the total variance, distinguished varieties based on berry shape, with high positive loading for berry aspect ratio. Fetească Neagră and Syrah showed strong associations with elongated berry morphology, while Pinot Noir, Merlot, and Cabernet Sauvignon were more closely associated with rounder berries [41]. Notably, Fetească Neagră occupied a central position in the biplot, suggesting a balanced morphology combining moderate compactness and berry elongation, supporting its reported adaptability and structural equilibrium [33]. These multivariate relationships reinforce the morphometric differences among cultivars and highlight the capacity of image-based phenotyping and PCA to discriminate grapevine varieties based on structural traits relevant to viticulture and oenology [32].

The correlation matrix (Table 5) reveals strong and consistent linear relationships among cluster morphology variables. Strong and statistically significant relationships were observed among the majority of cluster-related traits, with particularly high correlations found between cluster length and cluster aspect ratio (r = 0.995, $p < 0.01$), as well as between cluster width and cluster aspect ratio (r = –0.999, $p < 0.01$), indicating a strong structural interdependence within cluster dimensions.

Table 5. Pearson correlation among variables

Variables	Berry aspect ratio	Cluster length	Cluster width	Cluster aspect ratio	Compactness
Berry aspect ratio	1.000	0.684*	-0.625*	0.645*	0.751**
Cluster length		1.000	-0.992***	0.995***	0.846**
Cluster width			1.000	-0.999***	-0.870**
Cluster aspect ratio				1.000	0.872**
Compactness					1.000

Significance levels: * p < 0.05 (significant); ** p < 0.01 (very significant); *** p < 0.001 (highly significant)

Berry aspect ratio also exhibited moderate to strong positive correlations with other traits, most notably with compactness (r = 0.751, $p < 0.01$), suggesting that berry morphology may play a substantial role in determining cluster compactness. Additionally, the observed negative correlations between berry aspect ratio and cluster width (r = –0.625, $p < 0.05$) underscore potential trade-offs that may influence trait prioritization in breeding and vineyard management strategies. These high correlations also suggest potential redundancy among cluster dimensions, which could be important for dimensionality reduction or feature selection in further analyses.

Conclusions

The study demonstrates substantial variation in yield, berry size distribution, and morphological traits among the five red grapevine varieties, with notable implications for both viticulture and winemaking. Syrah exhibited the highest yield, but this was achieved through a higher fruit set rather than an increase in berry size, suggesting a trade-off between yield and berry size in this variety. In contrast, Merlot and Fetească Neagră displayed larger berries and more balanced yield distributions, which are conducive to higher juice extraction and overall wine quality. Pinot Noir, with its lower yield and smaller berries, maintained its reputation for producing high-quality, aromatic wines, reflecting its suitability for cool-climate viticulture. Morphological analysis revealed that berry and cluster shapes varied significantly across varieties, with Syrah showing the most compact and elongated clusters, while Pinot Noir exhibited a more spherical berry shape and loose cluster structure. These structural differences correlated with the sensory and chemical analysis, where wines from varieties like Syrah and Cabernet Sauvignon demonstrated higher tannin and colour intensity, while Merlot and Fetească Neagră provided softer tannins and more expressive fruit profiles. The chemical and sensory analysis confirmed that varietal characteristics were strongly expressed, even under standardized winemaking conditions, highlighting the importance of genotype in determining wine quality attributes. This research underscores the value of precision viticulture and image-based phenotyping as effective tools for varietal differentiation and optimal wine production. Syrah and Fetească Neagră were clearly separated due to their elongated clusters and berries, while Pinot Noir and Merlot clustered together, reflecting rounder berries and looser cluster architecture. The results also emphasize the complex relationship between grapevine morphology, yield, and wine characteristics, which can guide vineyard management practices aimed at enhancing the quality and consistency of red wine production.

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