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# EXPLORING THE MICRO AND MACRO TERROIR OF FETEASCĂ NEAGRĂ WINE FROM MOLDOVA

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**Abstract.** This study delves into the intricate realm of Moldovan winemaking, focusing on the iconic Fetească Neagră grape variety. The research highlights the importance of indigenous grape varieties in shaping a unique wine identity for the region. Drawing on the concept of terroir, the study investigates the microbial terroir specific to three designated geographical regions in Moldova during the 2022 vintage. The research employs a multifaceted approach, combining climate data analysis, mini vinification experiments, microbial DNA extraction, and sensory evaluation techniques. Results reveal significant variations in climatic conditions and microbial diversity across the three regions, influencing the sensory characteristics of the resulting wines. On vintage 2022 the Codru is temperature, and the Stefan-Voda and Vadul lui Traian are warm climates. All the 3 regions are moderately dry. The Stefan Voda is 14.0% , and manifests the highest ethanol content among the regions, alongside the lowest pH level. The sensory evaluations show Stefan Voda evincing heightened creaminess, Codru showcasing prominent herbal nuances, and Vadul lui Traian displaying elevated scores in berry, cherry, violet, and black pepper descriptors. Through meticulous analysis, the study underscores the dynamic interplay between environmental factors, microbial communities, and wine attributes, shedding light on the complex tapestry of Moldovan winemaking. Ultimately, this research contributes to a deeper understanding of terroir-driven wine production and emphasizes the importance of preserving indigenous grape varieties to uphold the distinctiveness of Moldovan wines on the global stage.

**Keywords:** *Fetească Neagră, terroir, Geographical Indications, indigenous varieties, microbial analysis, climate data, sensory evaluation.*

**Rezumat.** Acest studiu aprofundează tărâmul complex al vinificației moldovenești, concentrându-se pe soiul emblematic de struguri Fetească Neagră. Cercetarea subliniază importanța soiurilor de struguri indigene în formarea unei identități unice de vin pentru regiune. Pornind de la conceptul de terroir, studiul investighează specificul microbian a trei regiuni cu indicații geografice din Republica Moldova în perioada recoltei 2022. Cercetarea folosește o abordare cu mai multe fațete, combinând analiza datelor climatice, experimente de mini vinificare, extracția ADN-ului microbian și tehnici de evaluare senzorială. Rezultatele relevă variații semnificative în condițiile climatice și diversitatea microbiană în cele trei regiuni, influențând caracteristicile senzoriale ale vinurilor rezultate. In vintage 2022, zona Codru a avut un climat temperat, iar zonele Stefan-Vodă si Valul lui Traian - un climat cald. Toate cele 3 regiuni au avut climă moderat uscată. Vinurile din zona Stefan Voda au prezentat cel mai mare conținut de etanol -14,0%,vol., cu cel mai scăzut nivel de pH. Evaluările senzoriale arată că vinurile din zona Ștefan Vodă se evidențiază printr-o suavitate sporită, cele din zona Codru prezentând nuanțe proeminente de plante, iar vinurile din zona Valul lui Traian prezintă scoruri ridicate la descriptori de fructe de pădure, cireșe, violete și piper negru. Printr-o analiză meticuloasă a fost evidențiată interacțiunea dinamică dintre factorii de mediu, comunitățile microbiene și atributele vinului, aruncând lumină asupra tapiseriei complexe a vinificației moldovenești. În cele din urmă, această cercetare contribuie la o înțelegere mai profundă a producției de vin bazată pe teren și subliniază importanța promovării soiurilor de struguri indigene pentru a susține caracterul distinctiv al vinurilor moldovenești pe scena globală.

**Cuvinte cheie:** *Fetească Neagră, terroir, indicatii geografice, soiuri autohtone, analiză microbială, date climatice, evaluare senzorială*

## 1. Introduction

Fetească Neagră, alternatively referred to by synonyms such as Poama fetei neagra de Moldova, Poama fetei neagră, Păsărească neagră, and Coada rândunicii etc., stands as an ancient Romanian cultivar with historical origins linked to the Dacian heritage. It is posited as a discernible selection from Vitis silvestris, originating in the Iași region along the Prut River [1]. This grape variety holds a significant historical prominence within the aged vineyards of Moldova, specifically recognized for its role in enhancing the distinguished Uricani wine, alongside indigenous black grape varieties [2]. Currently, Fetească Neagră is cultivated throughout the wine-producing regions of both Romania and the Republic of Moldova, producing wines with both protected geographical indication (PGI) and conventional classifications. Until 2023, the planting area registered in the Moldova National Vine and Wine Registration System (RVV) was 423.0 hectares. According to data from the Romanian National Office for Vine and Wine Products (ONVPV), in Romania in 2023, the planting area of Fetească Neagră was 3,300 hectares.

The term "terroir," derived from France, is extensively utilized in the wine industry. Traditionally, terroir is conceptualized to encompass natural elements, including climate, soil, and topography, alongside human factors such as variety selection, cultivation methods, and winemaking technology [3,4].

In recent years, the concept of "microbial terroir" has surfaced in oenology, driven by advancements in high throughput sequencing (HTS) techniques. HTS enables the identification of microbial ecology in vitivinicultural regions [5]. Research has demonstrated that both grape variety and geographical origin exert substantial influence on the microbial diversity of grapes, thereby contributing to the distinct styles found in wines [6].

