# SHOOT TOPPING AND TRAINING SYSTEM AS ADAPTATION STRATEGIES IN A CLIMATE CHANGE CONTEXT IN FRANCIACORTA VINE GROWING REGION (NORTH ITALY)

Candidate
***Crescini Francesco***

Dissertation to obtain a Master's Degree in

***Curso de Mestrado em Engenharia da Viticultura e Enologia***

Supervisor: Prof. Cola Gabriele

Supervisor: Prof. Joaquim Miguel Rangel da Cunha Costa

***Jury:***

**PRESIDENT**
Carlos Manuel Antunes Lopes (PhD), Associate Professor with Habilitation at Instituto Superior de Agronomia, Universidade de Lisboa;

**MEMBERS**
Joaquim Miguel Rangel da Cunha Costa (PhD), Assistant Professor at Instituto Superior de Agronomia, Universidade de Lisboa;
Manuel Adão Marques Pacheco Botelho Moreira (PhD).

Academic Year 2023/2024

# Resumo

O presente trabalho de investigação descreve os resultados do primeiro ano de estudo de duas potenciais medidas de adaptação às alterações climáticas, analisando o impacto de gestão da parte aérea e dos sistemas de condução na maturação dos bagos, no rendimento e nos parâmetros qualitativos do vinho.

Os ensaios foram realizados com plantas da casta Chardonnay enxertadas em SO4, e na região vinícola de Franciacorta (norte da Itália) em 2023. No primeiro ensaio foram aplicados 4 tratamentos: sebe longa, sebe curta, desponta à veraison e sem desponta. No ensaio com sistema de condução foram testados 3 sistemas Cortina Dupla de Genebra (GDC), Guyot e Sylvoz.

Os resultados do estudo indicam que as medidas de adaptação analisadas tiveram um efeito significativo nos parâmetros medidos. No caso da desponta da parte aérea, as condições climáticas de 2023 favoreceram o crescimento vegetativo gerando um desequilíbrio entre a parte vegetativo-reprodutivo. A desponta mostrou também atrasar a maturação nas condições testadas. De fato, a maior acidez total das bagos localizados na parede de folhas inferior, enquanto níveis mais altos de açúcar foram obtidos no tratamento sem desponta. A comparação dos sistemas de condução revelou que a maturação foi retardada no GDC, que não atinge a maturação plena devido à elevada carga de cachos e baixa área foliar. O Sylvoz apresentou a maior acumulação de açúcares nos bagos, com o maior rendimento por planta, mas o menor rendimento por hectare. Na avaliação do equilíbrio vegetativo-produtivo, o Guyot foi o mais equilibrado, capaz de manter a acidez tanto no mosto quanto no vinho. A análise sensorial do vinho resultante revelou que os traços sensoriais foram afectados pela gestão da altura da sebe e menos pelo sistema de condução. Apenas o Sylvoz, resultou numa intensidade aromática ligeiramente maior, com notas florais e tropicais mais pronunciadas.

As condições meteorológicas da colheita de 2023 não foram limitantes nem para o vigor nem para a qualidade da produção, tal como é esperado ocorrer no futuro devido às alterações climáticas. Desta forma são precisos mais estudos para se ter uma perspectiva mais ampla e robusta das medidas de adaptação estudadas no contexto das alterações climáticas.

**Palavras-chave**: Alterações climáticas, estratégias de adaptação, gestão da sebe, sistema de formação, qualidade das uvas

# Abstract

The present research work focuses on the results of the first year of evaluation of two different adaptation measures to climate change analysing the impact of shoot hedging and the training system adopted on berry grape ripening, yield and wine parameters.

The experiment was performed using plants of the variety Chardonnay grafted on SO4 , in Franciacorta vine growing region (North Italy) in 2023. Two trials were carried out. The first trial evaluated shoot hedging and 4 treatments were applied : 1)long hedging, 2) short hedging, 3) hedging at veraison and 4) no hedging. The second trial evaluated the effect of the training system experiment. Three systems were studied: Geneva Double Curtain (GDC), Guyot and Sylvoz.

The results of the study show a significant effect of the treatments on the measured parameters. In the case of shoot hedging, the weather conditions favoured a high vegetative response which resulted in a vegetative-reproductive imbalance. In 2023 vintage shoot hedging resulted in delayed maturation. Moreover, the highest berry's total acidity was found with the smaller canopy wall treatment, while higher sugar levels were obtained in the no hedging treatment .The sensorial analysis of the resulting wine mainly differs in shoot wrapping treatment, being the more complex and reporting more mature sensorial traits. With reference to the training system trial , a delayed ripening of grapes was observed for GDC, which was not able to reach full ripeness due to the high bunch load and low leaf area. Sylvoz resulted in the highest sugar accumulation, with the highest yield per plant but the lowest yield per hectare. From the evaluation of the vegetative-productive balance Guyot resulted as the most balanced treatment, able to maintain the acidity in both, must and wine.

