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Acid composition of wines depending on grapevine (*Vitis* spp.) cultivars grown in Estonia

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Abstract. In Estonia's very cool climate, excessive acid content in grapes can be a challenge due to delayed ripening. This study aimed to compare the acid profiles of commercial single-cultivar wines produced by Estonian winemakers, and assess the influence of grapevine cultivar. The wines were made from grapes of five different cultivars: 'Solaris', 'Regent', 'Leon Millot', 'Cabernet Cortis', and 'Marquette'. The results revealed significant variation in malic, tartaric, citric, and lactic acid concentrations among the wines. Marquette exhibited the lowest malic acid content (0.3 g L^{-1}), while Leon Millot had the highest (4.4 g L^{-1}). Tartaric acid levels in wines ranged from 2.2 g L^{-1} in Leon Millot to 4.1 g L^{-1} in Regent. Citric acid levels varied considerably, with Solaris containing the highest concentration (1.44 g L^{-1}). Marquette had the highest lactic acid content (2.27 g L^{-1}), contributing to its smooth character. Total acid content in wines ranged from 6.9 g L^{-1} in Marquette to 9.4 g L^{-1} in Leon Millot, while pH values varied between 2.9 and 3.3. These findings indicate that grape cultivar significantly influences wine acid composition. Contrary to the hypothesis, excessive acid content was not a major issue in commercial wines; however, grape-growing conditions, such as high plastic tunnels, could alter this outcome. This study provides valuable insights for winemakers seeking to optimize acid balance and enhance wine quality in cool-climate viticulture.

Key words: lactic acid, malic acid, pH, tartaric acid, total acid.

INTRODUCTION

As global temperatures rise, the traditional boundaries for grapevine growing are shifting, affecting the suitability of certain grape cultivars in specific regions and potentially altering the characteristic profiles of wines from these areas (Schultz & Jones, 2010). Increasing temperatures turning the current wine production areas too warm and causing excess sugar levels, whereas the production of dry wines shifts further on to North (Sustainable adaption…2017). Consequently, cooler climate conditions present both challenges and opportunities in winemaking, significantly influencing the flavors and overall profiles of wines produced from specific cultivars. Viticulture in cooler regions is more labor-intensive and carries greater risks; however, it can also attract tourists and contribute to sustainable rural development. The unique climate and terroir may result in distinctive wine profiles that appeal to niche markets (Schernewski, 2011). Although Estonia is not widely recognized for grape cultivation due to its northern climate, interest in viticulture is growing as part of a niche industry. Since 2021, Estonia has been included in EU wine-growing zone A (Appendix I of Annex VII to Regulation (EU) No 1308/2013). In Estonian vineyards, the most common cultivar is 'Solaris', accounting for 43% of the total number of plants. It is primarily cultivated in high plastic tunnels, as it has not proven to be winter-hardy in open-field conditions. Other cultivars such as 'Regent', 'Cabernet Cortis', and 'Leon Millot' are also commonly grown exclusively in tunnels, and in recent years, wines produced from these cultivars have entered the Estonian market.

Wines from cooler regions are generally associated with higher acid content in grapes at harvest (Barnuud et al., 2014; Kemp et al., 2018; Riesterer-Loper et al., 2019). This is because cooler temperatures slow down metabolic processes that degrade organic acids during ripening. The slower ripening process leads to lower sugar concentrations and higher organic acid levels, particularly malic acid. The primary acids in grapes are tartaric and malic acid, but malic acid is affected by the temperature the most. In cold climates, the degradation of malic acid is slower, resulting in higher overall acidity in the grapes and, consequently, in the wines (Barnuud et al., 2014; Plantevin et al., 2024). The breakdown of malic acid begins once sugar accumulation starts and is more pronounced at higher temperatures (Rienth et al., 2016). The decrease in tartaric acid content is relatively small compared to malic acid degradation.

