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ASSESSMENT AND PREDICTION OF GRAPE AND WINE TRACEABILITY: A CASE STUDY OF FETEASCĂ NEAGRĂ AND PINOT NOIR CULTIVATED IN VARIOUS WINE-GROWING REGIONS

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Abstract

The study was conducted between 2022 and 2023 with the aim of tracing specific elements of chemical composition from grapes to wine, focusing particularly on the 'Fetească Neagră' and 'Pinot Noir' varieties. These grape varieties were cultivated in five distinct wine-growing regions across Romania. A significant part of the grape's substances is proportionally transferred into the wine, blending with other beneficial compounds resulting from the conversion of grape must into wine. The correlation between the chemical composition of wine and its derivation from the chemical composition of the grape is a critical factor in forecasting wine quality. The chemical composition of the grapes was assessed at full maturity, and included the following elements: water, proteins, total lipids, ash, dietary fibers, and sugars. The corresponding components were subsequently traced within the wine. The examination took place subsequent to the stabilization of the wines, carried out in anticipation of bottling and consumption. The determination of both grape and wine samples' chemical composition adhered to specific standards validated by the Association of Analytical Chemists.

Key words: *chemical composition, grapes, quality, traceability, wine.*

INTRODUCTION

Grapes are widely considered as important and valuable fruits and foodstuffs for human consumption mainly due to their complex chemical composition (Kim et al., 2020). The compounds found in grapes have various roles in human body, including providing vitamins, energy, minerals and overall invigoration (Aubert and Chalot, 2018). Moreover, certain compounds from grape berries are believed to have therapeutic properties, contributing to their importance in traditional medicine practices (Urbi et al., 2014). A considerable rate of compounds found in grapes is stored in both grape must and wine (Nemzer et al., 2021). During grape must fermentation, these compounds are supplemented by additional substances further enhancing the nutritional and health benefits of wine; many researchers consider wine to be the healthiest natural alcoholic beverage for human consumption (Wimalasiri et al., 2022). Understanding the relationship between the chemical composition of wine and the precursor grape is critical for forecasting wine quality (Ferrero-del-Tesso et al., 2020). Winemakers can acquire significant insights into the potential qualities and traits of a wine by analysing its chemical elements. This knowledge enables the development of high-quality wines that fulfil consumer tastes and standards (Simhizu et al., 2020). The wine industry has recently evolved into a highly efficient and competitive field, with competitors required to offer wines of great quality at economically viable prices in order to gain and sustain a market presence (Masset et al., 2023). To achieve this, viticultural practices must yield grapes with specifically chemical compositions that are matched to the demands of winemaking methodologies and facility, infrastructure and, most significantly, the desired wine type and

market niche (Rainer, 2021). Furthermore, viticulture has significant challenges due to climatic changes, particularly the ongoing increase of temperature. This phenomenon has resulted in an excessive accumulation of sugars in grape must, resulting in the production of highly alcoholic wines, which is significant concern for winemakers (Dobrei et al., 2023). 'Feteasca Neagra' is not just a grape variety, but also the most well-known Romanian wine in both domestic and international markets, setting the standard for Romanian viticulture and vinification processes (Dobrei et al., 2018). Benefiting from climatic fluctuations over the last 10-15 years, it has experienced a rapid expansion, currently spreading across almost all of Romania's wine-growing regions. Conversely, 'Pinot Noir' is a renowned and highly esteemed grape variety used in winemaking, particularly associated with Burgundy, France, but also grown in various wine regions worldwide, including the United States, New Zealand, and Australia It is considered one of the oldest grape varieties, with a long history dating back to ancient times (Nistor et al., 2019).
The main aim of this research was to investigate the distinct elements of chemical composition from grapes to wine, specifically emphasizing the 'Fetească Neagră' and 'Pinot Noir' varieties. By delving into the chemical makeup of grapes and its implications for wine quality, this study also aims to offer valuable insights for tackling challenges and leveraging opportunities within the Romanian wine industry.

MATERIALS AND METHODS

The research was carried out in the 2022-2023 growing seasons with the objective of tracing certain elements of chemical composition from grapes to wine, focusing on the 'Fetească Neagră' and 'Pinot Noir' varieties. These varieties were cultivated in five distinct wine-growing regions, encompassing some of Romania's most prominent wine-producing areas: Iasi, Recas, Dealu Mare, Sarica Niculitel and Blaj (Figure 1). The selection of the two grape varieties was motivated by distinct factors. 'Fetească Neagră', renowned as Romania's most esteemed grape variety among winegrowers and vintners, was chosen for its perceived value within the local viticultural community. In contrast, 'Pinot Noir' was selected as a comparative reference due to its global prevalence and prominence in the wine industry.

