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MONITORING OF PHYSICO-CHEMICAL INDICES DURING THE RIPENING AND MATURATION OF ŞARBĂ GRAPES

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Abstract. Monitoring the physicochemical parameters during the ripening and maturation of Șarbă grapes is crucial in viticulture, as it significantly impacts grape quality and wine production. Șarbă grapes, recognized for their unique flavor and aroma characteristics, experience a complex ripening phase marked by significant changes in color and chemical composition. The ripening process consists of two primary stages: initial berry growth following flowering, culminating in veraison, characterized by sugar accumulation and the diminishment of unfavorable substances. These modifications are crucial for improving the grapes' appeal and palatability, necessitating meticulous monitoring for winemakers seeking to maximize harvest timing and wine quality. The analyses presented in this study aimed to monitor the evolution of key physico-chemical parameters–sugar content, total acidity, and total phenolic content–during the ripening of Șarbă grapes from the Odobești vineyard over the 2022, 2023, and 2024 harvest seasons. Essential physico-chemical parameters (sugar concentration, titratable acidity, and total phenolic content) are crucial for evaluating grape maturity and suitability for winemaking. Fluctuations in these indexes can profoundly influence the flavor, balance, and overall quality of the resulting wine. Environmental conditions, such as temperature, humidity, and altitude, can impact ripening, leading to uneven ripening within grape clusters. Advanced monitoring tools help viticulturists optimize vineyard management and harvesting.

Keywords: Șarbă grapes, ripening, physico-chemical indices, technological maturity, grape quality, harvest variability

Introduction. Formulation of the problem

The maturation of grapes entails a multifaceted, two-phase process commencing post-flowering with the emergence of green berries. Following a period of growth, veraison begins, during which the berries undergo substantial changes. This encompasses a color metamorphosis from green to red, black, or yellow, including physical changes such as swelling and softening of the skin. Simultaneously, chemical changes occur; specifically, sugar accumulation begins, enhancing the berries' attractiveness as a source of energy for birds. This phase also involves eliminating unwanted anti-feedants, enhancing the palatability of the berries as they diminish in green-tasting methoxypyrazines, acidity, and tannin bitterness, ultimately resulting in improved flavor profiles. The timing of ripening was crucial and could be enhanced by choosing early-ripening varieties, especially in cooler regions where achieving full ripeness is often difficult [1].

Analysis of recent research and publications

Multiple factors affect the ripening process, including temperature, berry pH, and total soluble solids. Many studies have demonstrated reliable correlations between these ripening variables and environmental factors, which can help winemakers to monitor and to control grape maturity. This allows them to strategize essential operations, such as irrigation or canopy adjustments, and to determine the optimal harvest period [2].

Ripening initiation does not occur uniformly across the berrys; it extends over several weeks. For instance, skin pigmentation lags sugar accumulation and fruit softening, leading to bunches of varying maturity at harvest. This combination might confuse peak acidity evaluation, leading to underestimation at the onset of ripening [3].

The initial systematic examination of the maturity of red grape varieties also functioned as an inspiring framework for the study of white grape types. Essentially, this investigation included the sensory evaluation of the degree of ripeness of red grape varieties, physico-chemical (potential alcoholic value, total acidity, pH value, malic and tartaric acid content, potassium content, total polyphenol index, anthocyanins, absorbances at 420, 520, and 620 nm, color index), determined on the same samples [4]. The authors of the aforementioned systematic study [4] developed a model for identifying the technological and polyphenolic maturity of red grape varieties, which could also be extended to evaluate white grape maturity. The physicochemical elements mentioned earlier as technological variables, along with the average of the four sensory stability variables, were identified as the most important. The maturity stage of grapes at harvest is a critical parameter for the sensory quality of wines. Harvesting decisions should be based on analytical assessments of sugar concentration, titratable acidity, and pH of the grape must, as these factors provide essential information regarding technological maturity. However, these parameters only provide information on pulp maturity and overlook the actual maturity of the skins and seeds of the berries, which refers to aromatic and polyphenolic maturity. The stages of technological, aromatic, and polyphenolic maturity are not reached simultaneously, but, on the contrary, they tend to separate depending on several factors such as the grape variety, the sometimes restrictive meteorological conditions during the period of active vine growth and ripeness of the berries, the soil, the availability of water, and the applied viticultural practices [4].