The total acid content of grapes is also reflected in wines, although it changes to some extent during the winemaking process. Wines from cooler regions tend to have significantly higher concentrations of organic acids compared to those from warmer locations. For instance, red wines from Nova Scotia cooler and warmer locations showed strong differences in acids composition, whereas no apparent differentiation was observed among white and rosé wines (Chahine & Tong, 2019). The wine acid profile can also be influenced by the growing region. Wines from different regions in the USA and Italy exhibit significant variations in tartaric and malic acid concentrations (Lima et al., 2022). Cool-climate wines are characterized by elevated levels of organic acids, particularly malic acid, which can contribute to a sharper taste (Riesterer-Loper et al., 2019; Wojdyło et al., 2020). Red wines generally have higher acidity and lower alcohol content compared to those from warmer regions (Kemp et al., 2018). High acidity in wines helps to preserve their freshness and stability over time (Morata et al., 2019), which is crucial for maintaining desirable sensory attributes during aging.

The primary organic acids in wine include tartrate (~1.5–4.0 g L^{-1}), malate (~0–4.0 g L^{-1}), lactate (~0.1–3.0 g L^{-1}), acetate (> 0.2 g L^{-1}, measured as volatile acidity), citrate (~0–0.5 g L^{-1}), and, in some cases, succinate (0–2 g L^{-1}) (Ribéreau-Gayon et al., 2006). The grapevine cultivar plays a crucial role in determining these characteristics. Different cultivars exhibit varying rates of malic acid degradation during ripening (Plantevin et al., 2024). Some cultivars metabolize malic acid more rapidly, which affects the overall acidity of the wine. Cultivars also differ in how they modulate tartaric acid, particularly under high temperatures, impacting the wine's acid content and pH levels. White wines, such as Riesling, are often characterized by high acids. The choice of cultivar and the timing of malolactic fermentation significantly influence the final wines acid levels (Knoll et al., 2012; Wojdyło et al., 2020). Interspecific hybrid grape cultivars, such as 'Brianna', 'Frontenac', 'La Crescent', and 'Marquette', tend to exhibit high acid content, primarily due to elevated malic acid concentrations (Riesterer-Loper et al., 2019; Scharfetter et al., 2019). At the same time total acid levels in Danish Solaris wines were moderate to low considering the cool climate, which documented the good adaptation of these cultivar to the cool Scandinavian climate (Liu et al., 2015).

In addition to cultivar characteristics, acid content is also influenced by vine-growing techniques. For example, canopy management practices such as pruning time, leaf removal and shading can affect grape acid content (Rätsep et al., 2014; Lampíř & Źaloudek, 2018; Ghiglieno et al., 2023). Proper defoliation helps to maintain higher acid levels, which is particularly important for sparkling wines that require high acidity. Cluster thinning can also impact acids in grapes. For instance, early leaf removal and cluster thinning have been shown to decrease titratable acidity in certain cultivars, such as 'Cabernet-Sauvignon' (Ivanišević et al., 2020). Similarly, leaf removal at *véraison* combined with potassium foliar applications in 'Beibinghong' vines reduced titratable acidity (Le et al., 2022). A study on hybrid cultivars over three consecutive growing seasons demonstrated the significant beneficial influence of *pre véraison* leaf and lateral shoot removal on titratable acidity. This effect was associated with increased berry temperature and higher levels of photosynthetically active radiation in the fruiting zone (Scharfetter et al., 2019). The cultivation of wine grapes in high polytunnels significantly affected their technological maturity parameters: juice pH was significantly higher, and acid content was lower in tunnel-grown grapes compared to those grown in an open field (Maante-Kuljus et al., 2019a).

High acidity in cool-climate wines can make spontaneous malolactic fermentation problematic, yet this process is essential for developing desirable sensory characteristics (Vigentini et al., 2009; Mota et al., 2017). Spontaneous malolactic fermentation is a critical secondary fermentation process in winemaking, primarily driven by lactic acid bacteria such as *Oenococcus oeni*, *Lactobacillus*, and *Pediococcus* species. This process converts malic acid into lactic acid, reducing wine acidity while enhancing its stability and sensory profile (Alexandre et al., 2004; Lonvaud-Funel, 2022). High acidity can mask fruit flavors and result in a less balanced wine. Adjustments in winemaking practices, such as the use of specific yeast strains and fermentation techniques, are necessary to manage these effects (Knoll et al., 2012; Kemp et al., 2018). Properly managed malolactic fermentation can enhance the aromatic complexity and stability of wine, whereas improper management may lead to undesirable flavors and spoilage (Lasik-Kurdyś et al., 2017; Lasik-Kurdyś et al., 2018). The biological reduction of acidity has been shown to have no significant impact on phenolic content or antioxidant capacity (Wojdyło et al., 2020).