Figure 1. Viticultural areas for grapes and wine origin

The chemical composition analysis of the grapes was conducted at full ripeness, encompassing parameters such as water content, proteins, total lipids, ash, dietary fibers and sugars, along with macro and microelements including phosphorus, potassium, copper, iron and sodium. Subsequently, the same constituents were assessed in the resulting wines derived from these grape varieties, with analyses performed following wine stabilization in preparation for bottling and consumption.
The determination of chemical compositions in both grape and wine samples adhered to standardized protocols validated by the Association of Analytical Chemists (AOAC). Specifically, the AOAC 925.09 method was employed for water content, AOAC 985.29 for dietary fiber, AOAC 920.39C Gravimetry (ether extraction) for feeding fibers, AOAC 945.38F for total sugars, and a portable ZEISS refractometer for refractometric sugar analysis. Furthermore, phosphorus, potassium, copper, iron and sodium levels were assessed using the AOAC 994.02 standard, ISO 12193, or AOCS Ca 18c-91 Atomic Absorption methodologies. All results were reported per 100 grams of sample.
Statistical analysis of data was done by using XLSTAT by Addinsoft (2018) Statistical and Data Analysis Solution Version 2018.7.5., which facilitate Pearson correlations calculation which is essential for assessing the relationships between variables in the dataset. Additionally,

was computed the principal component analysis (PCA) diagram by transforming high-dimensional data into a lower-dimensional space.

RESULTS AND DISCUSSIONS

Irrespective of the prevailing climatic conditions and the inherent characteristics of the cultivation regions, the chemical composition of both grape varieties exhibited relatively narrow variations. This suggests the stability inherent to these varieties concerning their chemical makeup across different cultivation environments. Specifically, the content of dietary and food fibers (Figure 2) showed minimal divergence, both between the two grape varieties and across the five cultivation regions, falling within the ranges commonly reported in specialized literature. This consistent profile observed both temporally and spatially, indicates the stability and adaptability of these grape varieties regarding fiber content. This adaptability positions them favorably for inclusion in varietal assortments in vineyards, particularly in anticipation of changing climatic conditions.

In contrast, the sugar content measured at grape harvest, while exhibiting relatively similar values, displayed less consistency across cultivation regions (Figure 3). Naturally, the regions renowned for their tradition and aptitude in cultivating grape varieties for red wines (such as Dealu Mare, Recaș and Sarica Niculitel) recorded the highest sugar concentrations. Additionally, noteworthy is the attainment of sufficiently high sugar concentrations in the grapes from Iași and Blaj, areas previously regarded primarily for white wine production, lacking grape varieties suited for red wine production in their assortments. This suggests a notable shift in the viticultural landscape, with previously white wine-focused regions now demonstrating potential for high-quality red wine production.

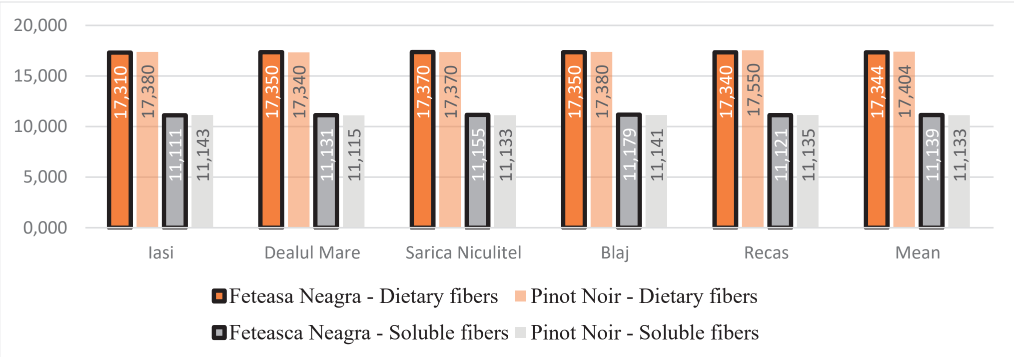


Figure 2. Berry grapes composition in dietary and soluble fibers (g) (mean for 2022-2023)

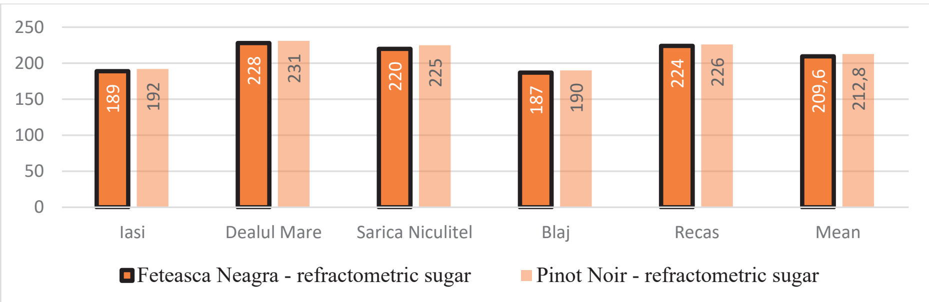


Figure 3. Total soluble solids (g/l) in grape must (mean 2022-2023)

