

# Assessing Estonia's viticultural potential based on the compositional analysis of sugars and acids of wine grape cultivars

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The primary objective of this study was to assess Estonia's potential for viticulture through the calculation of the Heliothermal Index and analysis of its 20-year dynamics. The secondary objective was to determine the variability in grape sugars and acids composition depending on vintage (2023, 2024) and cultivar characteristics in 'Solaris', 'Regent', 'Leon Millot', 'Cabernet Cortis', 'Marquette', 'Hasansky Sladky', 'Zilga', and 'Rondo'. Over the twenty years, the Heliothermal Index ranged from 872 to 1622, showing a warming trend with implications for viticultural potential. Fructose content in grapes ranged from 72 to 98 g l<sup>-1</sup>, with 'Marquette' having the highest and 'Zilga' the lowest. Glucose content was lowest in 'Zilga' (64 g l<sup>-1</sup>) and highest in 'Marquette' (98 g l<sup>-1</sup>). 'Zilga' had the highest tartaric acid content (5.9 g l<sup>-1</sup>), while 'Leon Millot' (3.5 g l<sup>-1</sup>), and 'Regent' (3.7 g l<sup>-1</sup>) had the lowest. 'Hasansky Sladky' had the highest malic acid content (5.5 g l<sup>-1</sup>), while 'Regent' (2.1 g l<sup>-1</sup>) and 'Solaris' (2.5 g l<sup>-1</sup>) had the lowest. The study confirmed that the tested cultivars are suitable for producing dry wine in Estonia, which belongs to EU viticulture zone A.

**Key words:** total sugars, fructose, glucose, total acid, tartaric acid, malic acid

## Introduction

Climate and weather are key factors influencing wine grape growing conditions. Various viticultural climatic indices, formulated from these variables, have been used in many regions to describe vineyard climates. Based on different weather data, studies indicate that it is now possible to cultivate vines in the Baltic Sea region using several early-ripening *Vitis vinifera* and hybrid cultivars (Karvonen 2014a, 2014b). In cool-climate regions, the most significant positive trends have been observed in the Huglin and Winkler indices, while less significant trends appear in the Cool Night, Latitude-Temperature, and Temperature-Variability indices (Jones 2018). Estonia has been recognized as an emerging very cold-climate region, where climatic conditions, particularly rising temperatures, are gradually altering growing conditions (Maante-Kuljus et al. 2019a). In Estonia, the Heliothermal Index (HI) has been  $\leq 1500$  in most years. Under such climatic conditions, certain regions cultivate interspecific hybrids or American *Vitis* species, which are more cold-resistant than *Vitis vinifera*, and only very early or early-ripening cultivars are capable of reaching full maturity.

Although Estonia is not widely known for grape cultivation due to its northern climate, interest in viticulture is increasing 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). However, Estonian wines remain largely unknown internationally due to the smallness of the country, and the viticulture for wine is at the very beginning of its development. Producers of commercial wine in Estonia are organized under the Estonian Wine Trail association (<https://veinitee.ee/en/home/>), which currently includes 26 wineries. The majority of production focuses on fruit and berry wines. Seven producers operate their own vineyards, while several others purchase wine grapes from growers who do not produce wine themselves. The annual wine (from grapes) production by members of the Estonian Wine Trail has typically been around 6000 liters. However, due to spring frosts, the production in 2024 dropped to just 3500 liters.

New vineyards are being established, and a significant increase in production is expected in the coming years. The grape cultivars grown in Estonia are typically winter-hardy cultivars capable of withstanding harsh winters and a short growing season. These are often hybrids specifically bred for cooler climates. In production areas, the most common cultivar is 'Solaris' (43% of the total number of plants), which is primarily grown in high plastic tunnels.

Other common cultivars include ‘Rondo’ (21%), ‘Zilga’ (10%), and ‘Hasansky Sladky’ (7%). Less commonly grown cultivars include ‘Frühburgunder,’ ‘Regent,’ ‘Cabernet Cortis,’ ‘Cabernet Noir,’ ‘Leon Millot,’ and ‘Müller-Thurgau’. Among these, only ‘Zilga’ and ‘Hasansky Sladky’ are commonly grown in open fields, as they have proven to be the most winter-hardy. Winter-hardy grapevines are primarily interspecific hybrids of *V. vinifera* with *V. labrusca* and *V. riparia*, giving them a chemical composition distinct from that of *V. vinifera* cultivars traditionally used for winemaking. This difference limits the applicability of existing knowledge in assessing grape maturity in very cool-climate conditions.