Based on the above, it could be hypothesized that excessive acid content may become a challenge in wines produced in Estonia's very cool climate. The aim of this study was to compare the acid composition of commercial single-cultivar wines produced by Estonian winemakers and to determine the influence of grapevine cultivar.

MATERIALS AND METHODS

Viticulture and vinification

The grapes for the test wines were harvested from three different vineyards in 2023 in South Estonia (58°17′1″N, 26°33′41″E, 57°58′58.6″ N 26°34′04.2″E, 57°55′24″N 26°43′9″E). The vines were grown in high plastic tunnels. These foundation-free tunnels measured 28 m in length, 7.6 m in width, and 4.6 m in height, and were covered with 0.18 mm thick UV-stable low-density polyethylene. The ends of the high plastic tunnels were open from spring to autumn.

Vines grafted onto SO_4 rootstock were planted in 1.6×2 m spacing, trained on low double-trunk trellises, and pruned using the spur method. The vine rows were oriented from north to south, with the ground covered by woven ground cover fabric. The vineyards' soil was high-productivity sandy loam *Haplic Luvisol*. Grapevines were cultivated in a tunnel without a foundation, and therefore, precipitation still affected the soil moisture regime within the tunnel. This can be explained by the fact that water in the soil moves not only vertically but also horizontally due to soil capillarity, porosity, and gradients in water potential. Consequently, rainfall outside the tunnel can spread laterally into the root zone soil, particularly in soils with good hydraulic conductivity and favourable structure. Therefore, the vine plants did not need fertilizers, or additional irrigation. At the beginning of *veraison*, leaves were removed from the cluster zone. In all vineyards, leaf removal was performed both below the grape clusters and on the side opposite to the clusters, in order to improve air circulation, enhance sunlight exposure, and reduce the risk of fungal diseases.

The experimental grapevine cultivars were as follows: ‘Solaris’, ‘Regent’, ‘Leon Millot’, ‘Cabernet Cortis’, and ‘Marquette’. Harvest dates differed among cultivars and were determined by monitoring the °Brix level of grape samples collected from the vineyard using a portable refractometer. Harvest was carried out once the °Brix value had stabilized and showed no further significant increase. The grapes for the experimental wines were picked in the morning in mid-September, and the berries were crushed and destemmed with a destemmer on the day of harvest. The resulting juice had the soluble solids content as follows: ‘Solaris’, ‘Regent’, and ‘Leon Millot’ 16 °Brix; ‘Cabernet Cortis’ and ‘Marquette’ 23 °Brix. Total acids contents were: ‘Solaris’ 6.8, ‘Regent’ 8.8, ‘Leon Millot’ 9.4, ‘Cabernet Cortis’ 8.5 and ‘Marquette’ 8.7 g L^{-1}, and pH: ‘Solaris’ 3.07, ‘Regent’ 3.01, ‘Leon Millot’ 3.25, ‘Cabernet Cortis’ 3.08 and ‘Marquette’ 3.20. Dried active yeast of the *Saccharomyces cerevisiae* strain was added to the musts according to commercial specifications. Fermentation with skins and seeds took place over seven days (including Solaris but excluding Cabernet Cortis rosé wine), with cap punching performed four times a day. For the production of Cabernet Cortis rosé wine, the maceration time was limited to 24 hours only. Pressing of all treatments was carried out using a 20 L stainless steel water-pressure press. Further fermentation and maturation were conducted in 100 L stainless steel tanks with floating lids at a temperature of 18–20 °C. To enhance the final alcohol concentration (excluding ‘Cabernet Cortis’ and ‘Marquette’), glucose was added prior to fermentation, based on findings that *Saccharomyces cerevisiae*, including commercial oenological strains, preferentially metabolizes glucose over other sugars due to its efficient uptake and rapid conversion via glycolysis (Berthels et al., 2004). Glucose was added based on the °Brix reading separately for each cultivar, and all wines were fermented to dryness (reducing sugar

< 4 g L^{-1}). No malolactic fermentation was carried out. The finished young wine was used for instrumental analysis four months later. The alcohol content was: 'Solaris' 9.8, 'Regent' 9.8, 'Leon Millot' 10.8, 'Cabernet Cortis' 10.7 and 'Marquette' 12.7%.