Climatic disturbances, particularly the recent rise in temperatures, have shifted the dynamics of sugar accumulation in grapes (Suter et al., 2021). Continuation of this climatic trend poses the threat of excessive sugar accumulation, resulting in wines with elevated alcohol content

(Leolini et al., 2019). Presently, across the majority of wine-growing regions in Romania and other countries with abundant solar radiation (such as Italy, France, Spain and Portugal), there is a noticeable uptrend in the alcohol content of wines (Vaquero et al., 2022). Rarely do wines exhibit alcohol levels below 12-13%. In light of these concerns, the two grape varieties under consideration emerge as promising options due to their early maturation stage, allowing for the attainment of technological grape maturity. Across all five regions, grapes reached technological maturity as early as the second decade of August. This timing minimizes the accumulation of excessive heat units and sunlight exposure, thereby limiting sugar accumulation to manageable levels. Specifically, sugar concentrations ranged from a maximum of 224-228 g/l for the 'Fetească Neagră' variety and 226-231 g/l for the 'Pinot Noir' variety. These moderate accumulations afford winemakers the opportunity to craft balanced wines during the winemaking process, ensuring that the final products do not exhibit excessive alcohol levels.

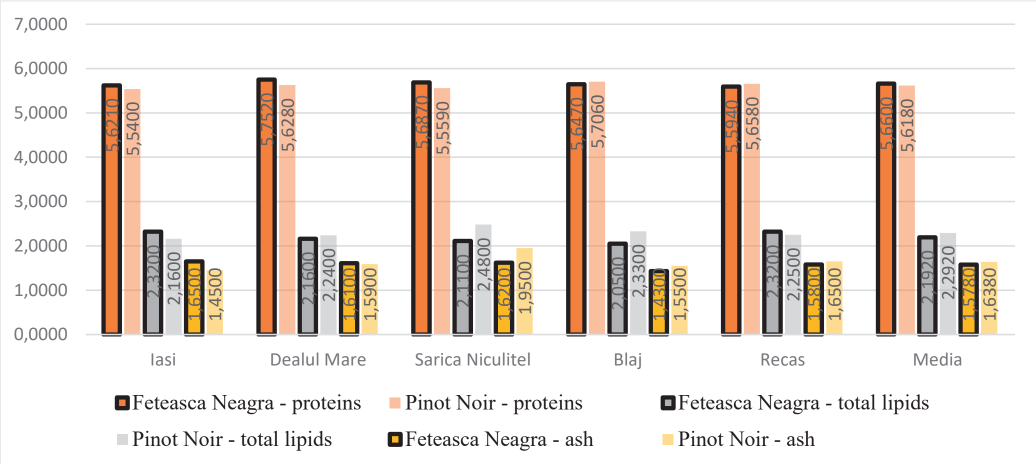


Figure 4. Berry grape composition in proteins, total lipids and ash (g) (mean 2022-2023)

Proteins, total lipids and ash constitute crucial components of grape composition, exerting significant influence on the sensory and biochemical characteristics of wines (Ovcharova et al., 2016). In this regard, both the 'Fetească Neagră' and 'Pinot Noir' varieties exhibited stability across all five regions, with recorded values (Figure 4) closely aligning with the ranges documented in specialized literature (Frîncu et al., 1019; Senila et al., 2020). Similarly, the levels of proteins, total lipids and ash in the resultant wines displayed consistent balance and proximity across all regions. However, it is noteworthy that the values observed in wine samples were naturally slightly lower compared to those in grapes, as wine is recognized for its relatively low protein and lipid content.

Qualitative compounds from grape berries encompass a wide range of chemical constituents that significantly influence the sensory characteristics of wines (Sam et al., 2021). The correlation among these qualitative compounds is complex and multifaceted. Understanding the interplay among these qualitative compounds is essential for winemakers to produce wines of consistent quality and style. By analyzing and managing these correlations, winemakers can optimize grape growing practices, fermentation techniques and aging processes to achieve desired sensory outcomes in the final wine product. The correlations between the variables that characterize 'Fetească Neagră' cultivated in several vineyards from Romania are presented in Table 1.