Moldova possesses a rich heritage in grape cultivation and winemaking, placing a primary emphasis on the exportation of its wines [7-9]. In recent times, Moldovan wines have achieved noteworthy success on the international stage [10]. Functioning as a cultural ambassador, Moldovan wine is gaining acclaim among a growing audience, comprising both consumers and experts in the field of winemaking. Despite its promising potential in viticulture and wine production, Moldova continues to be relatively underrepresented in the global market.

The success of the global wine market hinges on its originality and typicality, both of which are attributed to the concept of terroir. In the Republic of Moldova, our predominant cultivation involves grape varieties of European origin, with fewer instances of indigenous varieties, thus compromising the inherent typicality of the wine [11]. The cultivation of autochthonous varieties plays a pivotal role in enhancing product diversification and shaping a novel, specific wine identity that is characteristic and unique to our country.

Against the backdrop of a burgeoning and diverse Moldovan wine export market, the utilization of indigenous grape varieties, distinguished by their unique terroir, offers an opportunity for Moldovan wines to carve out and maintain a presence in the highly competitive European and global wine markets. Wines crafted from Moldova's native grape varieties not only showcase the distinctive terroir of the region but also enhance the competitiveness of Moldovan wine and the overall image of the nation.

In recent years, wines produced from native Moldovan-Romanian autochthonous grape varieties have gained increasing acclaim in both domestic and foreign wine markets. Fetească Neagră, celebrated as the most representative local variety for high-quality red wine, has become a focal point in global discussions about Moldovan wine. However, there is a paucity of research articles on the terroir specific to Moldovan Fetească Neagră.

This research aims to investigate Fetească Neagră wine produced in three PGI regions of Moldova in the 2022 vintage. Utilizing a combination of microbial analysis and sensory evaluation, the goal is to identify the microbial terroir unique to each production area in Moldova. The objective is to spotlight and establish the distinctive characteristics that contribute to the uniqueness of Moldovan Fetească Neagră wine.

## 2. Materials and Methods

**Grape Sample.** Fetească Neagră grapes were sourced from three vineyards representing Moldova's 3 PGI regions: Codru (C), Stefan Voda (S), Vadul lui Traian (T). In each region, 20 kg of healthy and mature grapes were chosen, resulting in a total harvest of 60 kg.

*Table 1*

**Classes of viticultural climate for the dryness index, heliothermal index and cool night index of the grape-growing regions** [12]

| Index | Class of viticultural climate | Acronym | Class interval |
|---|---|---|---|
| Heliothermal index, HI | Very warm | HI +3 | >3000 |
| | warm | HI +2 | >2400 ⩽ 3000 |
| | Temperate warm | HI +1 | >2100 ⩽2400 |
| | Temperate | HI -1 | >1800 ⩽2100 |
| | Cool | HI -2 | >1500 ⩽1800 |
| | Very cool | HI -3 | ⩽1500 |
| Night cold index, CI (°C) | Very Cool nights | CI+2 | ⩽12 |
| | Cool nights | CI+1 | >12 ⩽ 14 |
| | Temperate nights | CI-1 | >14 ⩽ 18 |
| | Warm nights | CI-2 | >18 |

*Continuation Table 1*

| | | | |
|---|---|---|---|
| Dryness index, DI (mm) | Very dry | DI+2 | ⩽−100 |
| | Moderately dry | DI+1 | ⩽50 > −100 |
| | Sub-humid | DI-1 | ⩽150 > 50 |
| | Humid | DI-2 | >150 |

**Climate data analysis.** This study encompasses the computation of average monthly temperature and rainfall for the vintage of 2022. Additionally, the study includes the calculation of average monthly temperature and rainfall for multiple years. In conjunction with these conventional measures, three synthetic and complementary viticultural climatic indices are employed: heliothermal index (HI), cool night index (CI), dryness index (DI) were selected, calculation method reference Jorge et al.'s articles [12].

*Table 2*

**The comparison of 2022 vintage with other famous production areas around the world**

| HI (Degrees x Days)/ DI (mm) | Very dry = ⩽−100 | Moderately dry = ⩽50 > −100 | Sub-humid = ⩽150 > 50 |
|---|---|---|---|
| **Cold (>1500 ⩽1800)** | Champagne, Alpine vineyards | Oregon USA, southern New Zealand | Washington, Columbia britanica |
| **Temperature (>1800⩽2400)** | Bordeaux, Charentes | **CODRU-2022** Languedoc, Valee du Rhone | Rioja, Chile (central part), Napa |
| **Warm (>2400⩽3000)** | Uruguay, India, Tailanda | **SV-2022, VT-2022** Corsica, Madeira, Canary Islands, Southern Brazil | Mendoza, California, Australia |

**Mini-vinification.** For each wine, 5 kg of Feteasca Neagra grapes were crushed by hand, 0.2 g/L *Saccharomyces. cerevisiae* inoculated, and 100 mg/L potassium metabisulphite (PMS) added. Alcoholic fermentation takes place under 26 ℃, and the must density be monitored daily. PMS adds. Malolactic fermentation is conducted by lactic bacteria when the sugar is <3g/L.