Chemical analyses

The analysis of different organic acids in the tested wines was performed in three replicates. For the measurement of total acids, malic and tartaric acids, the wine samples were carried over to the 5 ml syringe and injected into the flow system, and scanned using a horizontal platinum diamond attenuated total reflectance (ATR) single reflection sampling module cell mounted in a Bruker Alpha FT-IR Wine analyzer (Bruker Optics GmbH, Ettlingen, Germany). Before scanning, wine samples were automatically stabilized in the cell at 40 °C as recommended by the manufacturing company with reference background spectrum recorded between different samples using deionised water. The ATR-NIR spectra were recorded by OPUS software version 7.5 provided by Bruker Optics (Bruker Optics GmbH, Ettlingen, Germany). The spectrum of each sample was obtained by taking the average of 120 scans. The maximum deviation from average of IR-analysis for prediction for total acid was ± 0.5 (g L^{-1}), malic acid ± 0.6 (g L^{-1}), tartaric acid ± 0.3 (g L^{-1}) and pH ± 0.12.

Weather Conditions

To characterize the weather conditions during the grapevine growing season (May–September) in Southern Estonia in 2023, temperature and precipitation data were presented alongside the 1991–2020 long-term average (Fig. 1 and Fig. 2; Estonian Environment Agency, 2025). The average temperature in May was 11 °C, which is exactly the same as the long-term average, but May was the most extreme month, with a minimum temperature of -6 °C, which is unusually cold for spring (Fig. 1).

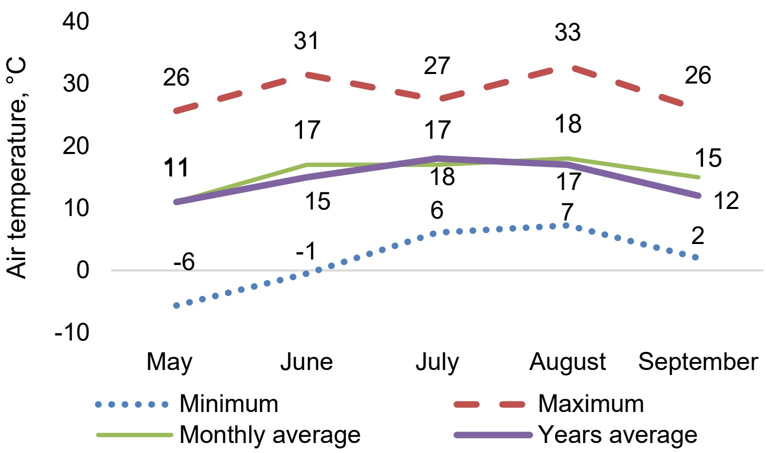

Figure 1. Monthly average, minimum and maximum air temperature (°C) from May to September 2023 in South Estonia, compared to the average of many years (1991–2020).

It was warmer than average during the ripening of the berries - the monthly average temperature in August was 18 °C, which is 1 °C higher than the long-term average of 17 °C, and in September 15 °C, which is 3 °C higher than the long-term average of

12 °C. The maximum temperatures during summer were consistent, ranging from 27 °C to 33 °C. September was still warm - the minimum temperature was 2 °C, suggesting cool nights, but the maximum reached 26 °C, which is quite warm considering early autumn. In general, it can be concluded that the weather in 2023 was highly variable, especially in spring. May was very cold and unstable, summer months were generally warm, and August was the warmest.

Spring and early summer (May and June) were unusually dry, with significantly less rainfall than average (Fig. 2). July was exceptionally wet, experiencing nearly twice the normal rainfall. August was near normal, and September was slightly drier than usual. Overall, 2023 had inconsistent precipitation patterns, with a very dry start, a wet mid-summer, and a slightly drier-than-normal early autumn.

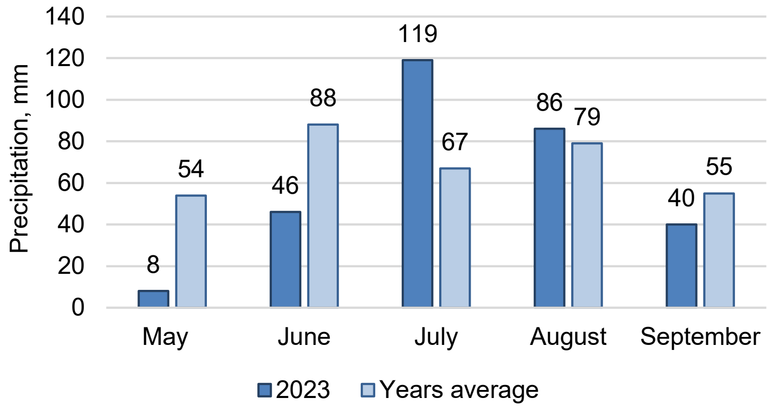

Figure 2. Monthly total precipitation (mm) from May to September 2023 in South Estonia, compared to the average of and many years average (1991–2020).