Technological parameters—such as total soluble solids (estimated sugar content), pH, and total acidity—serve as essential indicators for maturity assessment in cool climates. Grape’s ripening is characterized by a rapid accumulation of sugars and a decline in malic acid levels (Colak and Bengu 2024), with the timing and extent of these changes varying considerably depending on cultivar, climate, soil, and viticultural practices (van Leeuwen et al. 2023). Tartaric and malic acids are the most abundant organic acids in grapes, generally accounting for 62–92% of total organic acids (Kliewer 1966, Kupe et al. 2021). Studies have shown that the concentrations of tartaric and malic acids in grapes vary considerably between years, typically ranging from about 1 to 10 g l<sup>-1</sup> across different seasons (Kunter et al. 2024). The malic acid content tends to be higher in cool-climate regions, and lower in warmer regions (Volschenk et al. 2006, Conde et al. 2007). In cooler regions, cultivar selection and viticultural practices have been focused on achieving high sugar concentrations, which are considered beneficial for wine quality. However, the quality of some vintages in cool climates has not always been satisfactory due to low sugar content and high acidity (Gustafsson and Mårtensson 2005, Gaštoł 2015). Organic acids exhibit a strong vintage effect, with cool vintages associated with higher organic acid concentrations (Wang et al. 2025). The minimum maturation level achieved by most *V. labrusca* and hybrid grapes has been relatively low, with 44% of samples showing soluble solids content below 16 °Brix (Spinelli et al. 2024). Hybrid cultivars between *V. labrusca* and *V. vinifera* have been found to contain significantly higher total soluble sugars and fructose, as well as lower total acids and malic acid, compared to *V. vinifera* cultivars (Liu et al. 2006).

In Estonia, previous studies have shown that must soluble solids of grapes tend to be relatively low, while total acid content tend to be high. These characteristics have been significantly influenced by cultivar properties, different growing techniques, and weather conditions (Maante-Kuljus et al. 2015, 2019a, 2019b). In previous studies, the focus has been on total acidity, but for winemaking, the content of individual acids is also important. Under cool climate conditions, a common issue has been the high content of malic acid. The malic acid level can be adjusted through winemaking techniques, such as malolactic fermentation. Therefore, it is essential to understand the full acid profile. The concentrations of glucose and fructose in grapes are the primary determinants of the final alcohol content in wine. If the sugar content is too low for achieving proper wine alcohol content, it can be increased through the addition of sugars, which is permitted under EU legislation for wine-growing zone A.

Based on the above, it can be assumed that due to general climate warming, the climatic conditions in Estonia are becoming more suitable for viticulture. However, there is limited experience with different hybrid cultivars. The primary objective of this study was to assess Estonia’s potential for viticulture through the calculation of the Heliothermal Index and analysis of its 20-year dynamics. The secondary objective was to assess the variability in sugar (total sugars, fructose, and glucose) and acid (total acids, tartaric acid, and malic acid) composition depending on vintage and cultivar characteristics in widely cultivated grape cultivars such as ‘Solaris,’ ‘Regent,’ ‘Leon Millot,’ ‘Cabernet Cortis,’ ‘Marquette,’ ‘Hasansky Sladky,’ ‘Zilga,’ and ‘Rondo’ grown in production vineyards in Estonia.

## Material and methods

### Experimental sites and plant material

The grapes for the experiment were harvested from various vineyards in South Estonia (from open field 58° 21′ 27″ N, 26° 31′ 16″ E, and tunnel 57° 55′ 24″ N, 26° 43′ 9″ E; 58°17′00.6″N 26°33′47.2″E; 57°58′58.4″N 26°34′03.8″E) during 2023 and 2024. Most of the cultivars were grafted onto SO4 rootstock, except for ‘Zilga’ and ‘Hasansky Sladky’, which were grown as own-rooted. In each vineyard, the vines were trained using a low double-trunk trellis system with spur pruning with 12 buds left per plant. Additionally, at the beginning of grape coloration, leaves were removed from the cluster zone. The vine rows were oriented from north to south, the ground was covered with woven ground cover fabric, and no additional irrigation system was used. The vineyards soil was high-productivity sandy loam *Haplic luvisol*, with a soil fertility rating of 45–50 on a 100-point scale.

The harvest time for grapes was determined according to the regular soluble solids (°Brix) measurement, and the grapes were harvested when the soluble solids content of each tested cultivar reached a plateau and did not rise any longer. For the analysis, the first cluster from the lower part of the shoots was collected on the day of harvest in mid-September. A total of 12 clusters were collected from 15 plants of each cultivar. Experimental wine cultivars and species in pedigree: ‘Solaris’ (*V. vinifera*, *V. amurensis*), ‘Regent’ (*V. vinifera*, *V. amurensis*), ‘Leon Millot’ (*V. vinifera*, *V. riparia*), ‘Cabernet Cortis’ (*V. vinifera*, *V. amurensis*), ‘Marquette’ (*V. vinifera*, *V. riparia*), ‘Hasansky Sladky’ (*V. vinifera*, *V. amurensis*), ‘Zilga’ (*V. vinifera*, *V. labrusca*), and ‘Rondo’ (*V. vinifera*, *V. amurensis*).

## Measurements and analysis

The Heliothermal Index was calculated using the following expression (Huglin 1978):

$$HI = \sum_{Mi}^{Mf} \left[ \frac{(T - 10) + (T_{max} - 10)}{2} \right] * d$$

where “T” and “Tmax” are, the average mean and maximum monthly temperature (°C), respectively; “Mi” and “Mf” are the initial and the final month of the period, respectively; “d” is the length of day coefficient, with value of 1.09 for latitudes 58°.

For the measurement of total sugars, fructose and glucose, and total acids, malic and tartaric acids, the frozen (−20 °C) grape samples were thawed at room temperature until manual juice pressing was possible. The obtained juice was carried over to the 5 ml syringe. Juice samples were 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, juice 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 accuracy of prediction for malic acid was ±0.6 (g l<sup>-1</sup>) and tartaric acid ±0.3 (g l<sup>-1</sup>). The accuracy of prediction for glucose was ±0.9 (g l<sup>-1</sup>), for fructose ±0.8 (g l<sup>-1</sup>), and for total sugars ±1.7 (g l<sup>-1</sup>).