Multiple environmental factors, including climate, elevation, and soil composition, significantly influence grape maturation. The compatibility of the grape variety and rootstock is influenced by these characteristics, which are essential for attaining optimal development and fruit quality. Ripening indices are crucial for assessing grape maturity and are influenced by variations in total soluble solids, total acidity, and pH throughout the ripening process [5]. The correlation among these indices is crucial; for instance, as total soluble solids increase, acidity generally decreases, while pH levels tend to rise. This relationship is shaped by the varietal qualities of the grapes, as demonstrated in studies of different cultivars, such as Garganega and Glera, across several vintages. Climatic anomalies, including elevated temperatures driven by climate change, have been shown to accelerate ripening in grape cultivars. Research suggests that these alterations can lead to increased sugar levels, potentially elevating the alcohol content by 1–2% [6].

Monitoring physicochemical parameters during the ripening and maturation of Şarbă grapes is crucial for winemaking, particularly to optimize harvest timing and enhance wine quality. Evaluating grape maturity involves monitoring several key parameters, notably total acidity and pH levels, which are crucial for determining the optimal harvesting period. The date of grape harvest directly affects the balance of sugar and acidity, thereby influencing the flavor profile and quality of the resulting wine [6,7].

Determining the optimal harvest period is crucial for achieving optimal pH and overall grape quality. Premature grape harvesting can result in elevated acidity and inadequate phenolic compounds, whilst delayed harvesting may yield excessively ripe fruit with unbalanced sugar concentrations. Consistent assessment of grape pH and titratable acidity enables vineyard managers to make informed decisions regarding harvest timing, ensuring grapes are harvested at optimal maturity [7,8]. Selective harvesting procedures, which involve numerous trips through the vineyard to collect ripe berries while allowing under-ripe clusters to mature, enhance uniformity in grape ripeness. This method enhances the quality of harvested fruit, yielding wines with greater flavor and aroma complexity.

The objective of this study was to investigate the evolution of physico-chemical parameters–specifically carbohydrate content, must acidity, and total phenolic content– during the ripening process of *Şarbă* grapes cultivated in the Odobești vineyard, across three consecutive harvest years (2022–2024), to assess their influence on grape quality and technological maturity.

Research materials and methods

Plant material.The studies were conducted on grapes of the *Şarbă* variety, sourced from a private producer in the Odobești vineyard, between 2022 and 2024. The *Șarbă* white grape variety is a Romanian variety developed at SCDVV Odobești by crossing Tămâioasă Românească and Italian Riesling.

Grape sampling was conducted, considering all important points in the studied plots and the degree of sun exposure.

Chemicals and reagents. The following chemicals and reagents were used for the analytical methods: 0.1 N sodium hydroxide solution, phenol red indicator (0.02% solution), Folin Ciocâlteu reagent, and a 20% Na_2CO_3 solution. All chemicals were of analytical grade.

Grape must preparation.Several 250 grapes were weighed, and the mass of 100 grapes was calculated.

The grapes were crushed manually, then pressed in a laboratory press to separate the juice from the skins.

Determination of the carbohydrate content of the must. Grape must was used to determine the carbohydrate content using an Abbe refractometer, where the dry matter of the must was read. Subsequently, the carbohydrate content in the must was determined based on the dry matter value.

Determination of the acidity of grape must. Must acidity was determined by titrating 10 mL of must with 0.1 N NaOH using phenol red as an indicator and expressed as g/L H_2SO_4 or tartaric acid.

Determination of total phenolic content. A method first reported by Singleton and Rossi [9] was used, with slight modifications. Briefly, the following reagents were introduced into a 100 mL volumetric flask: 1 mL of must, 5 mL of Folin Ciocâlteu reagent, and 20 mL of 20% Na_2CO_3 solution. The flask was then made up to the mark with distilled water, shaken, and left to stand for one hour. After standing, the absorbance at 750 nm was measured with a spectrophotometer using a 1 cm quartz cuvette, and the result was compared with that of a control sample prepared with distilled water instead of the must. The results were expressed in g/L gallic acid using a standard curve whose regression equation was $y = 0.4256X-0.0010$, $R^2 = 0.9997$.

Statistical Analysis. This study reports the mean and standard deviation based on three replicates. Data normality and homoscedasticity were assessed using Minitab 19 (Minitab Inc., PA, USA), followed by a one-way ANOVA and Tukey's post hoc test to identify statistically significant differences ($p < 0.05$).

Results of the research and their discussion

Evolution of carbohydrate content during grape ripening. Sugars constitute approximately 90% of the soluble dry matter in grape must, with glucose and fructose accounting for 95–99% of the total sugar content at harvest [10]. The synthesis of sucrose drives the accumulation of sugars in grapes via photosynthesis in leaves or storage organs [11], followed by its hydrolysis by invertase enzymes, which facilitates the rapid accumulation of hexose sugars during ripening (10,12). Due to its agrobiological character, the *Şarbă* variety exhibited relatively linear accumulations of sugars, except for some notable jumps reported in the final stage of the ripening period (26.09 - 09.10), which occurred only in the 2022 and 2024 harvest years (Fig.1).