Statistical Analysis

The results in figures were represented as three replicates means ± standard deviations. One-way analysis of variance (ANOVA) was performed to evaluate the existence of differences between experimental wines′ acids. The coefficient of determination (R^2) was used to explain how much the variation in the dependent variable (acids, pH) can be explained by the independent variable (wines′ cultivar). Comparison of means was done by using Fisher's Least Significant Difference (*LSD*) test to confirm the statistically significant differences. Different letters in the figures indicate statistically significant differences ($p \leq 0.05$).

RESULTS AND DISCUSSION

The malic acid content in different wines revealed significant variation among them (Fig. 3). The lowest malic acid concentration was observed in Marquette (0.3 g L^{-1}), whereas Leon Millot wine exhibited the highest content (4.4 g L^{-1}). The other wines fell within this range, with Solaris containing 2.4 g L^{-1}, Cabernet Cortis 2.9 g L^{-1}, and Regent 3.7 g L^{-1}. The coefficient of determination (R^2 = 0.87) indicates a strong correlation within the dataset, suggesting reliable variability in malic acid content across different wines.

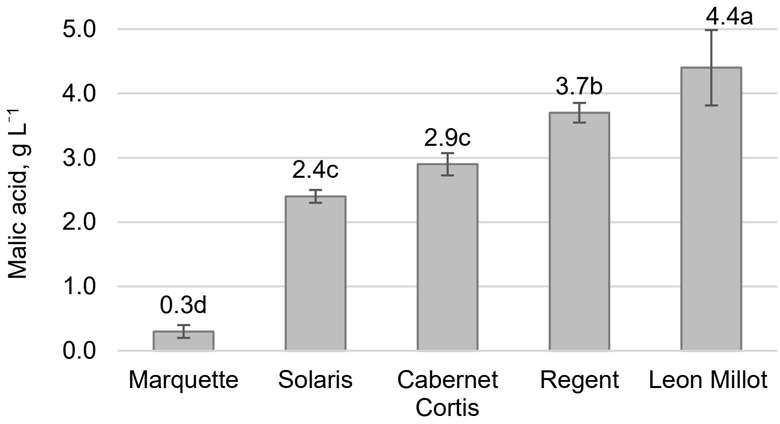

Figure 3. Effect of grapevine cultivar on malic acid content (g L^{-1}) in wine. Different letters present statistically significant differences at $p \leq 0.05$.

The tartaric acid concentrations varied among the tested wines (Fig. 4). The lowest level was detected in Leon Millot (2.2 g L^{-1}) and Solaris (2.5 g L^{-1}) whereas the highest was found in Regent (4.1 g L^{-1}), followed by Cabernet Cortis (3.7 g L^{-1}), and Marquette (3.6 g L^{-1}) wines. The R^2 value (0.96) suggests that 96% of the variation in tartaric acid content can be explained by cultivar differences.

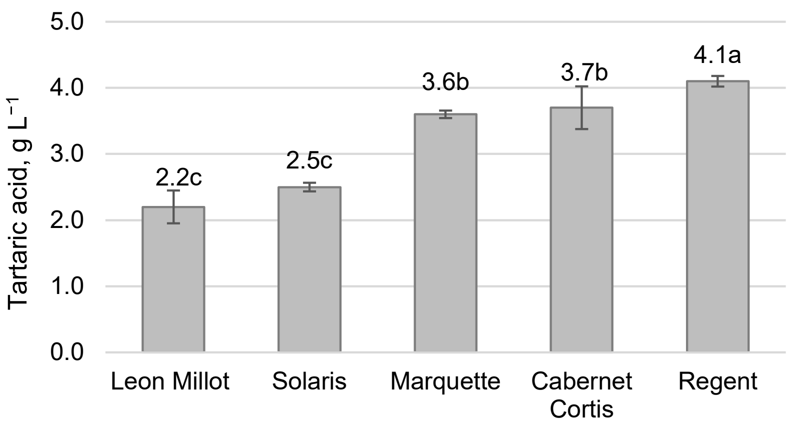

Figure 4. Effect of grapevine cultivar on tartaric acid content (g L^{-1}) in wine. Different letters present statistically significant differences at $p \leq 0.05$.