## Weather conditions

In both experimental years, the coolest months were May and September, with night frosts occurring in May (Fig. 1A). However, September was warmer than the average for many years. In 2023, the warmest month was August, with an average air temperature of 18 °C, whereas in 2024, the warmest month was July, with an average air temperature of 19 °C. However, the maximum recorded temperature in July reached 34 °C. July was the rainiest month, while September 2024 experienced drought conditions (Fig. 1B). According to Heliothermal Index, Estonia is located in a very cool, and in some years, it is considered a cool region (Maante-Kuljus et al. 2019a).

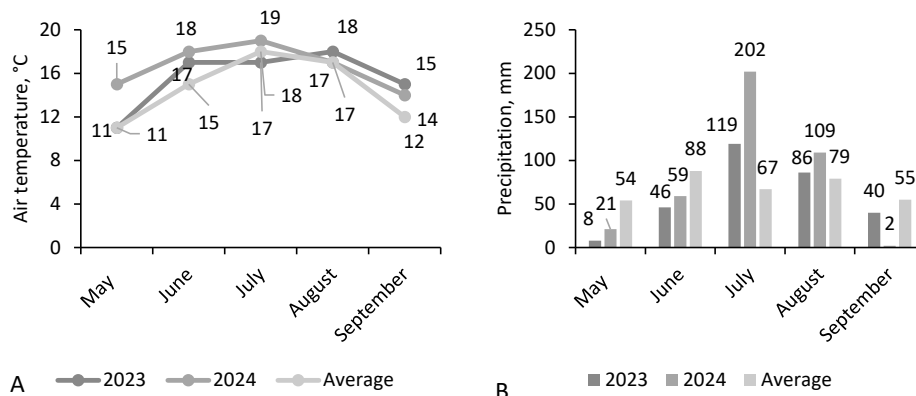


Fig. 1. A Monthly average air temperature (°C); B Monthly total precipitation (mm) and average of many years (1991–2020) from May to September in 2023 and 2024

## Statistical analysis

In the experiment, the influencing factors were cultivar and vintage; therefore, a two-factor analysis of variance (ANOVA) was used for data analysis. The coefficient of determination was used to explain how much the variability of one factor was caused by its relationship to another factor. Mean comparisons were conducted using Tukey honest significance difference test ( $p < 0.05$ ) to confirm statistically significant differences between vintages or cultivars. The results in the figures are presented as means of three replicates, and standard deviation are added. Different letters and asterisks in the figures indicate statistically significant differences between means.

## Results

Heliothermal Index ranged from 872 to 1622 in the years from 2004 to 2024, and in experimental years from 1400 to 1622 (Fig. 2). The trend line shows warming, but Heliothermal Index had large variability between test years.

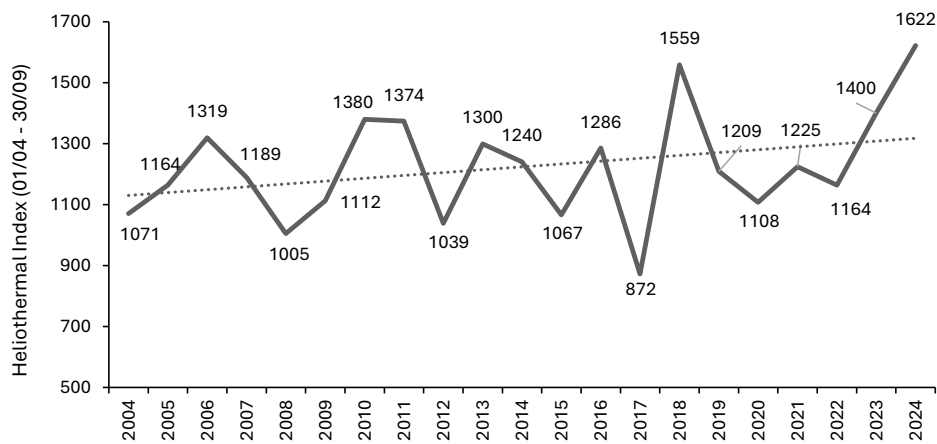
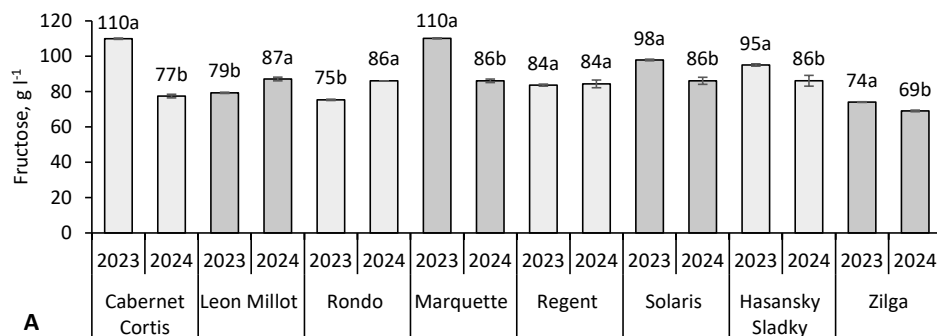


Fig. 2. Heliothermal Index and trend line for the years from 2004 to 2024. Data is according to the Estonian Environment Agency's Tõravere weather station.