**DNA extraction.** Fermentation samples (100 mL volume each) were centrifuged, and deoxyribonucleic acid (DNA) was isolated from the sediment. Isolation was performed according to the Biamp PowerFecal DNA extraction kit (QIAGEN) procedure.

**Physical Chemical and Sensory Analysis.** Fourier transform infrared spectroscopy (FT-IR) was utilized for physical-chemical analysis. The samples were served together at a temperature of 20 degrees in individual booths and in the International Organization for Standardization /the Institut National de l'Origine et de la Qualité (ISO-INAO) glasses into which about 75 mL of wine was poured. Each of the analyzed samples was coded with a three-digit code. The samples were evaluated by six panelists from the professional sommelier. The panelists have 3 women and 3 men, aged between 25 to 60 years, average age of 34 years. The Model of tasting sheet for sensory analysis of Fetească Neagră wine from the previous experiment [13].

*Table 3*

**The tasting sheet for sensory analysis of FN wine** [13]

| Olfactory description | Abbreviation | Gustatory description | Abbreviation | Persistence | Abbreviation |
|---|---|---|---|---|---|
| Forest fruit | O.F_fruit | Structure | G.Structure | Olfactory | Per.Gus |
| Cherry | O.Cherry | Body | G.Body | Gustatory | Per.Olf |
| Prune | O.Prune | Tannin | G.Tannin | | |
| Violet | O.Violet | Bitter | G.Bitter | | |
| Sweet spice | O.S_spice | Alcohol | G.Alcohol | | |
| Black pepper | O.B_pepper | Oak | G.Oak | | |
| Plant | O.Plant | | | | |
| Dairy | O.Dairy | | | | |
| Smoke | O.Smoke | | | | |
| Oak | O.Oak | | | | |

**Date analyze.** Microsoft Excel was used to collate the data, and **Origin Pro 2021** was used to generate graphical representations of the data.

## 3. Results

### 3.1 The Climate analysis

The HI serves as an informative metric regarding the heliothermal potential, calculated over a biologically acceptable average period. This index offers valuable insights into the sugar potential of grape varieties, surpassing traditional temperature sums, and thereby providing qualitative information.

The CI is defined as the mean minimum night temperature during the later stages of the ripening period. This index provides a measure of the ripening potential of a wine-growing region. Specifically, it indicates the suitability of the region concerning the development of secondary metabolites, such as polyphenols and aromas, in grapes and wines. By focusing on the minimum night temperatures during the critical phase of ripening, CI offers valuable information about the climatic conditions that can influence the synthesis of important compounds in grapes. Lower night temperatures during this period are often associated with the preservation of acidity, color compounds, and aromatic compounds in grapes, contributing to the overall quality of the resulting wines. Therefore, CI becomes a significant factor in assessing the potential of a wine-growing region in terms of producing grapes with desirable characteristics for wine-making [14]. While daytime warmth is essential for berry ripening, cooler nighttime temperatures produce secondary metabolites associated with high-quality flavor and aroma. High nighttime temperatures can elevate respiration and contribute to the degradation of malic acid in grapes [15]. Therefore, cooler nights play a critical role in preserving the acidity of berries. Malic acid, which often transforms into lactic acid through malolactic fermentation by winemakers, typically constitutes around half of the total acidity in both grapes and wines. In contrast, tartaric acid, the other primary acid, exhibits greater stability during the ripening process. Wines deficient in malic acid, either due to conversion to lactic acid or degradation, may exhibit a bland taste and heightened susceptibility to microbial spoilage.

Conversely, excessive malic acid degradation can result in wines lacking complexity, emphasizing the significance of maintaining a delicate balance in acidity to enhance overall quality and aging potential [16].

When the HI is coupled with the Cool Night Index (CI, discussed later), it enables effective discrimination of regional climates. This dual consideration accounts for both the overall heliothermal conditions during the vegetative cycle of the grape and the cool night conditions crucial during the ripening period. The combination of HI and CI contributes to a comprehensive understanding of the grapevine's environmental conditions, particularly about sugar development and the maturation process.

The DI is assessed through a modified adaptation of Riou's potential water balance of the soil index, specifically tailored for vineyard applications. This index serves as a tool for characterizing the water-related aspects of the climate within a grape-growing region. It provides insights into the potential availability of water in the soil, offering valuable information about the dryness level prevalent in a given region. This climatic factor holds significant importance concerning the ripening of grapes and the overall quality of the resulting wine. The Dryness Index thus plays a crucial role in understanding and managing the water dynamics within a vineyard, influencing key factors in grape development and, consequently, the ultimate characteristics of the wine produced [12].