Compared to the initial date of the maturation period (16.08), at the harvest stage (11.10) 112 g/L of sugars (6.59% vol alcohol) were accumulated in the 2022 harvest year, 92 g/L of sugars (5.41% vol alcohol) in the 2023 harvest year and 117 g/L of sugars (6.88% vol. alcohol) in the 2024 harvest year.

The sugar accumulation recorded in the last stage of the ripening period (27.09 – 11.10), signaled an increase in the concentration of sugars of 44 g/L (2.59 % vol. alcohol), which preserves the linear character of the evolution of this parameter in the 2022 harvest year, and of 50 g/L (2.94 % vol alcohol), which reflects a curved character of this evolution in the harvest year 2024, but an insignificant increase of only 4 g/L sugars (0.24% vol. alcohol) in the 2023 harvest year, which revealed a stationary nature of this accumulation.

Although it may seem paradoxical, the final alcoholic potential of the sugar concentrations accumulated by the *Şarbă* variety harvests up to the harvest stage correspond to the statistical data from previous harvest years only in 2023 (193 g/L sugars equivalent to 11.41% vol. alcohol) and less so in the harvest years 2022 and 2024, which more strongly reflect the influence of global warming (232 g/L sugars equivalent to 13.65% vol. alcohol in 2023 and 246 g/L sugars equivalent to 14.47% vol. alcohol in 2023, respectively). The average value of the sugar concentration in *Şarbă* grapes from the Odobeşti vineyard for the three harvest years analyzed (2022, 2023, and 2024), at the harvest stage, was 223.66 g/L.

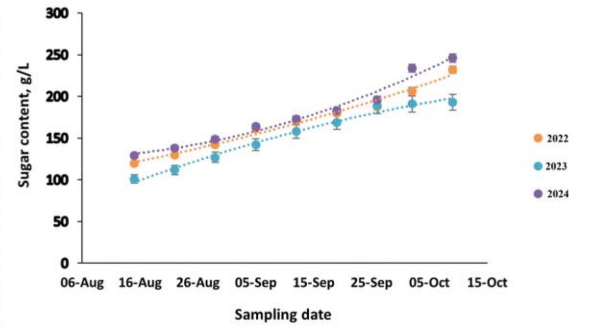

Fig. 1. Dynamics of the evolution of sugar content during grape ripening and maturation for the harvest years 2022, 2023, 2024

In another recently published comparative study [13], conducted in the Ştefăneşti – Argeş vineyard, the average of sugar content at harvest for three harvest years (2017, 2018, and 2019) in grapes of the *Şarbă* variety was 153.72 g/L. The significant difference in the value of 69.94 g/L sugars, i.e., higher by approximately 65% in the Odobeşti vineyard than in the Ştefăneşti vineyard, is justified by the ability of the *Şarbă* variety to express its agrobiological properties in significantly superior agrobioclimatic conditions in which it was obtained.

The thermal regime plays a crucial role in sugar accumulation in grapes, with optimal temperatures ranging from 25 to 35 °C [14] . Excessively high temperatures during the ripening period can disrupt both primary and secondary metabolic processes, leading to desynchronization between sugar and organic acid metabolism and ultimately delaying the accumulation of sugars and polyphenols [15].

Except in extremely hot climates, where excessive heat adversely affects carbohydrate accumulation, elevated temperatures generally accelerate sugar accumulation in grapes [16]. Although high temperatures hasten ripening, their direct impact on the final sugar content is limited. For a given variety, there appears to be a physiological ceiling to sugar accumulation, and soluble dry matter levels above 25º Brix are unlikely to be reached unless grape dehydration occurs [10]. Statistical data from SCDVV Odobești revealed that grape harvests from the *Şarbă* variety have never reached the previously mentioned critical limit for soluble dry matter content.

Wine regions located in milder climes may benefit from global warming, as rising temperatures could help grapes reach optimal technological maturity [17]. This climate shift is expected to result in wines with higher alcohol concentrations in most regions [18]. In response to changing consumer preferences–specifically, the increasing demand for wines with moderate or low alcohol content for health reasons [19])–certain producers have shifted from conventional chaptalization to physical alcohol reduction techniques such as reverse osmosis [20,21]. Considering the above aspects, the *Şarbă* variety could become a formidable protagonist for potential wine-growing areas with cooler climates that could benefit from the advantages of global warming.