The fructose content was consistent across the trial years only in the 'Regent' (Fig. 3A). For the other cultivars, the vintage effect was significant. The 'Leon Millot' and 'Rondo' had higher fructose content in 2024, while the other cultivars had higher levels in 2023. The average in fructose content across the two vintages for the trial cultivars ranged from 72 to 98 g l<sup>-1</sup>, with the cultivar having a significant effect (Fig. 3B). The cultivar 'Marquette' had the highest fructose content, and 'Zilga' had the lowest. The vintage effect was also significant, with the 2023 vintage having higher fructose content.



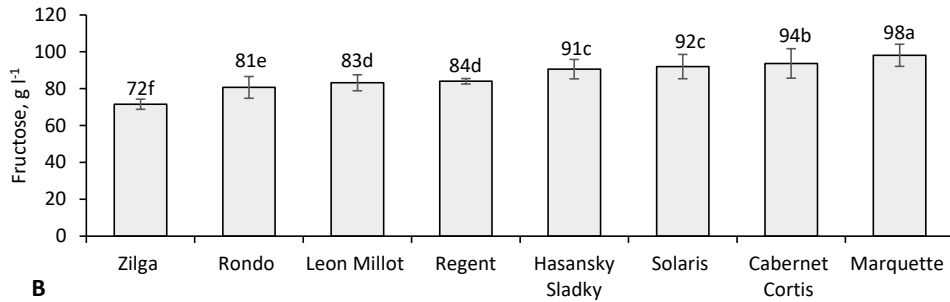


Fig. 3. The fructose content ( $\text{g l}^{-1}$ ) in grape cultivars for the years 2023 and 2024 (A), and as the two-year average (B). Different letters denote significant differences.

The vintage affected the glucose content (Fig. 4A). The ‘Cabernet Cortis’ and ‘Marquette’ had higher glucose content in 2023, while the ‘Leon Millot’, ‘Rondo’, and ‘Hasansky Sladky’ showed lower levels. There was no vintage effect on the ‘Regent’, ‘Solaris’, and ‘Zilga’. As two-year average significant differences were observed between the cultivars (Fig. 4B). The ‘Zilga’ had the lowest glucose content ( $64 \text{ g l}^{-1}$ ), while ‘Marquette’ had the highest ( $98 \text{ g l}^{-1}$ ). The ‘Rondo’, ‘Leon Millot’, and ‘Hasansky Sladky’ had similar glucose content.

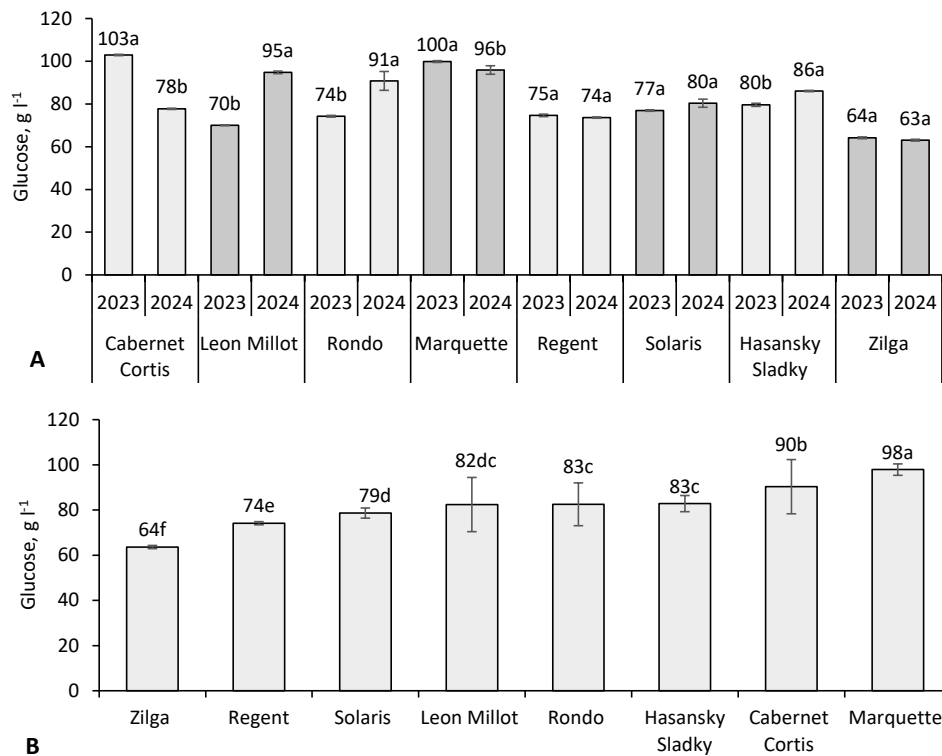


Fig. 4. The glucose content ( $\text{g l}^{-1}$ ) in grape cultivars for the years 2023 and 2024 (A), and as the two-year average (B). Different letters denote significant differences.