Table 1. Pearson's correlation between qualitative variables of 'Fetească Neagră' variety for 2022-2023 growing seasons

Variables	DF Fn	SF Fn	TSS Fn	RDS Fn	W Fn	P Fn	TL Fn	A Fn	P Fn	K Fn	Cu Fn	Fe Fn	Na Fn
DF Fn	**1**	0.677	0.418	0.508	**0.850**	0.511	-0.745	-0.272	-0.069	-0.289	0.359	0.434	0.778
SF Fn	-	**1**	**0.815**	-0.259	0.287	0.214	**-0.931**	-0.794	-0.322	-0.289	**0.828**	0.538	0.712
TSS Fn	-	-	**1**	-0.233	0.255	0.127	-0.722	**-0.958**	-0.025	-0.562	**0.991**	0.327	**0.824**
RDS Fn	-	-	-	**1**	**0.840**	0.431	0.099	0.423	0.400	-0.214	-0.339	-0.100	0.342
W Fn	-	-	-	-	**1**	0.426	-0.360	-0.079	0.349	-0.318	0.145	0.285	0.749
P Fn	-	-	-	-	-	**1**	-0.551	0.143	-0.583	-0.765	0.141	-0.537	0.419
TL Fn	-	-	-	-	-	-	**1**	0.611	0.532	0.512	-0.747	-0.249	-0.726
A Fn	-	-	-	-	-	-	-	**1**	-0.049	0.324	**-0.957**	-0.481	-0.671
P Fn	-	-	-	-	-	-	-	-	**1**	0.304	-0.141	0.401	0.117
K Fn	-	-	-	-	-	-	-	-	-	**1**	-0.564	0.520	-0.640
Cu Fn	-	-	-	-	-	-	-	-	-	-	**1**	0.275	0.759
Fe Fn	-	-	-	-	-	-	-	-	-	-	-	**1**	0.301
Na Fn	-	-	-	-	-	-	-	-	-	-	-	-	**1**

Fn – Feteasca Neagra; DF - Dietary fiber (g); SA - Soluble fiber (g); TSS – Total soluble solids (g); RDS - Refractometric Dry Substance (g/l); W - Water (g); P - Protein (g); TL - Total lipids (g); A - Ash (g); P - Phosphorus (mg); K - Potassium (mg); Cu - Copper (mg); Fe - Iron (mg); Na - Sodium (mg).

The correlation coefficients indicate the strength and direction of the relationships between the variables. For instance, variables such as dietary fibers (DF) and water (W) show a strong positive correlation (0.85), while total lipids (TL) and soluble fibers (SF) exhibit a strong negative correlation (-0.931). Positive correlations indicate that as one variable increases, the other variable tends to increase as well, whereas negative correlations suggest that as one variable increases, the other variable tends to decrease. It's essential to note that correlation does not imply causation. While the analysis identifies associations between variables, it doesn't establish a cause-and-effect relationship. The statistical analysis provides insights into the relationships between different variables related to the 'Fetească Neagră' variety, which can inform further research and decision-making in viticulture. The correlation matrix (Table 2) provides valuable insights into the relationships between different variables associated with 'Pinot Noir' grapes.

Table 2. Pearson's correlation between qualitative variables of 'Pinot Noir' variety for 2022-2023 growing seasons

Variables	DF Pn	SF Pn	TSS Pn	RDS Pn	W Pn	P Pn	TL Pn	A Pn	P Pn	K Pn	Cu Pn	Fe Pn	Na Pn
DF Pn	**1**	0.274	0.532	0.209	0.200	0.303	-0.172	0.013	-0.589	0.251	0.360	-0.503	-0.332
SF Pn	-	**1**	0.226	-0.778	-0.710	-0.058	-0.031	-0.202	-0.530	0.801	0.667	-0.421	-0.758
TSS Pn	-	-	**1**	0.234	-0.039	-0.633	-0.252	0.116	-0.365	-0.288	0.489	**-0.931**	0.277
RDS Pn	-	-	-	**1**	**0.927**	-0.071	0.275	0.595	-0.068	-0.682	-0.623	-0.133	0.626
W Pn	-	-	-	-	**1**	0.200	0.515	0.703	-0.208	-0.411	-0.798	0.050	0.352
P Pn	-	-	-	-	-	**1**	0.010	-0.220	-0.008	0.483	-0.176	0.637	-0.563
TL Pn	-	-	-	-	-	-	**1**	**0.897**	-0.582	0.234	-0.744	-0.039	-0.199
C Pn	-	-	-	-	-	-	-	**1**	-0.612	-0.094	-0.712	-0.327	0.113
P Pn	-	-	-	-	-	-	-	-	**1**	-0.535	0.016	0.630	0.526
K Pn	-	-	-	-	-	-	-	-	-	**1**	0.266	0.046	**-0.987**
Cu Pn	-	-	-	-	-	-	-	-	-	-	**1**	-0.399	-0.260
Fe Pn	-	-	-	-	-	-	-	-	-	-	-	**1**	-0.068
Na Pn	-	-	-	-	-	-	-	-	-	-	-	-	**1**