The sensorial analysis of the resulting wine doesn't show sharp differences except for Sylvoz that results with slightly greater aromatic intensity, with more pronounced floral and tropical notes.

The meteorological conditions of the 2023 vintage were not limiting for grapevine growth and production quality, as it is expected to be the case in the future due to climate change. Thereby the finding needs to be implemented with the future results allowing to have a broader perspective of the studied adaptation measures in a climate change context.

**Key word**: Climate change, adaptation strategies, shoot hedging, training system, berry quality

# Extended abstract

As alterações climáticas em curso estão a causar uma elevada variabilidade anual e fenómenos meteorológicos extremos que comprometem a produtividade das vinhas e a qualidade das uvas (IPCC, 2023; Jones et al., 2022; van Leeuwen e Destrac-Irvine, 2017). Assim, a introdução de técnicas agrícolas orientadas para a adaptação da vinha a estas condições ambientais tornou-se essencial para garantir a sustentabilidade económica do sector vitivinícola e vitivinícola. O presente trabalho de investigação faz parte do projeto financiado pela UE "RESILVINE: Práticas agronómicas para combater as alterações climáticas na viticultura" e centra-se nos resultados do primeiro ano de avaliação de duas medidas de adaptação diferentes que analisam o impacto de I) 4 tratamentos de gestão da altura da sebe através da desponta e II) 3 sistemas de condução na maturação dos bagos, produção e qualidade do vinho . Os ensaio foram realizados na variedade Chardonnay na região vinícola de Franciacorta (norte da Itália) em 2023. No ensaio de desponta foram aplicados 4 tratamentos: desponta longa (realizada três vezes a 145 cm acima da cana frutífera), desponta curta (realizada três vezes a 110 cm acima da cana frutífera), desponta à veraison (aplicada uma vez a 145 cm acima da cana frutífera) e sem desponta (envolvimento da parte aérea a 145 cm). O ensaio testando os sistemas de condução centrou-se no sistema em Cortina Dupla de Genebra (GDC), Guyot e Sylvoz.

Quando comparado com a média histórica de 1997-2023, o ano meteorológico de 2023 foi caracterizado por temperaturas ligeiramente mais altas e precipitação elevada durante a estação de crescimento. Desta forma não se verificou stress térmico estival e o elevado nível de água no solo garantiu o crescimento vegetativo da vinha sem limitações.

Os resultados do estudo indicam que as medidas de adaptação analisadas tiveram um efeito significativo nos parâmetros medidos. No caso da desponta, as condições meteorológicas favoreceram um vigor excessivo e, consequentemente, resultaram num desequilíbrio entre o desenvolvimento vegetativo-reprodutivo.

Em 2023, o desponta como prática de gestão da sebe mostrou atrasar a maturação. De fato, a maior acidez total dos bagos foi encontrada na parede de folhas inferior, enquanto níveis mais altos de açúcar foram medidos no tratamento sem desponta.

Em termos dos efeitos dos sistemas de condução, foi observada uma maturação retardada dos bagos no caso do GDC, que não atinge a maturação plena devido à elevada carga de cachos e à baixa área foliar. O Sylvoz apresentou a maior acumulação de açúcares, com o maior rendimento por planta, mas o menor rendimento por hectare. Na avaliação do equilíbrio vegetativo-produtivo, o Guyot se mostrou o tratamento mais equilibrado, capaz de manter a acidez tanto no mosto quanto no vinho. A análise sensorial do vinho resultante não mostrou grandes diferenças, exceto para o Sylvoz, que apresentou uma intensidade aromática ligeiramente maior, com notas florais e tropicais mais pronunciadas.

No contexto das alterações climáticas, a estratégia de adaptação a curto prazo resulta como profundamente dinâmica e facilmente implementável devido à possibilidade de o viticultor adaptar a gestão da vinha com base nas condições ambientais sazonais. Por sua vez os sistemas de condução implicam a manutenção a longo prazo da estrutura utilizada. É, portanto, essencial estudar a estabilidade produtiva e qualitativa dos sistemas de condução em diferentes contextos climáticos, avaliando a melhor escolha em um terroir específico, dependendo do objetivo enológico.

As condições meteorológicas do ano de 2023 não foram limitantes para o crescimento da videira (vigor) e para a qualidade da produção, como se espera vir a suceder no futuro devido às alterações climáticas. Portanto, mais trabalhos e estudos são necessários para complementar os resultados obtidos , permitindo ter uma perspectiva mais ampla e robusta da efectividade das medidas de adaptação estudadas e a implementar num contexto das alterações climáticas.

**Palavras-chave**: Alterações climáticas, estratégias de adaptação, gestão da sebe, sistema de formação, qualidade das uvas

# Table of Contents

# 1. List of tables, figures and abbreviations

Figure 13 - Canopy architecture. A: leaf layer number. B: external leaves %. C: external bunches %. D: leaf area index. Statistical analyses performed using the ANOVA test (p value ≤ 0.05); homogeneous subsets were identified through letters with Duncan's test.