Citric acid concentrations in wines were generally lower than malic and tartaric acid levels, but substantial variation was observed (Fig. 5). The lowest concentrations were recorded in Marquette (0.13 g L^{-1}) and Regent (0.14 g L^{-1}), whereas Cabernet Cortis contained 0.36 g L^{-1}. Higher concentrations were observed in Leon Millot (0.70 g L^{-1}), with Solaris showing the highest level (1.44 g L^{-1}). The cultivar effect on citric acid content was highly significant: 87% of the variation in total acids content could be explained by cultivar characteristics.

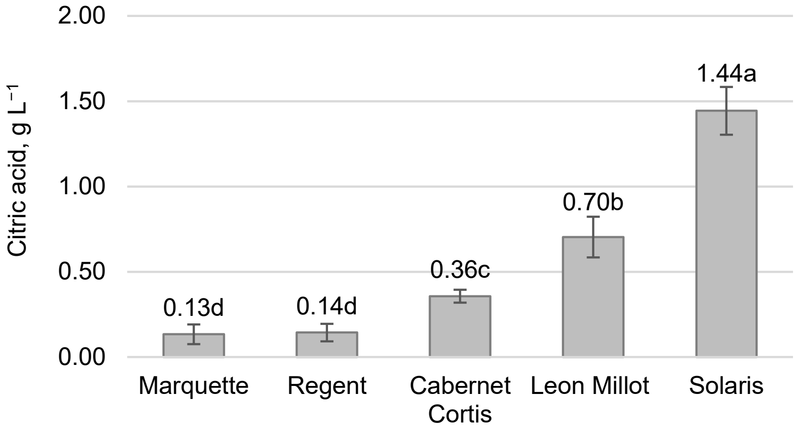

Figure 5. Effect of grapevine cultivar on citric acid content (g L^{-1}) in wine. Different letters present statistically significant differences at $p \leq 0.05$.

The results indicate significant variation in lactic acid concentration depending on the grape cultivar of wine (Fig. 6). Among the wines studied, Marquette exhibited the highest lactic acid concentration (2.27 g L^{-1}), which was considerably higher than the other wines. The lactic acid contents of the Leon Millot (0.52 g L^{-1}) and Regent (0.32 g L^{-1}) were similar, and Regent did not differ from the Solaris and Cabernet Cortis. The R^2 for the dataset was 0.98, indicating a very strong correlation between the observed values. This suggests that cultivar explains most of the variation in the lactic acid content.

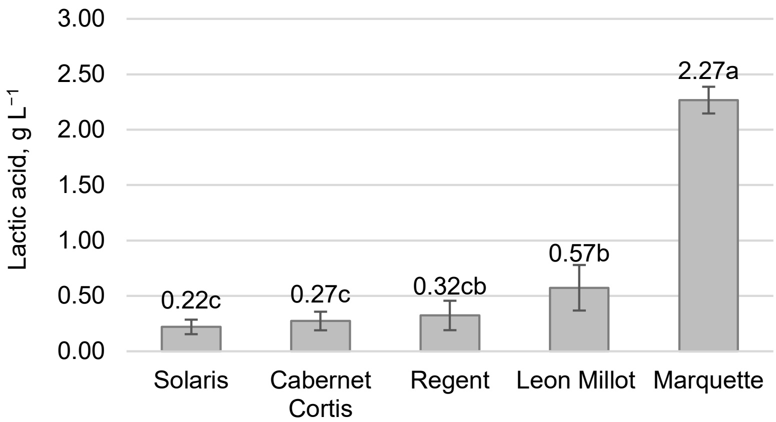

Figure 6. Effect of grapevine cultivar on lactic acid content (g L^{-1}) in wine. Different letters present statistically significant differences at $p \leq 0.05$.