High water content is positively correlated with reducing sugars (0.927), indicating ripe grapes with higher sugar levels, similar with the results found by Geng et al. (2022). Relatively high and negative correlation (-0.778), suggesting that grapes with higher sugar content may have lower fiber content. Total soluble solids show a strong negative correlation with iron (-0.931), implying that grapes with higher sugar content may have lower iron levels. Copper shows mixed correlations with different variables, indicating its complex relationship with grape composition. These insights can inform decisions related to irrigation, fertilization and harvest timing to achieve desired grape characteristics and wine quality.

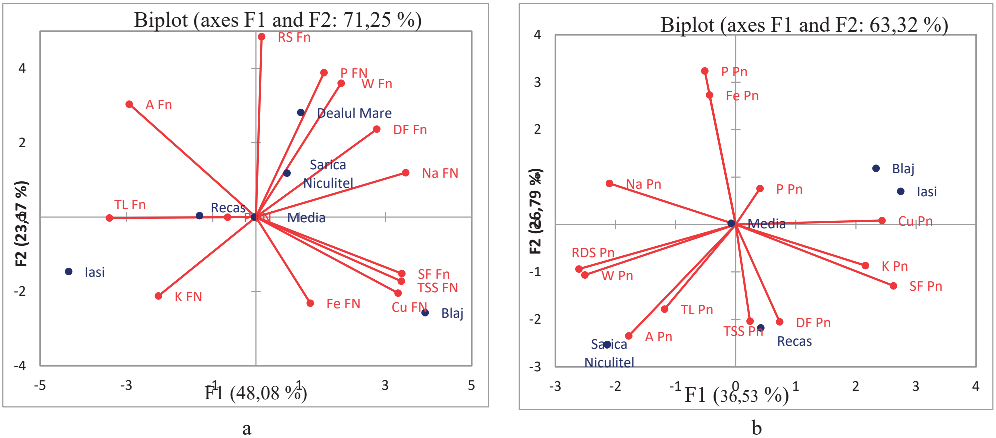


Figure 5. PCA diagram for 'Fetească Neagră' (a) and 'Pinot Noir' (b) varieties from several vineyards from Romania Fn – 'Fetească Neagră'; Pn – 'Pinot Noir'; DF - Dietary fiber (g); SA - Soluble fiber (g); TSS – Total soluble solids (g); RDS - Refractometric Dry Substance (g/l); W - Water (g); P - Protein (g); TL - Total lipids (g); A - Ash (g); P - Phosphorus (mg); K - Potassium (mg); Cu - Copper (mg); Fe - Iron (mg); Na - Sodium (mg)

The PCA diagram (Figure 5a) reveals distinct clusters of data points representing 'Fetească Neagră' grapes from different vineyards. Component 1, which accounts for 48.08% of the variance, appears to primarily differentiate the vineyards based on variables related to refractometric sugar, water content, dietary fiber, sodium and phosphorus. Component 2, contributing 23.17% of the variance, further separates the vineyards based on variables such as iron, soluble fiber, TSS and copper content. Notably, grapes from Dealu Mare vineyards exhibit the highest levels of refractometric sugar, water, dietary fiber, sodium and phosphorus, while those from Blaj vineyards display higher concentrations of iron, soluble fiber, TSS and copper. In contrast, grapes from Iasi vineyards demonstrate lower values across several variables, including refractometric sugar, water, dietary fiber, sodium, phosphorus, potassium and total lipids. Analysis of the PCA highlights significant variability in grape composition among different vineyards, reflecting variations in environmental conditions, soil characteristics and cultivation practices. Grapes from Dealu Mare vineyards exhibit characteristics associated with higher sugar content and nutrient levels, due to favorable climatic conditions and soil composition in the region. Conversely, grapes from Iasi vineyards show lower values across multiple variables, suggesting potential differences in agricultural practices or environmental factors that impacted grape quality and composition. The distinct clusters observed in the PCA diagram underscore the importance of considering geographical and environmental factors in grape cultivation and their influence on grape composition and quality. The PCA diagram for 'Pinot Noir' grapes (Figure 5b) shows distinct patterns among various vineyards, with Principal Component 1 representing 36.53% and Component 2 representing 26.79% of the variance. Grapes from the vineyards of Iasi and Blaj display higher levels of phosphorus and copper, suggesting potential differences in soil composition or fertilizer application practices in these regions. However, they exhibit lower levels of RDS, water, ash and total lipids, which may impact flavor profile and overall grape quality. In contrast, grapes from the Sarica Niculitel vineyard contain higher levels of ash and total lipids, indicating potential differences in soil fertility and vineyard management practices. Grapes from the Recas vineyards, while rich in sugar and dietary fiber, display deficiencies in essential nutrients such as phosphorus, iron and sodium, highlighting potential challenges in soil fertility or nutrient management strategies in this region.