Given the prevailing global trend of vigorously promoting Ice wines at international exhibitions and contests, investigating the use of Şarbă grapes for their production offers a significant opportunity. This variety exhibits advantageous traits for on-vine storage and subsequent exposure to sub-zero temperatures below -7°C, conditions that cause the water in the berries to crystallize, thereby concentrating the juice and facilitating the creation of unique dessert wines. The ongoing advancement of global warming poses an escalating challenge to the sustainability of ice wine production, rendering its future increasingly uncertain [22].

Evolution of acidity during grape ripening. As a rule, grapes from the *Şarbă* variety maintain an optimal titratable acidity at the harvest stage, which very rarely are below the critical limit of 6 g/L, expressed in tartaric acid, according to statistical data from previous harvest years established by SCDVV Odobești.

The comparative study of the dynamics of acidity reduction highlighted relatively constant decreases in this parameter that show a certain linearity, with the mention that these were more sharply differentiated in the last stage of the grape ripening period (27.09 – 11.10) (Fig.2). In the 2022 harvest year, the reduction in the titratable acidity of the harvest in the mentioned stage suffered a standstill (a barely perceptible reduction from 6.1 g/L to 6 g/L tartaric acid) followed by a steep decrease (from 6 g/L to 5 g/L tartaric acid), while in the 2023 harvest year, an inverse situation was reported in which a significant reduction in titratable acidity was highlighted in the first part of the mentioned period (from 7.6 g/L to 6.1 g/L tartaric acid) followed by a much smaller reduction (from 6.1 g/L to 5.8 g/L tartaric acid). In turn, the reduction in titratable acidity related to the mentioned period for the 2024 harvest year followed a similar evolution to 2023 (a larger decrease from 6 g/L to 4.7 g/L, followed by a smaller one from 4.7 g/L to 4.4 g/L tartaric acid).

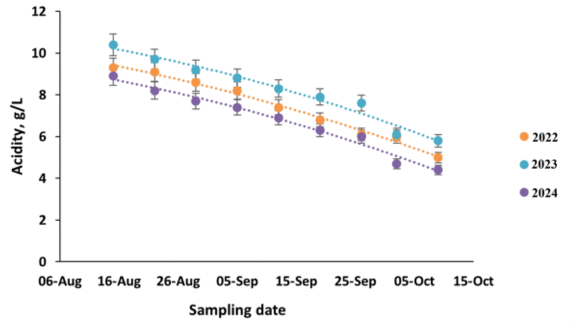

Fig. 2. Dynamics of acidity evolution during grape ripening and maturation for harvest years 2022, 2023, 2024

Given the data already provided, without considering the evolution of the mass of 100 berries in each harvest year, it would be possible to partially estimate the optimal periods for harvesting grapes of the Şarbă variety, as well as possible technological interventions to correct the composition of the grape harvest.

Around 04.10, for the 2022 harvest year, when the sugar concentration was approaching 206 g/L, and the titratable acidity presented an almost stationary character with a variation of only 0.1 g/L from 6.1 g/L to 6.0 g/L tartaric acid, in this harvest year, no composition corrections of the obtained harvest would be necessary (Fig.2).

On the date of 04.10 for the 2023 harvest year, when the sugar concentration rose to 191 g/L (the subsequent increase of only 2 g/L sugars, up to 193 g/L being technologically uninteresting), and the titratable acidity reduced to 6.1 g/L tartaric acid (with a variation of only 0.1 g/L from 6.1 g/L to 6.0 g/L tartaric acid); in the 2023 harvest year, a slight correction of the sugar content would be necessary, at least up to 204 g/L (which is equivalent to an alcoholic potential of 12% vol. alcohol).

Immediately after the date of 27.09 for the 2024 harvest year, when the sugar concentration followed an upward slope with a spectacular, rapid increase for one week from 196 g/L (11.53 % vol alcohol) to 234 g/L (13.76 % vol. alcohol), being accompanied by a marked reduction in titratable acidity in the same period from 6 g/L to 4.7 g/L tartaric acid. In the case of the 2024 harvest year, a daily control of the evolution of the sugar content and titratable acidity would have been required, so that the increase in sugar concentration would have risen much less (up to 204 – 210 g/L) which would have corresponded to a much smaller reduction in titratable acidity (up to 5.5 – 5.7 g/L tartaric acid); in this technological context, a reasonable correction of the harvest acidity of only 0.3 – 0.5 g/L tartaric acid would have been necessary.

In mature fruits, such as ripe grapes, acidity is predominantly influenced by variations in the amounts of organic acids [23]. Malic acid serves as a crucial respiratory substrate in grapes, reaching its maximum concentration at the onset of ripening and declining to its lowest levels by the end of this phase [24]. The deterioration is influenced by temperature and substrate availability [25]. Tartaric acid does not experience respiratory degradation; instead, its concentration fluctuations are primarily due to dilution effects and the production of salts with potassium ions (K^+) [23,25]. This information from the specialized literature will provide useful support for future analytical monitoring of the ripening parameters of the Şarbă variety, enabling the adoption of the most optimal technological solutions for producing wines from this variety.