The total acidity of the analyzed wines varied from 6.9 g L^{-1} in wine Marquette to 9.4 g L^{-1} in Leon Millot, which did not differ significantly from the wines Cabernet Cortis and Regent (Fig. 7). Intermediate value was recorded for Solaris (7.8 g L^{-1}). The R^2 value (0.87) in this dataset indicates that 87% of the variation in total acid content can be explained by cultivar differences.

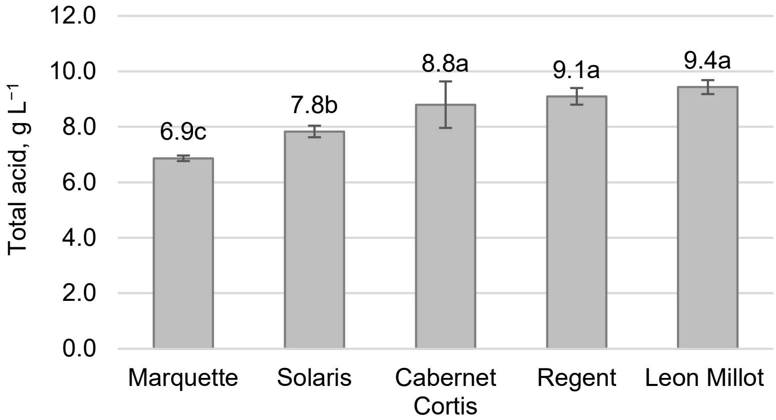

Figure 7. Effect of grapevine cultivar on total acid content (g L^{-1}) in wine. Different letters present statistically significant differences at $p \leq 0.05$.

The pH values of the analysed wines ranged from 2.9 to 3.3, indicating differences in acidity levels among the wine samples (Fig. 8). The lowest pH (2.9) was observed in Cabernet Cortis and Regent, suggesting a higher perceived acidity. Solaris and Marquette had similar pH values, whereas Marquette was similar to the wine Leon Millot (3.3). An R^2 of 0.76 indicates a moderately strong relationship between cultivar and pH level.

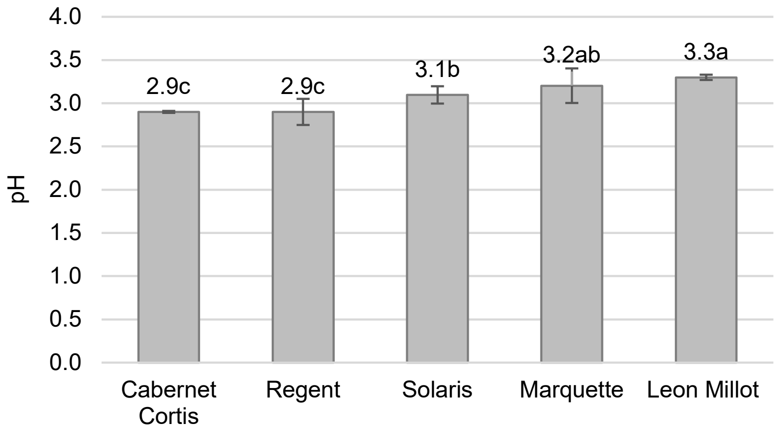

Figure 8. Effect of grapevine cultivar on pH in wine. Different letters present statistically significant differences at $p \leq 0.05$.

The results of this experiment illustrate the distinct acid profiles of the tested wines, which can significantly impact wine stability and aging potential. Acid content and pH play an important role in the sensory properties and equilibrium of wines (Comuzzo et al., 2019). At high pH values, red wines are naturally less protected against oxidation and are less stable (Forino et al., 2020). Meanwhile, tartaric acid, a key factor in wine acidity, exhibits notable differences that could affect overall sensory perception. Due to its stability and the fact that yeast and other microorganisms are unable to metabolize tartaric acid, it is the most commonly used acid for pH adjustment in the wine industry

(Volschenk et al., 2006). Tartaric acid levels in the tested wines ranged from 2 to 4 g L^{-1}, which is also common in wines from warmer climates (Ribéreau-Gayon et al., 2006).