Figure 14 - Winter pruning weight. A: Primary wood (Kg). B: Lateral shoot wood (Kg) C: Total wood (Kg). Statistical analyses performed using the ANOVA test (p value ≤ 0.05); homogeneous subsets were identified through letters with Duncan's test, n.s. indicates not significance (p > 0.05).

Figure 15 - Pruned wood partition expressed as percentage. A: Shoot wrapping. B: Long hedging. C: Short hedging. D: Topping at veraison

Figure 16 - Single lateral shoot winter pruning wood weight

Figure 17 - Number of lateral shoots per plant. Statistical analyses performed using the ANOVA test (p value ≤ 0.05); homogeneous subsets were identified through letters with Duncan's test.

Figure 18 - Lateral shoot internode number. Statistical analyses performed using the ANOVA test (p value ≤ 0.05); homogeneous subsets were identified through letters with Duncan's test.

Figure 19 - A: Yield per plant (Kg). B: Average bunch weight (Kg). Statistical analyses performed using the ANOVA test (p value ≤ 0.05); homogeneous subsets were identified through letters with Duncan's test.

Figure 20 - A: Shoot N°/m. B: Pruning wood (Kg)/m. C: Yield (Kg)/m. D: Ravaz Index Kg/Kg. E: N° lateral shoot/plant. Statistical analyses performed using the ANOVA test (p value ≤ 0.05); homogeneous subsets were identified through letters with Duncan's test.

Figure 21 - Total acidity expressed as g/l of tartaric acid measured during the sampling dates (01/08/2023 to 21/08/2023). Statistical analyses performed using the ANOVA test (* indicate p value ≤ 0.05, n.s. indicate not significance p value > 0.05); homogeneous subsets were identified through letters with Duncan's test.

Figure 22 - pH measured during the sampling dates (01/08/2023 to 21/08/2023). Statistical analyses performed using the ANOVA test (* indicate p value ≤ 0.05, n.s. indicate not significance p value > 0.05); homogeneous subsets were identified through letters with Duncan's test.

Figure 23 - Organic acids measurements in the grape must. A: Malic Acid (g/l). B: Citric acid (g/l). C: Succinic acid (g/l). D: Tartaric acid (g/l). Statistical analyses performed using the ANOVA test (* indicate p value ≤ 0.05, n.s. indicate not significance p value > 0.05); homogeneous subsets were identified through letters with Duncan's test.

Figure 24 - Organic acids partition among the treatments expressed as percentage.

Figure 25 - Sugar accumulation expressed as Brix measured during the sampling dates (01/08/2023 to 21/08/2023). Statistical analyses performed using the ANOVA test (* indicate p value ≤ 0.05); homogeneous subsets were identified through letters with Duncan's test.

Figure 26 - Canopy architecture and spatial distribution. A: Porosity %. External leaves %. External bunches %. B: leaf layer number. C: leaf area index. Statistical analyses performed using the ANOVA test (p value ≤ 0.05); homogeneous subsets were identified through letters with Duncan's test.

Spicy, Balsamic), gustatory characters (Acidity, Alcohol, Sweetness, bitter, sapidity, structure, persistence) and overall quality.

Figure I - Annual average temperature and rainfall (1997-2023)

**Abbreviations**:

E: Transpiration

G: Guyot

GDC: Geneva Double Curtain

Ig: Ground radiation intensity

Io: Incoming radiation intensity

LA: Leaf area; Y: yield

LAD: Leaf area density

LAI: Leaf Area Index

LH: Long hedging

LLN: Leaf layer number

Pn: net photosynthesis

PW: Pruning weight

S: Sylvoz

SH: Short hedging

SW: Shoot wrapping

TV: Topping at veraison

WUE: Water use efficiency

# 2. Introduction

## 2.1. Viticulture in the 21st Century

The concept of terroir is well-known in the viticultural and oenological world, and it is often associated with the idea of quality; it derives from the interaction of multiple variables, among which climate, soil, cultivar, and human practices stand out (Van Leeuwen and Seguin, 2006). Modifying one of these factors results in a plant response and a subsequent change in the final product, influencing the typicality of the wine itself. What is happening in the global viticulture is a shift in the climatic context (IPCC, 2023), which could lead to a loss of the characteristic traits of the wine productions (Poni et al., 2023) and may also affect sustainability of the sector, in particular in the drier and warmer regions such as the Mediterranean (Costa et al., 2022).

In Italy, the Lombard wine market contributes substantially to the economy of the national supply chain representing 3% of Italian must and wine production (2018-2022) and 4,5% of the national production value of 14.1 billion of euros (2022) (Ismea, 2024). Franciacorta plays a preponderant role in the production of quality wines and strongly linked to the territory.