The correlations between various chemical elements in grape berries (denoted with "bFn") and their corresponding elements in wine (denoted with "wFn") for the 'Fetească Neagră' variety are shown in table 3.

Table 3. Pearson's correlation between grapes must and wine qualitative variables of 'Fetească Neagră' variety for 2022-2023 growing seasons

Variables	P bFn	K bFn	Cu bFn	Fe bFn	Na bFn	P wFn	K wFn	Cu wFn	Fe wFn	Na wFn	TanFn	ProtFn	LipFn	AshFn
P bFn	1	0.304	-0.141	0.401	0.117	**0.757**	-0.141	0.035	-0.613	0.223	-0.085	-0.541	0.657	-0.031
K bFn	-	1	-0.564	0.520	-0.640	-0.209	0.666	**-0.787**	0.287	-0.529	0.126	**-0.921**	0.544	-0.199
Cu bFn	-	-	1	0.275	**0.759**	0.524	-0.567	**0.742**	-0.099	0.541	0.558	**0.737**	-0.566	-0.217
Fe bFn	-	-	-	1	0.301	0.450	-0.171	0.092	0.306	0.329	0.277	-0.344	-0.070	0.035
Na bFn	-	-	-	-	1	0.662	**-0.961**	**0.977**	-0.065	**0.955**	-0.077	0.649	-0.629	0.407
P wFn	-	-	-	-	-	1	-0.587	0.598	-0.609	0.627	0.177	0.085	0.144	-0.062
K wFn	-	-	-	-	-	-	1	-0.962	0.062	**-0.985**	0.342	-0.599	0.600	-0.607
Cu wFn	-	-	-	-	-	-	-	1	-0.147	**0.920**	-0.125	**0.758**	-0.636	0.400
Fe wFn	-	-	-	-	-	-	-	-	1	0.000	-0.159	-0.011	-0.603	0.418
Na wFn	-	-	-	-	-	-	-	-	-	1	-0.332	0.481	-0.568	0.626
TanFn	-	-	-	-	-	-	-	-	-	-	1	0.105	0.095	**-0.886**
ProtFn	-	-	-	-	-	-	-	-	-	-	-	1	-0.757	0.100
LipFn	-	-	-	-	-	-	-	-	-	-	-	-	1	-0.468
AshFn	-	-	-	-	-	-	-	-	-	-	-	-	-	1

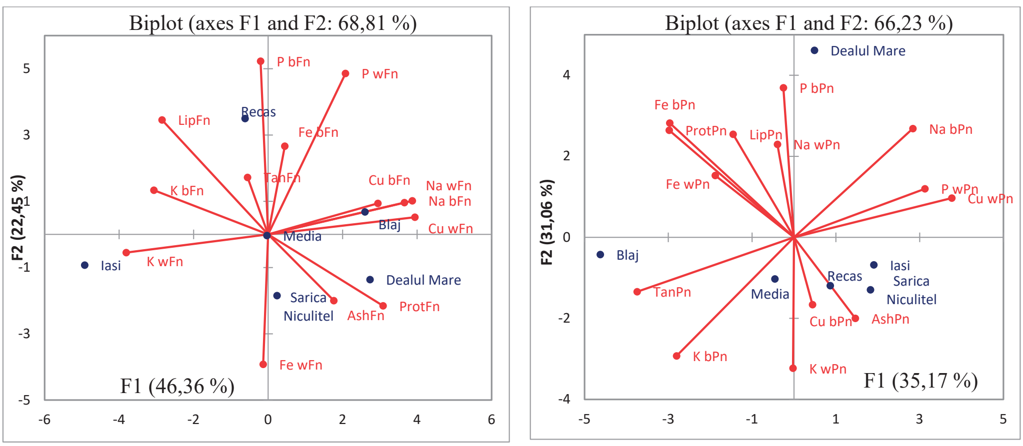
A significant positive correlation of 0.757 was found between phosphorus content in grape berries (P bFn) and wine (P wFn), indicating a potential relationship between nutrient levels in the grapes and the surrounding environment. Such a correlation indicates that the availability of phosphorus in the soil or vineyard environment may play a crucial role in determining the phosphorus content of grape berries. Grapes grown in environments with higher phosphorus levels may exhibit increased phosphorus content, which is then reflected in the phosphorus levels of the wine produced from those grapes (Piccin et al., 2017).