The vintage significantly affected the total sugars content in the cultivars of ‘Cabernet Cortis’, ‘Leon Millot’, ‘Rondo’, ‘Marquette’, ‘Hasansky Sladky’, and ‘Zilga’, although the direction of the effect varied (Fig. 5A). In 2023, the highest sugar content was observed in the ‘Cabernet Cortis’, ‘Marquette’, and ‘Zilga’, while in 2024, the highest sugar content was estimated in the ‘Leon Millot’, ‘Rondo’, and ‘Hasansky Sladky’. Significant differences between vintages were not found for the ‘Regent’ and ‘Solaris’.

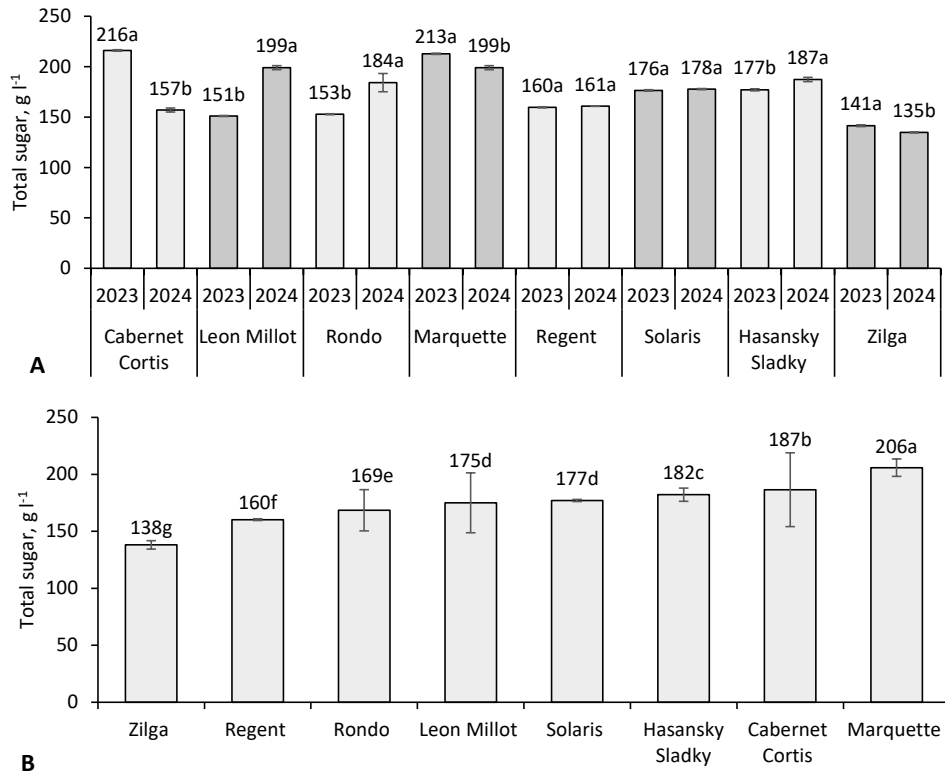
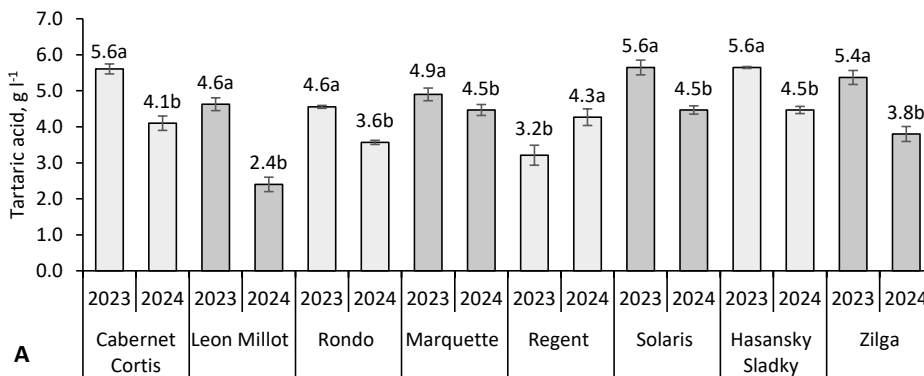


Fig. 5. The total sugars content ( $\text{g l}^{-1}$ ) in grape cultivars for the years 2023 and 2024 (A), and as the two-year average (B). Different letters denote significant differences.

The average sugar content in the berries over the two years showed considerable variability between cultivars, ranging from 138 to 206  $\text{g l}^{-1}$  (Fig. 5B). Significant differences were found between cultivars, with the 'Marquette' having the highest sugar content, and 'Zilga' the lowest. 60% of the variability in sugar content in the grapes can be explained by the differences between cultivars (determination coefficient 0.6). The interaction between vintage and cultivar (determination coefficient 0.39) showed that 39% of the variability in sugar content is explained by the interaction of cultivar and vintage. This indicates that the sugar content of some grape cultivars was influenced by the specific vintage, while others remained stable across years.

The tartaric acid content in 2023 was higher compared to 2024 in most cultivars, with only 'Regent' showing a higher tartaric acid content in 2024 (Fig. 6A). 'Zilga' ( $5.9 \text{ g l}^{-1}$ ) stood out with significantly higher tartaric acid content, while 'Leon Millot' ( $3.5 \text{ g l}^{-1}$ ) and 'Regent' ( $3.7 \text{ g l}^{-1}$ ) had the lowest value (Fig. 6B).