The strong territorial vocation of Lombardy's wine supply chain requires the guarantee of having grapes in adequate quantity and quality and with continuity over the years, reducing the uncertainty linked to the effects of the variability of meteorological phenomena.

This assumption clashes more and more frequently with the effects of ongoing climate change, which causes  more extreme weather events such as heat waves, droughts, hailstorms, and late frosts, and which compromise both, the yield of vineyards and berry quality, with very serious consequences on the profitability of wine production (IPCC, 2023; Jones et al., 2022; Cola et al. 2020; van Leeuwen and Destrac-Irvine, 2017).

Ongoing climatic changes promote the advancement of vine’s phenology. On one hand, this results in early budbreak, with higher risk of plant damage due to late frosts, with the risk of compromising its productivity for several years. On the other hand, advanced phenology makes more difficult vineyard management, affecting the quality of grapes that reach maturity during the warmest phase of the year, with negative implications on their technological maturity. (Cola et al. 2020; Santos et al., 2020; Bucur and Dejeu, 2022).

Moreover, high temperatures, coupled to more severe heatwaves, are also detrimental to yield and to berry composition, as they lead to the oxidation of varietal aromas and their precursors. The extent of the yield decrease is closely tied to the heatwaves period and how long they last (Fraga et al., 2020; Gouot et al., 2019). As consequence, adapting agricultural techniques to these conditions has become essential to ensure economic sustainability of the wine and viticultural sector.

It is therefore of primary importance to provide companies with a range of practices that can offer an advantage towards current climatic context and, at the same time, make future viticulture more resilient to future challenges.

## 2.2. Aim of the work

The present research work is part of the European funded project FEASR – Rural Development Program 2014-2020: ResilVine and it focuses on the first year of activity. The project addresses the primary theme of improvement and innovation in vineyard management, with a particular focus on keeping yield and quality through sustainable actions, paying particular attention to the conservation of natural resources.

The general objective of the project is to study and disseminate innovative agronomic practices in the viticultural sector that can enhance resilience of vineyards to extreme weather phenomena. Therefore, the project aims to study and demonstrate several techniques that, individually or combined, can respond to the needs of Lombard viticulture, in the context of climate change.

In the Franciacorta wine district in the Province of Brescia, Lombardy - Italy, the territorial vocation implies a specific oenological goal: the classic method for sparkling wine production. The main viticultural goal is the preservation of good acidity level together with a low alcohol content, for the production of pleasant and elegant wines. Besides these parameters, aromas also play an important role, enhancing the complexity and overall quality of the wines.

The studied adaptation measures aim to achieve a technological balance and preserve the varietal characteristics, which are sensitive to the effects of climate change (Fraga et al., 2020; Gouot et al., 2019, van Leeuwen and Destrac-Irvine, 2017).

These innovative and sustainable techniques could represent novel and easily implementable solutions, allowing for the maintenance of quantity and quality of production and the terroir.

Among the different adaptation measures reported in literature (Santos et al., 2020; Bucur and Dejeu, 2022), this work is focused on the role played by shoot hedging and training system.

## 2.3. Experimental area

The study area is included in the Protected and Guaranteed Designation of Origin Franciacorta (DOCG), which includes 122 producers situated in the North-East Lombardy region of Italy (Figure 1). This region is renowned to produce high-quality sparkling wines.

The focal area is located between the Iseo Lake and the city of Brescia. Characterized by sand- and silt-rich soils, typically deficient in clay but often considerably thick and highly permeable, the soil is abundant in gravel (Franciacorta Consortium, 2024).

Franciacorta is positioned at the extreme Northern edge of the Po Valley and forms part of the Alpine foothill bel, South of the Iseo Lake. Despite having a continental climate, the area benefits significantly from the nearby lake, which exerts a mitigation effect on temperatures during both summer and winter.

By a climatic point of view, this is an Insubric meso-climatic area. In the vine-growing period (April to October), the average rainfall is approximately 500-600 mm, constituting roughly two-thirds of the annual total (Province of Brescia - Agrometeorological Network, 2024).

*Figure 1 - DOCG location. Insidewine (2024).*

# 3. Vineyard adaptation strategies: state of the art

Literature describes a set of adaptative methods that differ in the timing of implementation and effectiveness. They can be divided in short, medium, and long-term adaptation measures (Santos et al., 2020; Bucur and Dejeu, 2022). The present research work focuses on two adaptation measures that can provide support in the short and medium term and whose reproducibility is easily applicable in the Franciacorta district.

## 3.1. Shoot hedging as short-term adaptation strategy

Short-term adaptation strategies include numerous techniques, generally targeted to different specific goals such as with the objective of the minimization of thermal and water stress, the delay of ripening, the reduction of sugar accumulation, in favour of acidity, and so on.