Organic acids play key roles in energy production, amino acid biosynthesis, osmotic stress response, and defense against predation [26]. They are major contributors to must pH, affecting wine color, stability, and sourness, while also modulating sweetness perception [27]. Tartaric and malic acids are predominant in grapes, with minor amounts of acetic, citric, lactic, and succinic acids also present [28]. Tartaric acid is primarily synthesized between flowering and ripening, both in grapevine leaves–particularly during their expansion–and in the berry pulp [29]. Limited irrigation before ripening can reduce tartrate accumulation. After ripening, tartaric acid levels tend to stabilize, as they are less affected by light and temperature, with observed decreases mainly due to dilution from berry growth [30,31].

Malic acid accumulates in grape berries primarily before ripening, with optimal synthesis occurring at temperatures between 20 and 25 °C. At temperatures above 38 °C, malic acid biosynthesis significantly declines, as the respiratory substrate shifts from glucose to malate after ripening [10]. Sustained high temperatures throughout the ripening period typically lead to reduced malate levels, especially in warmer harvest years [24]. However, studies have shown that a 4–6 °C of increase in temperature does not always reduce malate content, suggesting that malate metabolism may be regulated differently during day and night cycles. Other studies have demonstrated that elevated temperatures during grape ripening can desynchronize sugar and organic acid metabolism, inducing genetic reprogramming by altering the transcriptome–the complete set of mRNA molecules expressed in a cell or tissue at a given time. This transcriptomic shift reflects changes in gene activity, as genes are first transcribed into mRNA before being translated into proteins [32].

During grape ripening, irrigation or elevated temperatures can lead to increased K^+ accumulation in the berries, resulting in higher pH levels [31]. Potassium, the most abundant cation in grapes, plays critical roles in plant signaling (through phytohormones), osmoregulation, maintenance of cation-anion balance, pH regulation, and activation of enzymes involved in protein and starch synthesis [33]. Elevated K^+ concentrations and pH can negatively impact wine color, microbiological stability, and fermentation dynamics [10]. In warm viticultural regions, excessive heat can produce grapes with low titratable acidity, high pH, and high K^+ levels, necessitating acid corrections–typically through the addition of tartaric acid–to restore balance, enhance microbial stability, and ensure optimal winemaking outcomes [10]. Grape acidity is influenced by multiple factors, including grape variety, vineyard soil characteristics, and prevailing climatic conditions, and is closely correlated with the stage of berry ripening. As grapes mature, their acidity decreases, primarily because of respiratory metabolism and dilution of the grape juice. Several studies have highlighted that the degradation of specific organic acids in grapes is strongly temperature-dependent, with higher temperatures accelerating acid breakdown [34].

Evolution of the sugar-acidity index during grape ripening. It was not imperative to analyze the dynamics of the evolution of the tartaric acid/malic acid ratio [35], given that it is not applied in wine production, and that the evolution of the sugars/titratable acidity ratio (Fig. 3) was also comparatively analyzed for the studied harvest years.

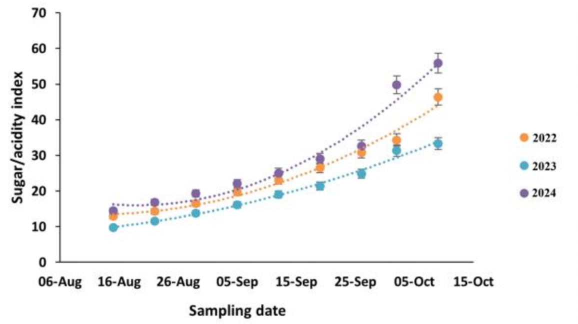

Fig. 3. Evolution of the sugars - acidity index during grape ripening and maturation for the harvest years 2022, 2023, 2023

For each of them, normal evolutions of this parameter were observed, with an increase of 3.59 times (from 12.90 g/L to 46.40 g/L) for the year 2022, 3.42 times (from 9.71 g/L to 33.27 g/L) for the year 2023 and 3.89 times (from 14.49 g/L to 55.90 g/L) for the year 2024, with a maximum variation of the increase of only 0.47; the results obtained revealed that no possible correlations could be established between the value of the sugars-acidity index and the agrobiological properties of the *Şarbă* variety. These findings were confirmed by the results of previous research [13] which highlighted that the variation of the sugars/acidity index could not be correlated with the agrobiological properties specific to white wine varieties; For example, this research revealed that in the 2017 harvest year, the lowest value of the sugars/acidity index was reported for the *Şarbă* variety (38.77). The highest value was recorded for the Muscat Ottonel variety (48.6), indicating that in the following harvest years, the values of the mentioned index were variable, with a maximum for the *Sauvignon* variety (49.72) and a minimum for the *Riesling* variety (36.88). In 2019, the differences between the minimum and maximum values for the same index were insignificant (46.23 and 49.96).