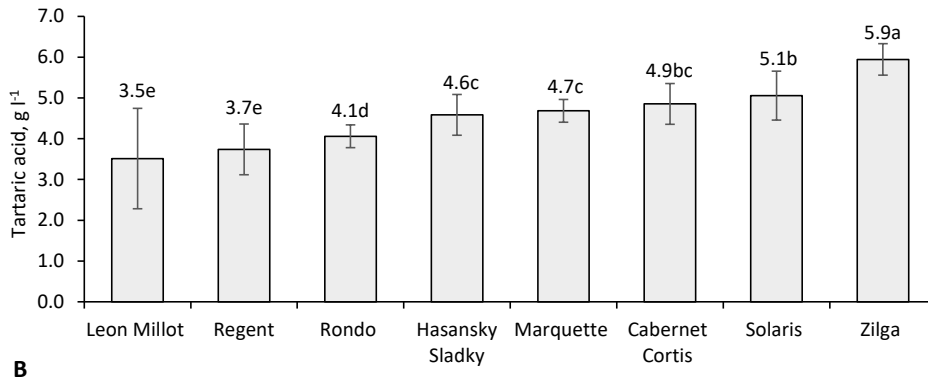


Fig. 6. The tartaric acid content (g l<sup>-1</sup>) in grape cultivars for the years 2023 and 2024 (A), and as the two-year average (B). Different letters denote significant differences.

There were noticeable differences in malic acid content between the vintages for the cultivars (Fig. 7A). In 2023, the ‘Leon Millot’, ‘Rondo’, ‘Regent’, and ‘Hasansky Sladky’ showed higher malic acid content, while ‘Cabernet Cortis’, ‘Solaris’, and ‘Zilga’ had higher values in 2024 compared to 2023. ‘Hasansky Sladky’ (5.5 g l<sup>-1</sup>) stood out with the highest malic acid content, while ‘Regent’ (2.1 g l<sup>-1</sup>) and ‘Solaris’ (2.5 g l<sup>-1</sup>) had the lowest. On average, the malic acid content across cultivars was similar in 2024 compared to 2023 (Fig. 7B).

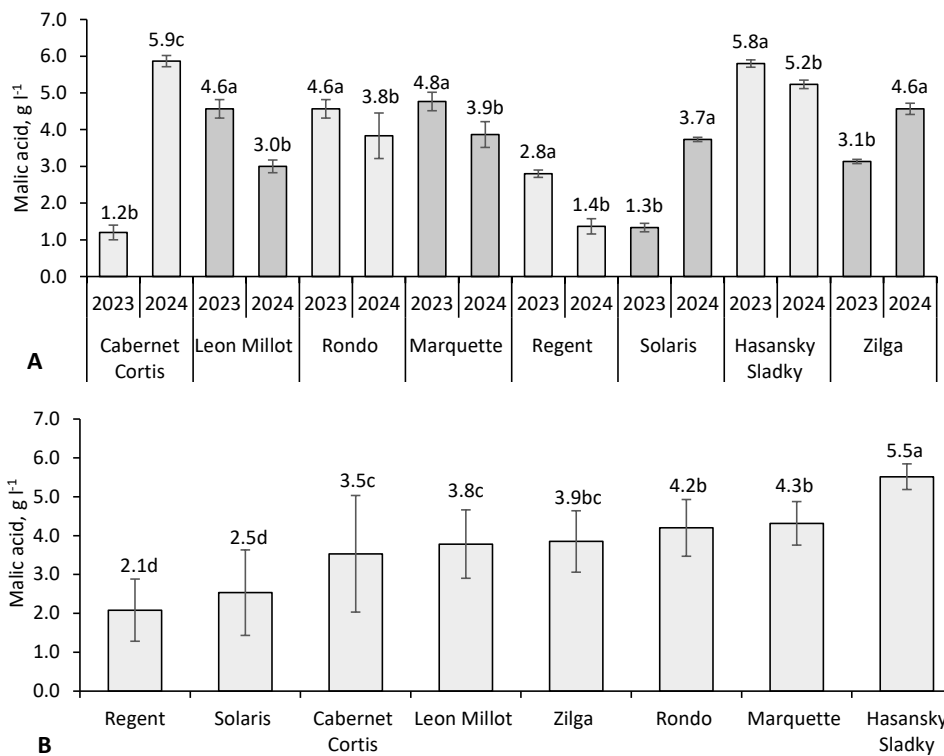


Fig. 7. The malic acid content (g l<sup>-1</sup>) in grape cultivars for the years 2023 and 2024 (A), and as the two-year average (B). Different letters denote significant differences.

The total acid content was higher in the ‘Solaris’ and ‘Zilga’ in 2024, and the most noticeable annual change was observed in the ‘Cabernet Cortis’, where the total acid content increased from 8.5 g l<sup>-1</sup> (2023) to 11.1 g l<sup>-1</sup> (2024) (Fig. 8A). Across the vintage’s, the ‘Rondo’ and ‘Marquette’ had similar acid content.