The Leaf Area to Fruit Weight ratio is a crucial parameter influencing vineyard performance, impacting both on yield and grape composition (Poni et al., 2009).

By altering this ratio, phenology can be delayed, prolonging the vegetative phase. This influence ripening timing, moving it towards a colder period, less affected by detrimental high temperatures (Santesteban et al., 2017). This adjustment also mitigates the potential impacts of heatwaves during maturation (Torres et al., 2021; Garcia-Tejera et al., 2023) both in terms of radiative and thermal stress.

Furthermore, by modulating the extent of the leaf surface area, it is possible to reduce evapotranspiration, with positive effects on water availability and use during the vegetative and reproductive growth (Garcia-Tejera et al., 2023).

Shoot hedging is often aimed to keep a more uniform canopy size, thereby facilitating vineyard operations such as spraying, and soil management (Dokoozlian, 2012). However, it induces many vine responses. Considering physiological effects induced by this operation, changes in ripening dynamics can be achieved. The outcome, whether promoting or delaying ripening, is dependent on factors such as the timing and severity of treatment, environmental conditions, and crop load pre-trimming (Mota et al., 2010). Research conducted by Parker et al. (2014) on Pinot Noir and Sauvignon Blanc grapes showed that diminishing potential carbohydrate sources at post-flowering, by reducing leaf area via trimming, can delay the onset of maturation. In opposite, the same authors report that, the removal of the crop showed little influence on the time of initiation of maturation. Therefore, when attempting to influence the veraison date, it is essential to consider how the leaf area to fruit weight ratio is modified. This is likely attributed to the fact that the fruit is a major sink in the plant, whereas leaves are the primary source.

A subsequent study reported that early-season crop removal performed at fruit set, or the same treatment at veraison, resulted in a comparable increase of the rate of total soluble solids accumulation, with minimal variations noted among cultivars (Pinot Noir and Sauvignon Blanc). In contrast, leaf removal through shoot trimming demonstrated a more pronounced reduction in total soluble solids at harvest. The most substantial decline in total soluble solid rates was an outcome of the synergistic effect of delaying onset and retarding the total soluble solid accumulation (Parker et al., 2015).

The leaf area to fruit weight ratio can also influence vine’s response in terms of sugar accumulation in berries. It varies depending on the temporal and environmental scale at which the treatment is performed, as well as the severity of the treatment. Under irrigated conditions, and when hedging is carried out early (between flowering and the initial stages of berry growth), vegetative regrowth compensates for the loss of leaves, resulting in delayed sugar accumulation due to a limited leaf area to yield ratio and due to laterals competition. Differently, under water stress conditions and with a delayed treatment, vegetative regrowth does not compensate for the loss of leaf area and in such circumstances, differences in plant's response depend on the severity of the treatment (Poni et al., 2023).

Moreover, under non-limiting leaf/yield conditions, (1 $m^2$ of leaf surface/kg  of grapes), there was a slight decrease in sugar accumulation at harvest, and a similar condition for anthocyanin accumulation (Herrera et al., 2015).

In a limiting situation post-trimming treatment, where the leaf area was less than 0.5 $m^2$ per kg of grapes, a delay in sugar accumulation was observed with a slight impact on anthocyanin accumulation (Bobeica et al., 2015). An explanation for these results is proposed by Poni et al. (2023) and it involves the influence of late seasonal hedging, where the decrease in the leaf area to fruit weight ratio impacts sugar accumulation due to reduced source strength (leaves) and due to their reduced efficiency resulting from aging.

Beyond studies related to shoot hedging with the aim of influencing the sugar content, due to the more and more common periods of water stress caused by climate change, it is of primary importance to assess the effect of partial canopy removal on plant's water balance. Abad et al. (2019) through stem water potential and carbon isotope ratio analysis, evaluated the plant water status after trimming treatments and found higher values of stem water potential (measured between fruit set and harvest) and lower values of δ13C (in berries at harvest) under water-limiting conditions in hedged vines, whereas during non-drought periods, the differences between treated and untreated vines were negligible.

In accordance with the aforementioned study, Mirás-Avalos et al. (2017) confirm that, under warm and dry conditions, vines hedged to a height of 90cm experienced less water stress compared to the hedged pruned vines (130cm).

Abad et al. (2019) hypothesized that the limited impact of the treatment under non-drought conditions, could be represented by the replacement of the leaf area by means of the lateral shoots growth that compensate the lost area. This trend is even more recognizable in case of soil fertility, vigorous variety and rootstock that enhance the lateral shoot formation.  However, water availability remains the main driver of this process.

Santesteban et al. (2017) investigated the effects of severe hedging conducted three weeks post fruit-set to diminish the leaf area. The study revealed that trimming substantially decreased leaf area and yield, consequently enhancing water availability in pruned plants. Irrigation has been applied in pruned plants until harvest, boosting competition between the cluster and lateral shoots, leading to a delay in maturation.