*Table 4*

**The HI, CI and DI of 3 site in vintage 2022**

| Region | HI | CI | DI |
|---|---|---|---|
| Codru | 2017 | 6.31 | -25.21 |
| Stefan-Voda | 2408 | 6.59 | 16.10 |
| Vadul lui Traian | 2433 | 1.94 | -50.22 |

**Note:** HI - heliothermal index; CI - cool night index; DI - dryness index.

Table 4 shows the HI, CI, and DI indicators for the three production regions in Moldova in 2022, combined with previous research by Yao Meiling et al. [17] on the relevant indicators for the three regions from 2018 to 2020. In Jorge et al.'s Géoviticulture Multicriteria Climatic Classification System, the three production regions in Moldova are classified as follows: according to the HI classification, the Codru region is in the HI+1 (temperate warm) zone, while S and T are in the HI+2 (warm) zones. The CI zones of the three regions all belong to CI+2 (very cool nights). The DI indicator shows significant variation between years, with the C and T regions mainly in the DI--1 (sub-humid) zone, and S mainly in the DI+2 (very dry) zone. World-famous production regions in the HI+1 and HI+2 zones include Rioja (Spain), Lujan de Cuyo (Argentina), and Mildura (Australia), while those in the DI--1 and DI+2 zones include Bordeaux (France), Sacramento (USA), and Modena (Italy). Compared to other world-famous production regions, Moldova's three regions have the potential to produce high-quality red wines.

#### *3.1.1 Temperature*

The annual average temperature and monthly averages at the three sites (Purcari, Mircesti, and Bugeac) in 2022 surpass the multi-year average temperature. At the Purcari site, the 2022/multi-year average temperature is 12.1/9.58 °C. For the Mircesti site, it is 10.8/9.0 °C. At the Bugeac site, the values are 11.8/9.9 °C. Notably, the average temperature in February exceeds that in March, potentially impacting early grapevine budding. During the critical months of June, July, and August, when grapes undergo growth and ripening, there is a significant increase in the average monthly temperature compared to other months.

The temperature during these berry growth and ripening months significantly influences grape flavor.

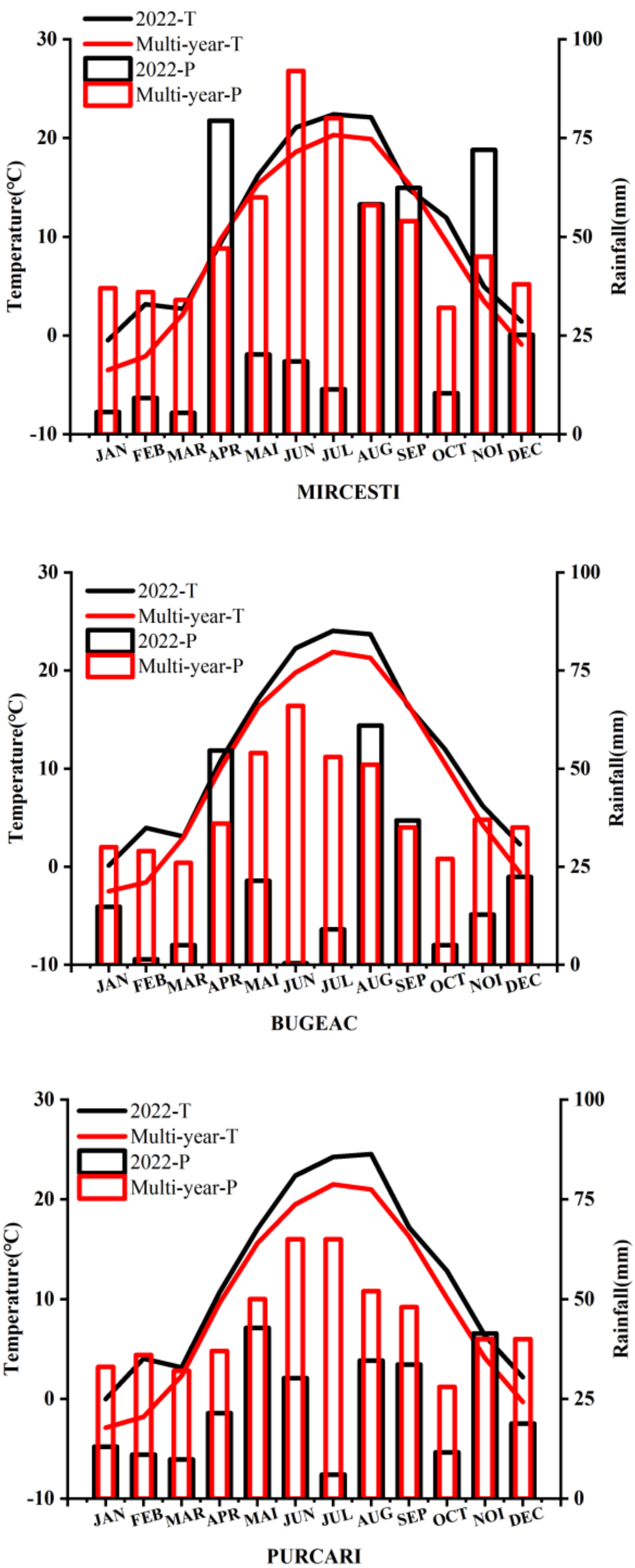


**Figure 1.** The climate data of 3 site in vintage 2022 compare with the multi-year.

The temperature during the months of grape growth and ripening is crucial for flavor development. Reference to Alex et al.'s study on Chablis wine indicates that a gradual warming trend between 1963 and 2018, especially during the growing season, led to an increase in favorable years for Chablis wine [14]. According to Alex et al.'s study, the average temperature during the growing season (April to September) is a pivotal factor in the scoring model for Chablis wine [18].