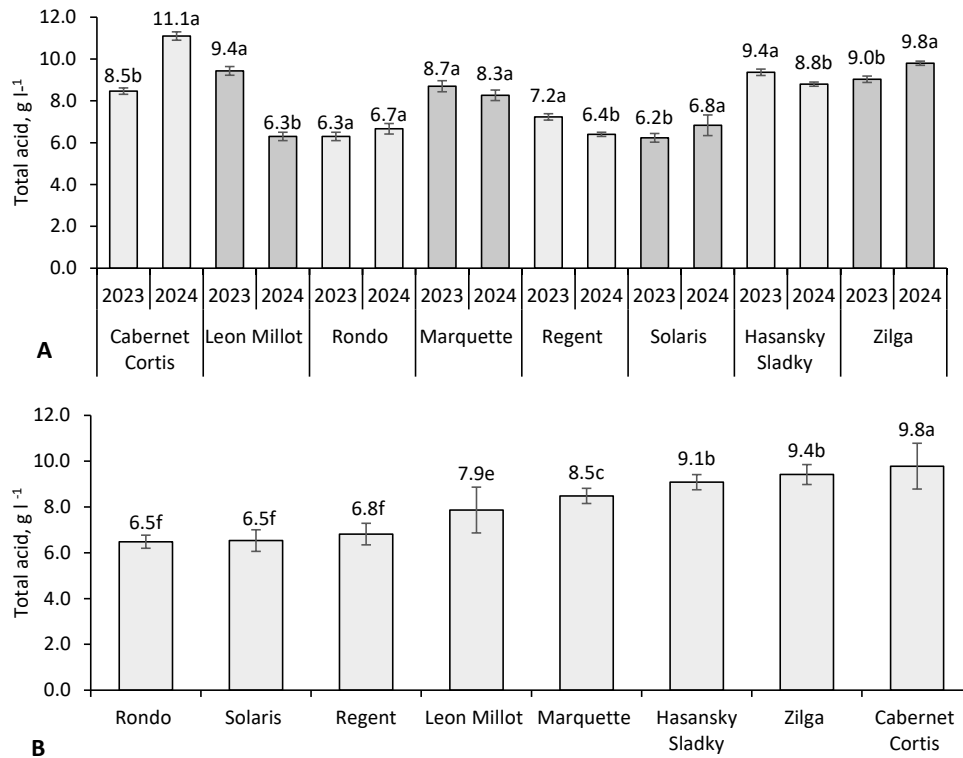


Fig. 8. The total acids content ( $\text{g l}^{-1}$ ) in grape cultivars for the years 2023 and 2024 (A), and as the two-year average (B). Different letters denote significant differences.

The total acid content varied between different grape cultivars (Fig. 8B). The highest acid content was in ‘Cabernet Cortis’ ( $9.8 \text{ g l}^{-1}$ ), followed by ‘Zilga’ ( $9.4 \text{ g l}^{-1}$ ), and ‘Hasansky Sladky’ ( $9.1 \text{ g l}^{-1}$ ). The cultivars with the lowest acid content were ‘Rondo’ ( $6.5 \text{ g l}^{-1}$ ), ‘Solaris’ ( $6.5 \text{ g l}^{-1}$ ), and ‘Regent’ ( $6.8 \text{ g l}^{-1}$ ). The cultivar effect on acid content was highly significant: 71% of the variation in total acids content could be explained by cultivar characteristics (determination coefficient 0.71). The interaction between cultivar and vintage explained 27% of the variation (determination coefficient 0.27).

## Discussion

Over the past 20 years, the HI has been  $\leq 1500$  in most years. However, for the first time, in both 2018 and 2024, the HI exceeded 1500, which would shift Estonia from the very-cold to the cold viticultural region category according to the classification by Tonietto and Carbonneau (2004). These trends indicate significant changes in Estonia’s climate, with important implications for the region’s viticultural potential. In the cold viticultural climate class, the Heliothermal potential allows for a much wider range of grape cultivars, both white and red, to reach full ripeness. If this warming trend continues, it may become possible to grow a greater diversity of grape cultivars in open-field conditions in the future.

In general, summers are becoming warmer, but a significant limiting factor – spring night frosts – remains, which can have a severe negative impact on grape production. In cooler climates, an early spring warming that is followed by late spring frosts can highly likely damage the fruit-bearing shoots, and later also affect the yield and berry ripening (Schrader et al. 2020). A similar effect was observed during the experimental years: late spring frosts in May damaged the shoots, leading to the growth of new shoots from dormant buds. The extent of damage from spring frosts depends on the growth vigor and recovery capacity of the vines. Due to the reasons above, ‘Cabernet Cortis’ and ‘Solaris’ were particularly affected, suffering significant damage from spring frost, which resulted in a considerably lower grape sugar content and a higher acid content in 2024.

The vintage affected the sugar profile of the experimental cultivars differently, as also presented in other experiments. For example, the composition of sugars in grapes remained more stable across years, while acids were sensitive to climate changes (Liu et al. 2006, Preiner et al. 2013). However, at the same time, no significant differences were observed in the malic, citric, and titratable acid, and glucose contents nor changes in the grape pH of

'Vidal' among the three production areas (Yan et al. 2022). Long-term experiments in Estonia have demonstrated a significant effect of the vintage on the grape's maturity, which was associated to the variable weather conditions across the ten years of observations (Maante-Kuljus et al. 2019a). This finding is consistent with other studies showing that a year with increased precipitation and cooler temperatures is characterized by higher organic acid levels, whereas berries from a warmer and drier vintage contain relatively less organic acid (Pereira et al. 2006), due to the increased accumulation of sugars. The test years were distinguished by a warmer and drier September than average for many years, which positively affected grape ripening.