In another experiment using a multichamber whole-canopy gas exchange system, Poni et al. (2021) showed that in an early pruning treatment, subsequent vegetative regrowth balanced the initial transpiration reduction (-26% transpiration as compared to pre-treatment rates) by the end of July. A delayed trimming resulted in 44% reduction in transpiration, recovering the same compensation point during the same period (July).

All the above-mentioned studies outlined the difficult generalization of treatment results on vine's water balance, emphasizing the importance of evaluating environmental conditions and vigour before pursuing the goal of water saving.

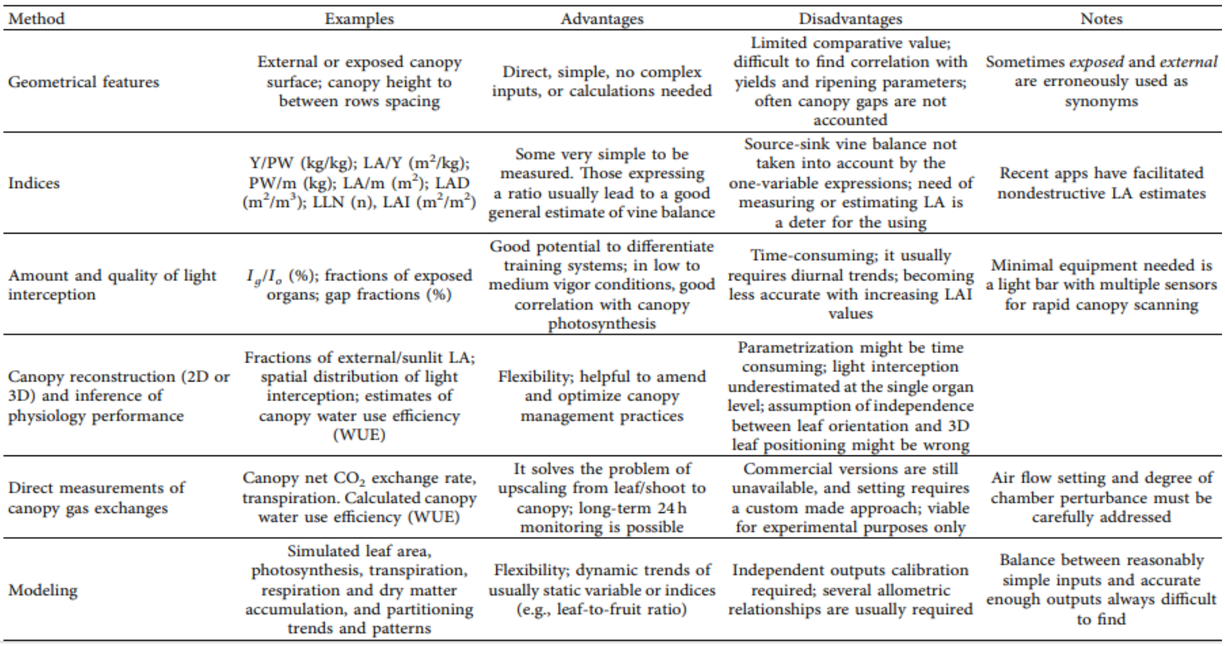
Moreover, it results interesting to evaluate the mitigation effect provided by hedging in a context of heatwaves risk. It has been shown that canopy hedging before a heatwave allows to diminish maximum leaf temperature reached during heatwave (Garcia-Tejera et al., 2023). The extent of the reduction in leaf maximum temperature depends on soil water conditions. Variability in the effect of hedging is attributed to changes in stomatal conductance and to the decrease in light interception in treated and untreated plants. Under non-limiting soil water conditions, stomatal conductance reached its maximum, and the reduction in light interception due to pruning explained the decrease in leaf maximum temperature. As the soil dried, and stomatal conductance decrease due to stomatal closure the ratio of root area to leaf area and the water potential remained more favourable in pruned vines, contributing to keep plant water status and counteracting the effect of reduced soil water availability.

As an alternative to shoot hedging, other canopy management practices were proposed and employed by grape growers. One alternative involves wrapping the shoot on the last wire of the trellis system avoiding its hedging. Faralli et al. (2022) conducted a study to assess the differences between the two proposed solutions and concluded that wrapping the shoot increased polyphenols content and must acidity under condition of high temperature and high irradiance. The result can be explained by the higher density of the upper part of the canopy, which results in larger shading of the clusters compared to the hedging treatment. Furthermore, due to apical dominance, most lateral shoots developed in the cluster zone, providing more shading for the clusters themselves. In the aforementioned study, no measurements of humidity within the canopy were taken. It is also important to consider the feasibility of implementing wrapping in areas prone to fungal diseases or at high risk of bunch rot. Additionally, it is of fundamental importance to evaluate the applicability of the treatment in organic vineyards, due to the limitation in the use of plant protection products.