The study conducted by Wu et al. [19] on Cabernet Sauvignon and Sauvignon Blanc in Bordeaux vineyards revealed interesting findings regarding the impact of temperature on grape metabolites. With a moderate increase in temperature, the study observed that the content of primary metabolites in grape berries did not exhibit significant changes.

However, the study underscores the necessity of paying attention to the influence of high temperatures, particularly on the polyphenols of grape berries. High temperatures may have potentially negative effects on the aroma quality of the grapes.

These results suggest that while moderate temperature increases might not markedly alter primary metabolites, the impact on secondary metabolites like polyphenols can be more pronounced. Polyphenols play a crucial role in wine characteristics, and their alteration due to high temperatures could influence the overall aroma quality of wines made from these grape varieties. This underscores the importance of understanding the nuanced effects of temperature changes on different grape components for informed viticultural and wine-making practices.

This temperature analysis suggests that the 2022 conditions, with elevated temperatures during critical growth and ripening months, may have a substantial impact on grape flavor, akin to findings in studies on other wine regions.

#### *3.1.2 Rainfall Analysis*

The monthly average rainfall at the three stations in 2022 differs significantly from the multi-year monthly average.

The total rainfall in 2022 is notably lower than the multi-year average rainfall. Mircesti Site Rainfall in 2022 was 377.8 mm. The multi-year average was 613 mm. Bugeac Site Rainfall in 2022 was 244.6 mm. The multi-year average was 479 mm. Purcari Site Rainfall in 2022 was 274.2 mm. The multi-year average was 526 mm.

In April, a critical month for grape budding, both Mircesti and Bugeac experienced higher rainfall than the multi-year average. In August, the Bugeac site witnessed higher rainfall compared to the multi-year monthly average. Similarly, the Mircesti site experienced higher rainfall in September compared to the multi-year monthly average.

These variations in rainfall, especially during critical months like April for budding and August to September for grape ripening, can significantly influence the grapevine growth and maturation process. The differences between the rainfall in 2022 and the multi-year averages highlight the need for careful consideration of these factors in viticulture and winemaking practices.

### 3.2 The fungi diversity of 3 regions

The microbial diversity within grapevines is subject to a range of influences, encompassing both anthropogenic and natural factors. Climatic elements, such as temperature, ultraviolet light, and rainfall, can substantially affect the abundance and diversity of microorganisms. However, unraveling the specific impacts of these factors on the microbial community is intricate due to the intricate nature of their interactions. Previous research has presented conflicting outcomes, with some studies proposing that increased rainfall correlates with heightened microorganism populations, while others suggest the contrary.

The advent of high-throughput sequencing techniques has markedly improved our comprehension of the grapevine microbiota. Nevertheless, the influence of climate on microorganisms remains intricate and not fully elucidated. Numerous studies underscore that the microbial community is shaped by a myriad of factors, including grape variety, vintage, and geographical location. In contrast to human-related factors, the impact of natural factors on the microbial community has garnered comparatively less attention. Researchers typically conduct statistical analyses on microbial communities categorized by distinct natural factors deemed statistically significant, highlighting the complexity and multifaceted nature of these interactions [20].

The origins of microorganisms in wine are intricate, stemming from various sources such as those inherent in grape berries, introduced through the winery environment and equipment, and intentionally added through the inoculation of commercial *Saccharomyces cerevisiae* during the fermentation stage. The structure of the yeast community changes at different growth stages of grape berries. The yeast species identified in grape berries at harvest are predominantly the same taxa initially present at the onset of alcoholic fermentation. Subsequently, these yeasts are succeeded by other non-*Saccharomyces* yeasts, which persist and contribute to the fermentation process until its completion.

Throughout the alcoholic fermentation, *Saccharomyces cerevisiae* remains consistently present in the grape juice, owing to its higher ethanol tolerance compared to other yeasts found in the winemaking environment.