Conversely, a negative correlation of -0.141 was observed between potassium content in grape berries (K bFn) and wine (K wFn), indicating a weak negative relationship between the two. High potassium levels in the soil may decrease potassium absorption by grapevines, resulting in reduced potassium content in both grape berries and the resulting wine (Hu et al., 2023). Environmental conditions, such as temperature, rainfall patterns, and sunlight exposure, also play a crucial role in potassium uptake and accumulation in grapevines. Extreme weather events or drought conditions may hinder potassium absorption, resulting in fluctuations in potassium levels in grapes and wine (Villette et al., 2020). Additionally, fermentation methods, yeast selection, and clarification techniques impact the extraction, retention, or removal of potassium during winemaking processes (Payan et al., 2023). A weak positive correlation of 0.035 was noted between copper content in grape berries (Cu bFn) and wine (Cu wFn), suggesting a consistent copper presence across different parts of the grape. The vineyard management practices and agricultural inputs, such as copper-based fungicides or fertilizers, can impact copper levels in grape berries. Regular application of copper-based products to control fungal diseases like mildew or botrytis may lead to the accumulation of copper in grape tissues, subsequently influencing its presence in the wine. Factors such as maceration, pressing and fermentation methods may influence the release, extraction, or retention of copper during winemaking, thereby influencing its concentration in the wine (Donici et al., 2019). A moderate negative correlation of -0.613 was found between iron content in grape berries (Fe bFn) and wine (Fe wFn), indicating a moderate negative relationship between the iron levels in the two. Soil characteristics, such as pH levels and soil composition, can affect the availability of iron to the grapevine roots. Additionally, microbial activity in the soil can influence the solubility and availability of iron, thereby affecting its uptake by grapevines (Zebek et al, 2021). During winemaking, processes such as pressing, fermentation and clarification can impact the transfer of iron from grape berries to wine. A moderate positive correlation of 0.223 was also observed between sodium content in grape berries (Na bFn) and wine (Na wFn), suggesting a moderate positive association between sodium levels in grape berries and wine. Various correlations ranging from -0.886 to 0.758 were noted for tannins, proteins, lipids, and ash; tannin content is positively correlated with iron in wine, indicating a potential influence on the sensory characteristics of the wine; proteins exhibit strong negative correlations with potassium in berries and wine, indicating a potential antagonistic relationship affecting protein metabolism in the grapes. Lipids in berries show positive correlations with lipids in wine and negative correlations with other minerals, suggesting a complex relationship influenced by multiple factors (variety, growing conditions, climate, soil, viticultural practices, winemaking techniques, etc). All findings provide insights into the associations between the chemical compositions of grape berries and wine, indicating potential impacts on wine quality.

The strong negative correlation between potassium levels in berries and wine suggests that higher potassium content in berries leads to lower levels in wine, which could impact the taste and quality of the wine. Moderate positive correlations for phosphorus, sodium and iron between berries and wine suggest that these elements are consistently transferred from berries to wine during winemaking processes. The weak correlations for tannins and lipids indicate that there may be factors other than berry composition influencing their presence in wine

Table 4. Pearson's correlation between grapes must and wine qualitative variables of 'Pinot Noir' variety for 2022-2023 growing seasons

Variables	P bPn	K bPn	Cu bPn	Fe bPn	Na bPn	P wPn	K wPn	Cu wPn	Fe wPn	Na wPn	TanPn	ProtPn	LipPn	AshPn
P bPn	1	-0.535	0.016	0.630	0.526	-0.080	-0.563	0.264	0.174	0.508	-0.267	0.609	0.273	-0.783
K bPn	-	1	0.266	0.046	-0.987	-0.747	0.384	-0.782	-0.088	-0.116	0.891	0.080	-0.210	0.024
Cu bPn	-	-	1	-0.399	-0.260	-0.331	0.270	0.207	-0.631	0.154	0.012	-0.423	-0.473	-0.500
Fe bPn	-	-	-	1	-0.068	-0.423	-0.445	-0.537	0.629	0.342	0.457	0.990	0.603	-0.543
Na bPn	-	-	-	-	1	0.681	-0.276	0.793	0.107	0.000	-0.909	-0.086	0.109	-0.006
P wPn	-	-	-	-	-	1	-0.284	0.646	-0.072	0.041	-0.744	-0.475	0.245	0.480
K wPn	-	-	-	-	-	-	1	-0.188	0.145	-0.893	0.138	-0.425	-0.373	0.279
Cu wPn	-	-	-	-	-	-	-	1	-0.502	0.115	-0.960	-0.537	-0.366	0.053
Fe wPn	-	-	-	-	-	-	-	-	1	-0.395	0.254	0.596	0.703	-0.014
Na wPn	-	-	-	-	-	-	-	-	-	1	0.040	0.311	0.217	-0.502
TanPn	-	-	-	-	-	-	-	-	-	-	1	0.464	0.205	-0.153
ProtPn	-	-	-	-	-	-	-	-	-	-	-	1	0.502	-0.501
LipPn	-	-	-	-	-	-	-	-	-	-	-	-	1	-0.175
AshPn	-	-	-	-	-	-	-	-	-	-	-	-	-	1