Evolution of the 100-berry mass indicator during grape ripening. According to the international reference in specialized foreign literature [36], the grape ripening period concludes when the mass (weight) of 100 berries, collected under standardized criteria, stabilizes, after which it begins to decline, indicating the shift to the overripe phase of the harvest. In the comparative study, the harvest of grapes of the Şarbă variety showed an increase in the 100-berry mass index (Fig. 4), yielding the following findings. In the 2022 harvest year, the mass of 100 berries remained constant (170 g) in the first days following 27.09; the determined value of 170 g of the mass of 100 berries corresponded to a titratable acidity of 6 g/L in tartaric acid and a sugar content of over 190 g/L.

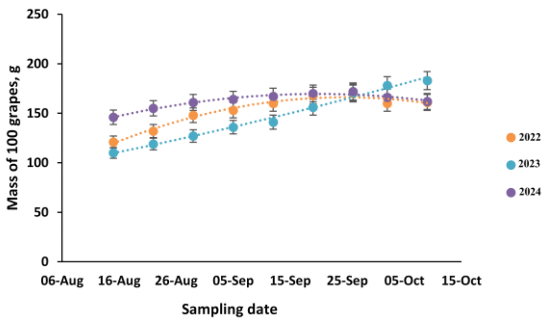

Fig. 4. Evolution of the parameter mass of 100 grapes during grape ripening for the harvest years 2022, 2023, 2024

In the 2023 harvest year, the mass of 100 berries reached a maximum value of 183 g, which was determined at the end of the ripening period (11.10), without any other increase, constant maintenance or decrease in the determined value being reported; under these conditions, it can be stated that the value of 183 g of the mass of 100 berries is an objective one, given that, in the final stage of the ripening period (27.09 – 11.10), the sugar concentration value remained relatively constant (increased by only 4 g/L, from 189 to 193 g/L), while the titratable acidity recorded a vertiginous decrease from 1.8 g/L, from 7.6 g/L to 5.8 g/L in acid.

In the 2024 harvest year, the mass of 100 berries remained constant (172 g) around 27.09. At this stage of the determination (27.09), the value of 172 g of the mass of 100 berries corresponded to a titratable acidity of 6.0 g/L in tartaric acid and a sugar content of over 196 g/L.

In this context, the 2024 harvest year is very similar to the 2022 harvest year, and both differ from the 2023 harvest year. The aforementioned differences are explained only by the different climatic conditions specific to the harvest year, given that the other factors involved were identical (the vineyard plot studied, the soil and subsoil, the solar exposure of the plot, the variety, the agrotechnical works and phytosanitary treatments during the vegetation period, the stage and criteria of sampling, the analytical investigation methods).

Evolution of total polyphenol content during grape ripening and maturation. The evolution of total polyphenol content during ripening in white grape varieties, such as Şarbă, could provide insight into the chromatic properties of the resulting dry wines and their susceptibility to oxidation. However, this evolution may have helped confirm the optimal ripeness of the grapes.

According to Ribéreau–Gayon et al. [37], the total polyphenol content of dry white wines ranges from 50 to 250 mg/L. However, it is below 10% of the total polyphenol content specific to red wines. In a comparative experimental study on white grapes from the Şarbă variety in the Odobeşti vineyard, conducted over three harvest years (2022, 2023, and 2024), the following findings were reported regarding their total polyphenol content (Fig. 5). At the end of the maturation period, the variations in total polyphenol content ranged from 2.53 mg/g in 2022 to 2.91 mg/g in 2024, indicating an intermediate value of 2.71 mg/g in 2023. To what extent and in what context these values can be correlated with the sensory profiles of the resulting dry wines remain to be established through further research. The increase in the total polyphenol content over the entire period of its analytical monitoring (16.08 – 11.10) is greater than 1 mg/g (1.32 mg/g for the 2022 harvest year and 1.23 mg/g for the 2023 harvest year, respectively) or at least equal to 1 mg/g (for the 2024 harvest year).