In cooler climates, however, malic acid can become a problem. Under very cool climate conditions, malic acid can comprise up to 50% of the total acidity because malic acid-related respiration is slower at lower temperatures (Volschenk et al., 2006). According to Ribéreau-Gayon et al. (2006), the malic acid content in wines can reach up to 4 g L^{-1}. Based on this, it can be concluded that only Leon Millot wine had high total acidity (9.4 g L^{-1}) with a dominance of malic acid (4.4 g L^{-1}). Previous experiments in Estonia have shown that the cultivation method (either open field or tunnel) also has a significant effect, and malic acid levels were at an appropriate level in tunnel-grown grapes of 'Rondo' (Maante-Kuljus et al., 2019a). In Estonia, the temperature in high plastic tunnels for viticulture has been 2–4 °C higher than in the open field (Maante-Kuljus et al., 2019b) The tested wines in this study were all made from berries grown in a tunnel, and the weather in the tested year also had an impact - it was warmer than the average of many years, during the berry ripening period in August and September. In Estonia, a major viticultural challenge is early spring warming followed by late spring frosts, which can severely damage fruit-bearing shoots and subsequently affect both vine growth and berry ripening. During the experimental vintage, night frosts in spring reached as low as –6 °C, significantly delaying the onset of vine growth. However, the test year were distinguished by a warmer and drier September than average for many years, which positively affected grape ripening. For all cultivars, leaf removal was also performed around the grapes, which further enhances sunlight exposure and increases berry temperature. The breakdown of malic acid begins once sugar accumulation starts and is more pronounced at higher temperatures (Rienth et al., 2016). Therefore, the late summer weather has a significant impact on the malic acid content.

The variation in malic and citric acid content suggests differences in metabolic pathways among the tested wines, which may influence their suitability for malolactic fermentation. At the beginning of the production of Marquette wine, the initial acid content of the must was high, 8.7 g L^{-1}, but after fermentation 6.9 g L^{-1}. The wine had an extremely low malic acid content (0.3 g L^{-1}) and a high tartaric acid content (3.6 g L^{-1}), meaning it is naturally stable and smooth. However, this tested wine had a very high lactic acid content (2.2 g L^{-1}), suggesting that most of the malic acid may have been metabolized during fermentation, possibly due to spontaneous malolactic fermentation. When only alcoholic fermentation occurs, lactic acid levels in the wine remain low, typically below 0.3 g L^{-1} (Bauer et al., 2005), as the conversion of malic acid to lactic acid has not taken place. Malolactic fermentation is recommended for wines with very high malic acid levels. For example, if the malic acid level is 9.5 g L^{-1}, successful malolactic fermentation can significantly reduce malic acid levels, often by more than 80% (Lasik-Kurdyś et al., 2017).

The pH of the grape juice across different cultivars ranged from 3.0 to 3.2, and that of the corresponding wines from 2.9 to 3.3. The common pH range of wines is between 3 and 4, and pH measurement is also important because, at high pH values, wines are naturally less protected against oxidation and are less stable (Forino et al., 2020). A significant drop in anthocyanin solubility was observed at pH 3.3, indicating that the red tested wines also have good colour stability. Wines with high acidity typically have low pH values, and this is because organic acids, such as tartaric and malic acids, contribute to the overall acidity of the wine, thereby lowering the pH (Vilela, 2019). Cabernet Cortis and Regent wines exhibited the lowest pH (2.9), indicating a higher total acid content. However, this relationship was not observed in all wines. For example, Leon Millot wine had a high acid content but also a higher pH value, which was influenced by its higher malic acid content. Previous wine analyses have shown that different organic acids have varying strengths and buffering capacities (Picariello et al., 2019; Gancel et al., 2022). Therefore, pH is not always directly related to acid content, making it important to consider multiple acidity indicators.

CONCLUSIONS

These findings highlight the distinct acid profiles of test wines made from different grape cultivars grown in Estonia, allowing predictions about their stability and suitability for aging. The hypothesis was not confirmed, as excessive acid content did not become a problem in common commercial single-cultivar wines produced in Estonia, in a very cool climate condition. However, it should be noted that the hypothesis does not hold if the grapes used for winemaking are grown in high plastic tunnels.

Based on the grape cultivars of tested wines, the following conclusions can be drawn regarding wine acidity:

- Cabernet Cortis and Regent wines exhibit high acid content and relatively low pH, suggesting a fresh, crisp taste. Leon Millot wine has high total acid content, dominated by malic acid. These wines may benefit the addition of oak chips to soften acidity.
- Solaris wine has balanced acidity, moderate pH, and high citric acid content, making it a well-structured wine with potential for both freshness and stability.
- Marquette wine is naturally smooth, with very low malic acid content, indicating spontaneous malolactic fermentation.

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