## 3.2. Training system as medium-term adaptation strategy

Among the medium-term adaptation strategies, the evaluation of alternative training system is particularly interesting. Modification of whole plant architecture determines multiple physiological responses. In the specific context of Franciacorta, the aim is to change the dynamics of maturation, delay ripening and moving it to a period that has less impact on quality. Changing canopy architecture affects sunlight interception, shoots and cluster's position and exposure to direct light, thereby reducing the risk of sunburn or spring frost. (van Leeuwen et al., 2019; del Zozzo e Poni, 2024).In addition, the microclimate of the bunch may be also changes as function of the trunk's height and, therefore, the training system used (van Leeuwen et al., 2019).In the past decades, the choice of the training system aimed to optimize light penetration within the canopy, to favour bud flower differentiation, create optimal conditions for cluster microclimate and allow a more efficient phytosanitary management (Shaulis and May, 1971). More recently, the choice of the training system has focused on the compromise between light interception and light distribution within the canopy, as well as the feasibility of mechanization. Today, the choice of the training system must account for a multitude of factors, considering climate change as an additional challenge that must be given priority to, especially in the most susceptible wine producing regions. Various methods have been described to compare the training system efficiency and are summarized in Table 1.

Table 1 – List of methods used or currently available to determine and compare efficiency of different grapevine training systems. LA: leaf area; Y: yield; PW: pruning weight; LAD: leaf area density; LAI: Leaf Area Index; LLN: leaf layer number; $I_o$ incoming radiation intensity; $I_g$: ground radiation intensity (Source: Del Zozzo and Poni, 2024).



| Method | Examples | Advantages | Disadvantages | Notes |
|---|---|---|---|---|
| Geometrical features | External or exposed canopy surface; canopy height to between rows spacing | Direct, simple, no complex inputs, or calculations needed | Limited comparative value; difficult to find correlation with yields and ripening parameters; often canopy gaps are not accounted | Sometimes *exposed* and *external* are erroneously used as synonyms |
| Indices | Y/PW (kg/kg); LA/Y ($m^2$/kg); PW/m (kg); LA/m ($m^2$); LAD ($m^2/m^3$); LLN (n), LAI ($m^2/m^2$) | Some very simple to be measured. Those expressing a ratio usually lead to a good general estimate of vine balance | Source-sink vine balance not taken into account by the one-variable expressions; need of measuring or estimating LA is a deter for the using | Recent apps have facilitated nondestructive LA estimates |
| Amount and quality of light interception | $I_g/I_o$ (%); fractions of exposed organs; gap fractions (%) | Good potential to differentiate training systems; in low to medium vigor conditions, good correlation with canopy photosynthesis | Time-consuming; it usually requires diurnal trends; becoming less accurate with increasing LAI values | Minimal equipment needed is a light bar with multiple sensors for rapid canopy scanning |
| Canopy reconstruction (2D or 3D) and inference of physiology performance | Fractions of external/sunlit LA; spatial distribution of light interception; estimates of canopy water use efficiency (WUE) | Flexibility; helpful to amend and optimize canopy management practices | Parametrization might be time consuming; light interception underestimated at the single organ level; assumption of independence between leaf orientation and 3D leaf positioning might be wrong | |
| Direct measurements of canopy gas exchanges | Canopy net $CO_2$ exchange rate, transpiration. Calculated canopy water use efficiency (WUE) | It solves the problem of upscaling from leaf/shoot to canopy; long-term 24 h monitoring is possible | Commercial versions are still unavailable, and setting requires a custom made approach; viable for experimental purposes only | Air flow setting and degree of chamber perturbance must be carefully addressed |
| Modeling | Simulated leaf area, photosynthesis, transpiration, respiration and dry matter accumulation, and partitioning trends and patterns | Flexibility; dynamic trends of usually static variable or indices (e.g., leaf-to-fruit ratio) | Independent outputs calibration required; several allometric relationships are usually required | Balance between reasonably simple inputs and accurate enough outputs always difficult to find |

Following the need to identify the optimal efficiency of the training system, the Ravaz index provides a useful insight, because the ratio between yield and the pruning weight is easily to measure and provide a good indication of vine's vigour (Howell et al., 2001).

Other methodologies to evaluate the impact of training system consider the leaf area to fruit weight ratio ($m^2$/kg). This kind of measurement is becoming easier to perform, thanks to the 3D reconstructive technologies that allow the estimation of the vine leaf area and, as a consequence, the training system ability to efficiently capture light (Louarn et al., 2008).

Considering the drought conditions affecting several European wine-growing regions, van Leeuwen and Destrac-Irvine (2017) report that the Mediterranean bush vine or gobelet appears to respond well to water stress conditions mainly because of the reduced leaf area, which decreases transpiration and, consequently, water needs. However, maintaining the same leaf area to fruit weight ratio obviously results in low yields per hectare. Therefore, the combination of low yields/ha and the inability of mechanization resulted in the abandonment of this training system.