The evolution of the value curves of the total polyphenol index is similar for the harvest years 2022 and 2024, except for the evolution of this parameter in the last interval (04.10 - 11.10) of the ripening period; in the case of 2024, an increase of 0.15 mg/g was recorded in the mentioned interval, after previously reported reductions of 0.15 mg/g (in the interval 20.09 - 27.09) and only 0.04 mg/g (in the interval 27.09 - 04.10), while for 2022 a slight decrease of 0.12 mg/g was reported after previously the evolution recorded very small increases of 0.05 mg/g (both in the interval 20.09 - 27.09 and the interval 27.09 - 04.10).

For the last interval (04.10 – 11.10) of the ripening period, a similar evolution was observed, marked by a reduction in the total polyphenol index for the harvest years 2022 (0.12 mg/g) and 2023 (0.10 mg/g).

The variations in the total polyphenol index during the analyzed period, although within normal limits, showed variable increases in value during the period 15.08 - 19.09 (of 1.34 mg/g in 2022, of 0.82 mg/g in

2023 and of 1.04 mg/g in 2024, respectively), new increases during the period 20.09 - 04.10, either more attenuated for the year 2022 (from 2.55 to 2.65 mg/g), or more notable for the year 2023 (from 2.30 to 2.81 mg/g) or even reductions in the case of the year 2024 (from 2.95 to 2.76 mg/g).

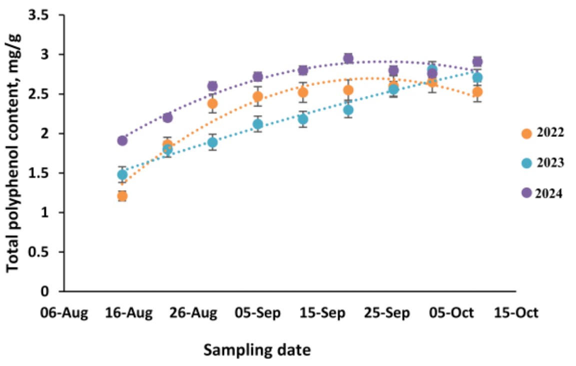

Fig. 5. Total polyphenol content during grape ripening

Quercetin is the predominant flavonol in most white types, constituting over 70% of total flavanols [38]. However, myricetin is the most prevalent flavonol in most red types [39]. Cultivation at higher altitudes has been shown to significantly enhance the synthesis of anthocyanins and flavonols, particularly cyanidin-type anthocyanins and quercetin-type flavonols, by activating flavonoid 3′-hydroxylase (F3′H), a key enzyme in the flavonoid biosynthetic pathway [40]. This effect is primarily attributed to the progressive decrease in temperature with increasing elevation, where adiabatic cooling reduces temperatures by approximately 0.60–0.65°C per 100 m of altitude gained [41]. Additionally, phenolic profiles in wines from white grape varieties have proven useful for varietal differentiation, with hydroxycinnamic acids (notably p-coumaric and caftaric acids) and flavan-3-ols, including (+)-catechin and (–)-epicatechin, identified as effective chemotaxonomic markers [42].

According to Billet et al. [43], polyphenols serve as valuable chemotaxonomic and terroir-specific bioindicators, aiding in the identification of grape variety, geographical origin, and vintage year. Due to their potent biological activities, they are also recognized as key contributors to the health-promoting effects of wine. In a recent comprehensive study, Šarac et al. [44] revealed that hydroxycinnamic acids, particularly caffeic acid, are the predominant phenolic compounds in white wine varieties. The study also identified specific polyphenols as potential The inversely proportional evolution of grape production with the mass of 100 berries determined at the time of harvest: 161 g, corresponding to 8.8 t/ha, in 2022; 162 g, corresponding to 8.7 t/ha, in 2023; 183 g, corresponding to 8 t/ha, in 2024. The lack of correlative elements between the value of grape production and the values of sugar concentration, titratable acidity, and total polyphenol content, specific to each harvest year.

chemotaxonomic markers for distinguishing between different grape varieties. For instance, *Furmint* was distinguished by its higher levels of p-hydroxybenzoic acid, kaempferol 3-O-glucoside, and esculetin. In contrast, malvidin 3-O-glucoside served as a distinguishing compound among several white varieties, including *Furmint*, *Italian Riesling*, *Rhine Riesling*, *Chardonnay*, and the Serbian cultivars *Sila* and *Traminac*.

In the study conducted by Hosu *et al.* [45], the impact of various characteristics of white wines–such as typology, vintage, and geographical origin–on total polyphenol and flavonoid content, antioxidant activity, total sugar concentration, pH, and the $^{18}O/^{16}O$ isotopic ratio was evaluated. Using chemometric techniques, including analysis of variance, cluster analysis, and principal component analysis, the authors demonstrated that both grape variety and vineyard significantly influenced the parameters under study. Additionally, the study revealed statistical interactions between harvest year and vineyard, as well as between harvest year and grape variety, underscoring the effectiveness of chemometric approaches for discriminating between white wine samples based on these factors.