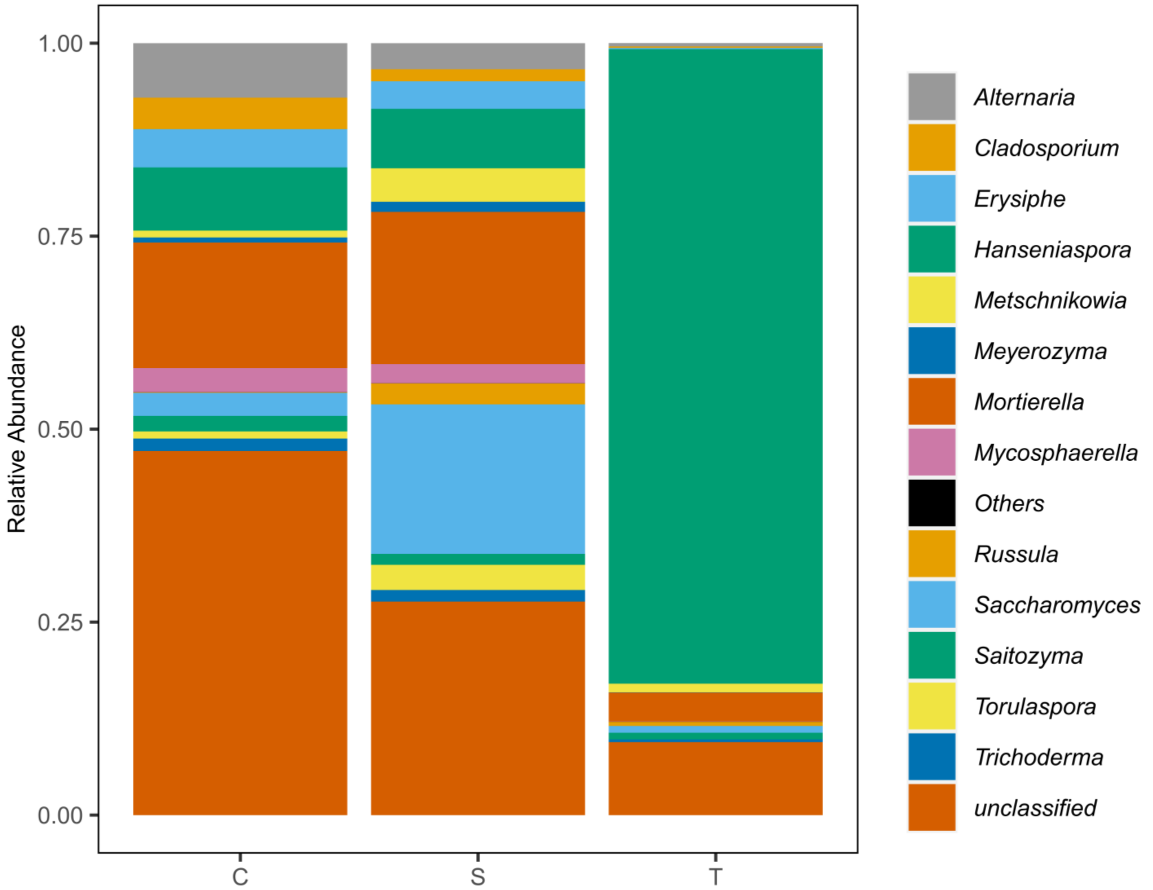


**Figure 2.** The fungi diversity of 3 PGI regions: C-Codru, S-Stefan Voda, T-Vadul lui Traian.

This resilience positions *Saccharomyces cerevisiae* as an indispensable component in the production of high-quality wines. Additionally, there is a growing exploration of the active involvement of these non-*Saccharomyces* yeasts in mixed starter cultures, aimed at enhancing the complexity of wine aromas. *Metschnikowia spp.* is a kind of non-*Saccharomyces* yeast conducting the fermentation before the alcoholic fermentation takes place, it is recognized for a weaker alcohol-producing ability than *Saccharomyces. cerevisiae* which can vary between 20%-30%. The advantage of this is that the varietal aroma is not masked by the high alcohol concentration [21]. *Saitozyma podzolica* is an oleaginous yeast that was found in the sample from Codru and Stefan Voda. This yeast isolate produces large amounts of single-cell oil (SCO) and gluconic acid (GA), although so far there is no report on the effect of *Saitozyma podzolica* on the wine taste, it has the potential to enhance the "fatty" taste of the wine [22]. This recognition of the diverse contributions of different yeast species underscores the evolving understanding of microbial dynamics in winemaking and the potential for optimizing wine quality through strategic yeast management [23]. The origin of grape berry-associated microbes is so far not fully understood [24]. The microbial community present on the surface of the fruit is believed to derive from the surrounding vineyard environment. Each locality, marked by its unique geographical and environmental conditions, contributes to the establishment of a distinct microbial signature. This microbial signature is fundamental in shaping the regional characteristics of wines produced in that specific area. The intricate interplay between the local environment, including soil, air, and vegetation, gives rise to a unique microbial ecosystem on the fruit surface. Understanding and appreciating this microbial diversity not only enhances our comprehension of the intricate ecology of vineyards but also underscores its profound impact on the distinctive qualities and flavors encapsulated in wines from different regions [25].

### 3.3 The results of physical-chemical and organoleptic analysis of the 3 wines

Caroline Knoll et.al studied the influences of pH and ethanol esters and acids that are important for the sensory profile and quality of wine [26]. Figure 3. shows, that the alcohol content across the three stations varies between 12.8% and 14.0%, with wine Stefan Voda displaying the highest alcohol content.

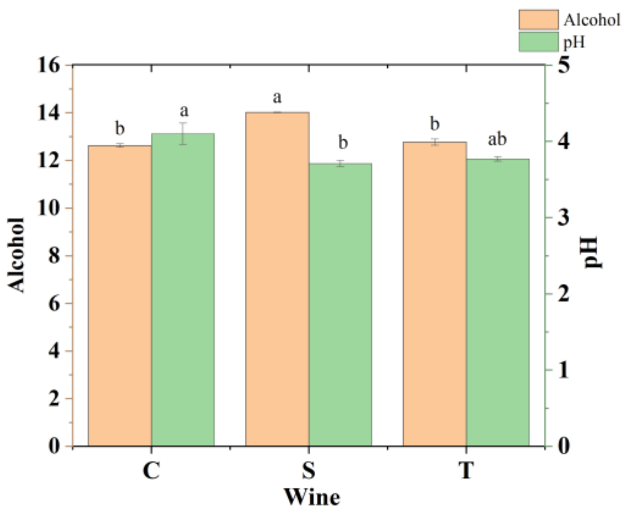


**Figure 3.** The result of alcohol and pH of 3 wines: C-Codru,S-Stefan Voda, T-Vadul lui Traian.

Average value with standard deviation represented by error bar (n=2). Different letters are significantly different for P ≤ 0.05 between PGI regions. The difference between any two values, followed by at least one common letter, is insignificant.