a b

Figure 6. PCA diagram for 'Fetească Neagră (a) and 'Pinot Noir' (b) varieties from several vineyards from Romania Fn – 'Fetească Neagră'; Pn – 'Pinot Noir'; A - Ash (g); P - Phosphorus (mg); K - Potassium (mg); Cu - Copper (mg); Fe - Iron (mg); Na - Sodium (mg); Prot – Proteins; Lip – Lipids, Tan- Tannins

The PCA diagram (Figure 6a) indicates that the first principal component (F1) contributes 46.36% to the overall variability, while the second principal component (F2) contributes

22.45%. These components collectively explain a substantial portion of the variability observed in the dataset. For the 'Fetească Neagră' variety, notable patterns emerge in the accumulation of certain compounds across different vineyards. In the Blaj vineyard, there is a pronounced accumulation of copper and sodium, both in the grape berries and the resulting wine. This suggests that environmental or soil conditions in the Blaj vineyard may favor the uptake and retention of these elements by grapevines, leading to higher concentrations in both grapes and wine. Conversely, the Recas vineyard exhibits greater accumulations of phosphorus in grape berries and wine, along with a lesser extent of lipids. This contrasts with the patterns observed in the Blaj vineyard, indicating distinct soil compositions or management practices that influence nutrient uptake by grapevines. Additionally, the protein and ash content in the wine show higher accumulations in the Sarica Niculitel and Dealu Mare vineyards. This suggests that factors specific to these vineyards, such as soil composition, microclimate, or viticultural practices, may contribute to the enrichment of proteins and ash in the resulting wine. Interestingly, across all vineyards, the accumulation of iron in the wine is observed to be minimal. This consistent pattern suggests that iron levels in the soil or grapevines may be inherently lower or that winemaking processes may result in the removal or reduction of iron compounds in the final wine product. In the PCA graph, it is observed that the first principal component (F1) accounts for 35.17% of the variability, while the second principal component (F2) contributes 31.06%. Analysis of the 'Pinot Noir' variety reveals distinct patterns in nutrient accumulation across various vineyards. In the vineyard located at the Dealu Mare, notably high concentrations of phosphorus are recorded in grape berries, alongside elevated levels of sodium in both the berries and the resulting wine. Additionally, copper and phosphorus concentrations in the wine from this vineyard are observed to be notably high. These findings suggest that environmental factors or soil characteristics in the Dealu Mare vineyard may contribute to the enrichment of these elements in grape berries and wine. In the vineyards of Recas, Iasi, and Sarica Niculitel, the wine exhibits large accumulations of ash, copper and potassium in grape berries. This indicates that these vineyards may possess soil compositions or viticultural practices that favor the uptake and retention of these elements by grapevines, subsequently influencing their concentrations in the resulting wine. In the Blaj vineyard, the concentration of tannins in the wine and potassium in the berries is notably low. This suggests that environmental or management factors specific to the Blaj vineyard may result in lower levels of these compounds in grape berries and wine.

CONCLUSIONS

Both studied varieties exhibited grapes with highly comparable chemical compositions regardless of the vineyard of origin, indicating that the varieties are stable and adaptable to pedoclimatic conditions in all cultivated areas. Both the 'Fetească Neagră' and 'Pinot Noir' varieties reach maturation much earlier than other varieties from vineyards and accumulate amounts of sugars that allow them to produce balanced wines without the risk of accumulating excessive amounts of sugars, which would result in wines that are overly alcoholic. The chemical composition of the wines produced from the two types was also balanced and uniform, regardless of the vineyard of origin. The analysis of correlations among different components in grape must and wine for both varieties reveals valuable insights for vineyard management and winemaking practices. The distinct patterns observed in the PCA diagrams emphasize the importance of considering geographical and environmental factors in grape cultivation and their impact on grape composition and quality. Further research could explore the specific factors driving these differences and their implications for viticulture practices and grape quality optimization in each region. Additionally, targeted interventions such as soil amendments or nutrient management strategies may be warranted to address nutrient deficiencies and optimize grape quality in specific vineyards.

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