In summary, several key parameters of the analyzed white wines–such as total polyphenol and flavonoid content, antioxidant activity, and total sugar concentration–were significantly influenced by the vineyard. Grape variety had a notable impact on total flavonoid levels, antioxidant activity, sugar concentration, and pH. Although the harvest year alone did not significantly affect these parameters, it interacted strongly with the vineyard for total polyphenol content, antioxidant activity, sugar concentration, and $\delta^{18}O$ values, as well as with the grape varieties for antioxidant activity [45] . All the knowledge from the recent specialized literature presented above serves as reference milestones for further in-depth research on the polyphenolic profile of the *Şarbă* variety.

A current topic of interest in oenological research that remains insufficiently clarified is the astringency of white grape wines [46]. This characteristic is less pronounced in the *Şarbă* variety. It is closely associated with the wine's phenolic profile, which, in turn, is influenced by the timing of the grape harvest and the quality of the raw material.

Evolution of grape production depending on the harvest year

The production of grapes of the *Şarbă* variety (Fig. 6) was 8.8 t/ha in the 2024 harvest year, which is very close to that of the 2022 harvest year (8.7 t/ha) and slightly higher than that of the 2023 harvest year (8 t/ha).

These values of grape production for the Şarbă variety enable the following assessments.

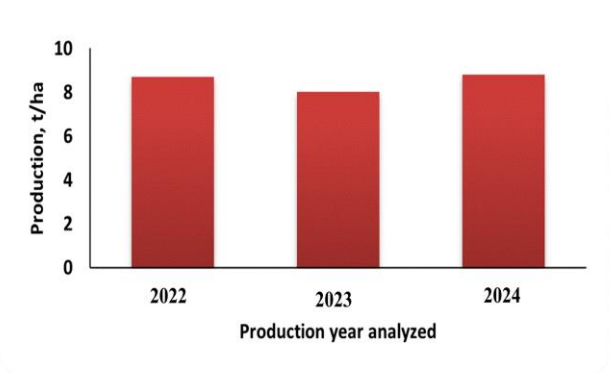

Fig. 6. Grape production in harvest years 2022, 2023, and 2024

Conclusion

Compared to the date of completion of the ripening period, at the harvest stage, 232 g/L of sugars (13.64 % vol alcohol) were accumulated in the 2022 harvest year, 193 g/L of sugars (11.35 % vol alcohol) in the 2023 harvest year, and 246 g/L of sugars (14.4 % vol. alcohol) in the 2024 harvest year, respectively. The acidity of the grapes when the harvest was triggered was 5 g/L of tartaric acid for the grapes from the 2022 harvest year, 5.8 g/L of tartaric acid for the grapes from the 2023 harvest year, and only 4.4 g/L of tartaric acid for the grapes from the 2024 harvest year. In the 2022 harvest year, the mass of one hundred berries reached a value of 161 g. In the 2023 harvest year, the mass of 100 berries reached a maximum value of 183 g, and in the 2024 harvest year, the mass of 100 berries will have a value of only 162 g. At the end of the ripening period, the variations in total polyphenol content for the grape samples studied ranged from 2.53 mg/g in 2022 to 2.91 mg/g in 2024, indicating an intermediate value of 2.71 mg/g in 2023. The evolution of grape production has an inversely proportional variation with the mass of 100 berries determined at the time of harvest: 161 g, corresponding to 8.8 t/ha, in 2022; 162 g, corresponding to 8.7 t/ha, in 2023; 183 g, corresponding to 8 t/ha, in 2024.

Several viticultural techniques can be used to mitigate the adverse effects of high temperatures and global warming, thus ensuring the postponement of early grape ripening; some of these adaptive techniques are based on changes in altitude and solar exposure of the vineyard plantations and/or on the use of late-maturing grape varieties, clones and rootstocks suitable for this purpose, delayed or minimal pruning during the growing season, more rigorous monitoring of budding and other phenological stages of the vine.

A suggestion in assessing the quality of white wine grape harvests such as Şarbă could be to extrapolate the monitoring of sensory properties of table grape berries from various white varieties that refer to certain textural properties of the skin and pulp of the berries (hardness, gumminess and chewiness perceived in the oral cavity as well as certain textural properties specific only to the skin of the berries (the force and energy required to break the skin, the elasticity of the skin) as revealed by the results of previous research, without omitting essential parameters such as the content in sugars, organic acids and phenolic composition of the investigated varieties.

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