The pH levels range from 3 to 4, and notably, the wine Stefan Voda has the lowest pH. These differing alcohol content and pH values can exert subtle effects on the sensory characteristics of the wines, an aspect that is reflected in the sensory evaluation of the three wines.

Organic acids, constituting one of the foundational components of wines, play a crucial role in influencing the sensory quality. Key organic acids include tartaric acid, malic acid, citric acid, and lactic acid. Among these, tartaric acid is distinctive for its rougher and more robust flavor compared to other acids. It is typically derived from grapes, occurring naturally in the fruit. The variations in organic acids, along with alcohol content and pH levels, contribute to the nuanced sensory profile of each wine, making them unique and reflective of the specific viticultural and winemaking conditions at each station. Malic acid is one of the more prevalent organic acids in plants, mostly in the form of L-malic acid, which tastes tart, slightly tangy, slightly bitter, astringent, and long presentation [27].

*Table 5*

**The result Organic acids of 3 wines in vintage 2022**

| | Total Acidity (g/L) | Volatile Acidity (g/L) | Lactic Acid (g/L) | Tartaric Acid (g/L) |
|---|---|---|---|---|
| C | 6.03±0.04 [b] | 0.54±0.02 [b] | 1.75±0.01 [a] | 3.36±0.01 [b] |
| S | 6.46±0.01 [a] | 0.51±0.01 [b] | 1.43±0.01 [b] | 5.01±0.01 [a] |
| T | 6.45±0.06 [a] | 0.65±0.04 [a] | 1.19±0.01 [c] | 5.07±0.05 [a] |

**Note:** C-Codru,S-Stefan Voda,T-Vadul lui Traian. Average value ± standard deviation (n=2). Different letters are significantly different for P ⩽ 0.05 between PGI regions. The difference between any two values, followed by at least one common letter, is insignificant.

In terms of total acidity Table 5 shows, that Codru exhibits the minimum at 6.03 g/L. There is not a substantial difference between Stefan Voda and Vadul lui Traian, but both are higher than Codru.

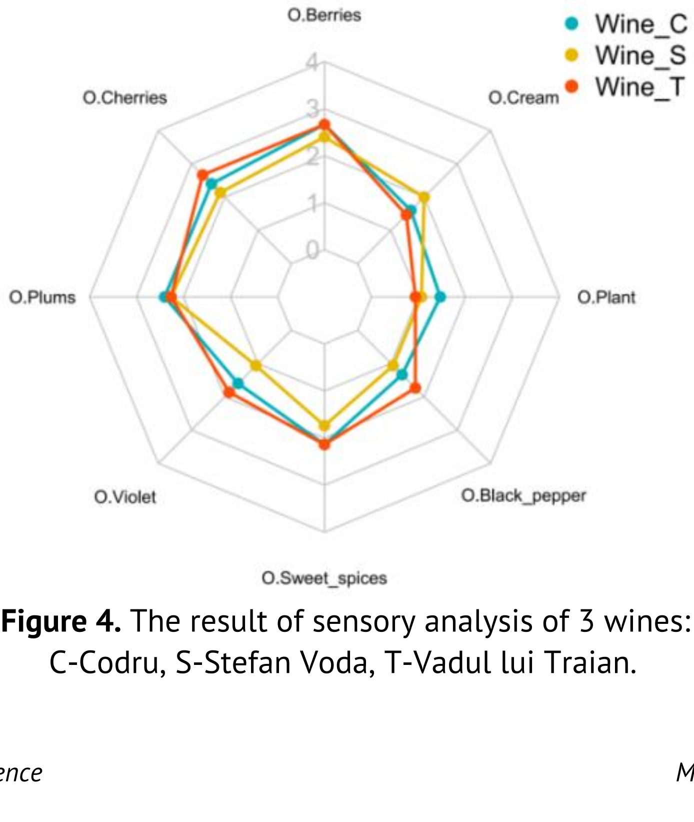


**Figure 4.** The result of sensory analysis of 3 wines: C-Codru, S-Stefan Voda, T-Vadul lui Traian.

The highest volatile acid content is found in Vadul lui Traian at 0.65 g/L, while the lowest is in Stefan Voda at 0.51 g/L. Codru has the highest lactic acid content at 1.75 g/L, whereas Vadul lui Traian has the lowest at 1.19 g/L. Tartaric acid content is also highest in Vadul Lui Traian at 5.07 g/L, with a slight difference of 5.01 g/L compared to Stefan Voda. The lowest content is in Codru at 3.36 g/L.

Regarding sensory evaluation indicators, the radar chart (Figure 4) reveals that the three samples have the closest scores in plums. However, there are notable differences in the scores for cherries, violets, and black pepper. Stefan Voda wine exhibits more creaminess, while Codru has more pronounced herbal characteristics. Vadul lui Traian's scores in the four indicators of berries, cherry, violet, and black pepper are higher compared to the other two wines.