The sugar content was significantly influenced by the cultivar and vintage. The most stable cultivars in terms of sugar content were 'Regent' and 'Solaris'. It has been shown that in general, the sugar content of ripe grapes varies between 150 and 250 g l<sup>-1</sup> (Dharmadhikari 2006). Most of the cultivars studied (except 'Zilga') remained within this range in both years (151–216 g l<sup>-1</sup>). 'Zilga' stood out for its low sugar content, having both the lowest fructose and glucose levels. However, it has also been noted that labrusca-type cultivars should be harvested before full maturity, as wine made from fully ripe berries with high sugar content tends to have a stronger foxy taste (Plocher and Parke 2008). On average, the tested berries contained more fructose than glucose in 2023, but in 2024, glucose and fructose were present at equal levels, which is consistent with findings reported in the literature (Dharmadhikari 2006). At the ripening stage, glucose and fructose are usually present in equal amounts (1:1 ratio), though some variation in the glucose-to-fructose ratio may occur among cultivars. In wine production, analyzing the sugar profile is important, as yeasts generally exhibit a slightly higher preference for glucose than fructose, confirming the glucophilic nature of *Saccharomyces* wine yeasts (Tronchoni et al. 2009).

Grape sugar concentration is the primary determinant of the final alcohol content of wine, and is therefore an important factor in choosing winemaking techniques. The expected ethanol production can be estimated based on the measured sugar concentration, applying the official European conversion ratio of 16.83 g l<sup>-1</sup> of sugar to produce 1% (v/v) ethanol. The average sugar content of the tested grapes ranged from 138 to 206 g l<sup>-1</sup>, from which it can be concluded that the potential alcohol content would be between 8.2% and 12.2%. Sugar supplementation is necessary for 'Zilga', because the alcohol content of the wine should be above 8.5%. For other tested cultivars, this may not be necessary in every year. According to the legislation, sugar may only be added to increase alcohol by up to 3%, so based on the data provided, mainly dry wine can be produced in Estonia. In traditional wine regions, the production of dry wines has become increasingly challenging. For example, Duchêne and Schneider (2005) showed that over the last 30 years, the estimated alcohol level of 'Riesling' grapes in Alsace has increased by 2.5% (v/v) due to warmer ripening periods and earlier phenology. However, the results of this experiment indicate that it is possible to produce dry wine with a lower alcohol content in Estonia, which could be more appealing to consumers.

It is important to note that the composition of organic acids was significantly influenced by vintage, though not for all tested cultivars. The most stable cultivars in terms of acids were 'Rondo' and 'Marquette'. It also became evident that the vintage affected the ripening of most of the tested cultivars, but the direction of this effect varied for each cultivar. Malic acid is the most problematic among the acids, as wines with excessive malic acid can taste aggressively sour and tart. In the tested years, malic acid was lower in 2023, which was affected by significantly warmer weather conditions in August and September. Too high malic acid content can be regulated in winemaking through malolactic fermentation, a process in which malic acid in wine is converted into softer, creamier lactic acid. The experimental results showed that 'Cabernet Cortis' has a low malic acid content in a favorable year, but after spring damage and therefore, late ripening, the content may become higher than expected. In the case of 'Hasansky Sladky', malolactic fermentation would be recommended in both years. Based on the two years average total acids content, the cultivars can be divided into three categories. Cultivars with high acidity (>9 g l<sup>-1</sup>): 'Cabernet Cortis', 'Zilga', 'Hasansky Sladky'; with medium acidity (7–9 g l<sup>-1</sup>): 'Leon Millot', 'Marquette'; with low acidity (<7 g l<sup>-1</sup>): 'Rondo', 'Solaris', 'Regent'. Previous wine trials showed that the average total acid content in young wines over a three-year period was 7.7±0.6 g l<sup>-1</sup> for 'Solaris', and 8.0±0.4 g l<sup>-1</sup> for 'Zilga' (Maante-Kuljus et al. 2024). These results indicate that Estonian-grown grapes contain high levels of organic acids, making them suitable for wine styles that emphasize freshness and aging potential.

## Conclusions

Over the last twenty years, the trendline shows warming with important implications for the region's viticultural potential. The composition of grapes organic acids and sugars was influenced by vintage, though not for all tested cultivars. The most stable cultivars in terms of sugars content were 'Regent' and 'Solaris', and in terms of acids

content ‘Rondo’ and ‘Marquette’. It was also found that some grape cultivars grown in Estonia may be characterized by low sugar and elevated acid levels. The two-year average sugar content in the grapes showed considerable variability between cultivars. The ‘Marquette’ had the highest sugar content and the potential alcohol content of the wine would be 12.2%. In the case of the ‘Zilga’, it is recommended to add sugar, because the natural alcohol content of 8.2% does not meet the requirements for wine. The malic acid content was high in the grapes of the ‘Hasansky Sladky’ in both years, therefore malolactic fermentation is recommended when producing wine from this cultivar. In conclusion, it can be stated that, according to the requirements of the legislation of viticulture zone A, dry wine can be made from the cultivars that were tested.

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