*Table 6*

**The organoleptic analysis results of 3 wines from the 2022 vintage**

| | | Bugeac | Purcari | Mircesti |
|---|---|---|---|---|
| Olfactory | Forest fruit | 3.33±0.47 a | 3.00±0.0 a | 3.33±0.0 a |
| | Cherry | 3.33±0.00 a | 2.67±0.0 c | 3.00±0.0 b |
| | Plums | 2.83±0.24 a | 2.83±0.24 a | 3.00±0.0 a |
| | Violet | 2.33±0.00 a | 1.33±0.0 c | 2.00±0.0 b |
| | Sweet spice | 2.67±0.00 a | 2.17±0.24 a | 2.67±0.47 a |
| | Black pepper | 2.17±0.24 a | 1.33±0.47 a | 1.67±0.47 a |
| | Plant | 1.17±0.24 a | 1.33±0.00 a | 1.83±0.24 a |
| | Dairy | 1.83±0.24 a | 2.50±0.71 a | 2.00±0.94 a |
| | Smoke | 0.67±0.47 a | 1.00±0.0 a | 0.83±0.24 a |
| | Oak | 0.83±0.24 a | 0.67±0.0 a | 0.67±0.0 a |
| Gustatory | Structure | 3.17±0.24 ab | 3.33±0.0 a | 2.50±0.24 b |
| | Body | 2.83±0.24 a | 3.33±0.0 a | 2.83±0.24 a |
| | Tannin | 3.33±0.0 a | 4.00±0.47 a | 4.67±0.47 a |
| | Bitter | 1.33±0.0 a | 1.33±0.0 a | 1.67±0.47 a |
| | Alcohol | 2.83±0.24 a | 2.83±0.24 a | 2.67±0.0 a |
| | Oak | 1.50±0.24 a | 1.00±0.0 a | 1.17±0.24 a |
| | Persistence Gustatory | 3.33±0.47 a | 3.00±0.0 a | 3.17±0.24 a |
| | Persistence Aromatic | 3.50±0.24 a | 3.00±0.0 a | 3.17±0.24 a |

**Note:** C-Codru, S-Stefan Voda, T-Vadul lui Traian. Average value ± standard deviation (n=2). Different letters are significantly different for P ⩽ 0.05 between PGI regions. The difference between any two values, followed by at least one common letter, is insignificant.

This nuanced analysis provides a comprehensive understanding of the compositional and sensory distinctions among the three wines, contributing to a detailed appreciation of their unique qualities, Table 6.

## 4. Conclusions

The climatological investigation conducted for Moldovan PGI regions in 2022 reveals nuanced insights into the regional climatic dynamics. Notably, the Codru region is characterized by favorable heliothermal conditions, as evidenced by a Heliothermal Index (HI) of 2017, indicative of a temperate warm climate. Conversely, the Stefan-Voda and Vadul lui Traian regions exhibit warmer climatic profiles, with HI values of 2408 and 2433, respectively. Nevertheless, all regions benefit from nocturnal cooling, a phenomenon conducive to the synthesis of secondary metabolites pivotal for wine quality enhancement. Disparities in the Dryness Index (DI) across regions are also evident, with Stefan-Voda predominantly classified as sub-humid, while Vadul lui Traian experiences notably arid conditions. These indices, corroborated by antecedent research findings, underscore the oenological potential inherent in Moldova's viticultural locales.

Furthermore, the scrutiny of fungal diversity elucidates the intricate nexus between environmental parameters and microbial ecology within grapevine ecosystems. Variables such as temperature, UV radiation exposure, and precipitation exert substantial influence on the abundance and diversity of microflora. Employing high-throughput sequencing methodologies augments our understanding of grapevine microbiota dynamics, wherein Saccharomyces cerevisiae assumes a central role in fermentation processes, while non-Saccharomyces yeast strains contribute to olfactory and gustatory nuances. Each viticultural enclave imparts a discernible microbial imprint, thus endowing regional wines with distinctive organoleptic profiles.

The comprehensive physico-chemical and sensory appraisal of wines from the 2022 vintage reveals discernible differentials in compositional attributes and sensory characteristics. Parameters such as ethanol content, pH levels, and organic acid composition exert a pronounced influence on the sensory perception of wines. Notably, Stefan Voda manifests the highest ethanol content among the regions, ranging from 12.8% to 14.0%, alongside the lowest pH level. Sensory evaluations further delineate the unique olfactory and gustatory profiles exhibited by wines from each viticultural zone, with Stefan Voda evincing heightened creaminess, Codru showcasing prominent herbal nuances, and Vadul lui Traian displaying elevated scores in berry, cherry, violet, and black pepper descriptors.

In essence, this exhaustive inquiry endeavors to delineate the terroir specificity inherent in each viticultural precinct in Moldova, thereby enriching our comprehension of the singular attributes encapsulated in Moldovan Fetească Neagră wines. By amalgamating macroclimatic scrutiny, microbial examination, and sensory assessments, this study seeks to elucidate the multifarious factors underpinning the distinctive oenological character of Moldovan wines.

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