During the 1st International Symposium on alcohol level reduction in wine (Bordeaux, 2013), Novello and De Palma (2013) reported that Sylvoz and Lyra systems enable a reduction in sugar accumulation in Sousón grapes, as these training systems increase vigour, plant yield, and cluster coverage. A similar outcome has also been observed by Diaz-Losada et al. (2013) in the case of Godello and Loureira varieties.

In recent review by del Zozzo and Poni (2024), the authors analysed the most widespread vineyard training system worldwide and assessed numerous parameters related to the influence of climate change. These parameters include water stress, duration of the vegetative season, potential delay in maturation, and factors related to frost damage, heat stress and to sunburn predisposition. Additionally, the review discusses susceptibility to diseases, vine vigour, potential yield, and predisposition to winemaking styles. The winemaking style inclination is considered in relation to yield and cluster coverage; medium to high yield with greater cluster coverage is considered as predisposing to sparkling wine production.

The study also describes the main characteristics of training systems considered, namely for the Geneva Double Curtain (GDC), Sylvoz (S) and vertical shoot positioning (G) has been analysed and subsequently reported (figure 2 and figure 3).

Figure 2 - Training system considered. Geneva Double Curtain (GDC), Sylvoz (S) and Guyot (G). Adapted from Del Zozzo and Poni, 2024.

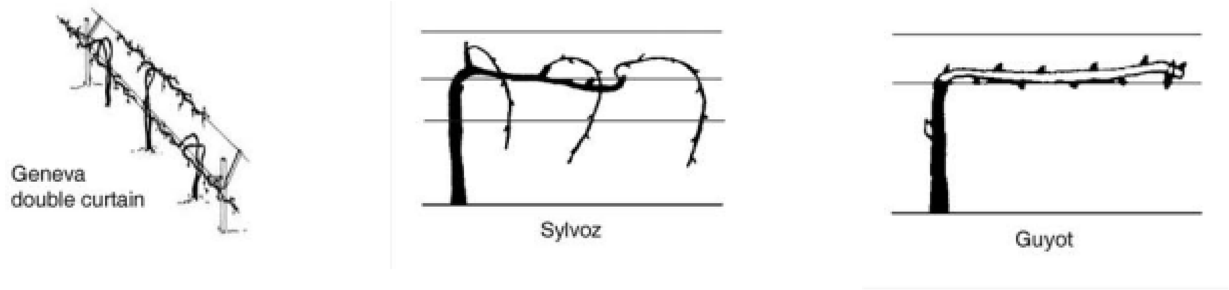


Figure 3 – Schematic representation of the training system considered. Geneva Double Curtain - GDC; Sylvoz - S; Guyot - G. Adapted from Reynolds and Heuvel, 2009.

Geneva double curtain (GDC) and Sylvoz (S) benefit from the high trunk, which provides an excellent response to spring frosts, and they are less susceptible to radiative heating from the ground under dry and hot conditions (Leeuwen et al., 2019).

Furthermore, GDC provides good tolerance to cluster sunburn because clusters are consistently under shade along the growing season. Due to its characteristics in term of high productivity, this training system has the potential to benefit from an extended growing season. For the same reason, maturation may occur later, under less elevated temperatures. Overall, these characteristics make it suitable for sparkling wine production (del Zozzo and Poni, 2024).

The high bud charge of both Sylvoz and GDC provides as well, a good control over vine vigour, and the susceptibility of these two training systems to fungal diseases is considered good, as it is difficult to have a high leaves density around the cluster. Guyot is used to produce a premium still wine, but it presents controversial characteristics regarding the effects of climate change, requiring more canopy management. It is also prone to spring frosts due to the lower canopy position, and during the summer, it has a higher possibility of overheating or sunburn (del Zozzo and Poni, 2024).

It is important to emphasize the significance of a high-trunk training system as the distance of the canopy from the ground influences the cluster microclimate. Indeed, it is well demonstrated that there is a typically vertical gradient of temperature in the canopy especially under dry and warm conditions (Costa et al., 2019). In response to increasing soil and air temperatures attributed to climate change, the trunk height can be adjusted, thereby mitigating the radiative influence from the ground. In a study conducted by van Leeuwen et al. (2019), temperature sensors were installed at various heights (30, 60, 90, and 120 cm) within the row. In the determination of the Winkler canopy Index, a difference of 60 degree-days was observed at 120 cm compared to 30 cm, resulting in a seven-day delay in maturation.

Regarding water use efficiency (WUE = Pn/E), the larger canopy leaf area could be a drawback in water-stress situations. Del Zozzo and Poni (2024) reported that canopy division or reduction of inter-row spacing increases water consumption in the vineyard.

However, further investigation would be needed to better explore the WUE behaviour in different training systems, as literature often reports unsatisfactory results.

# 4. Material and methods

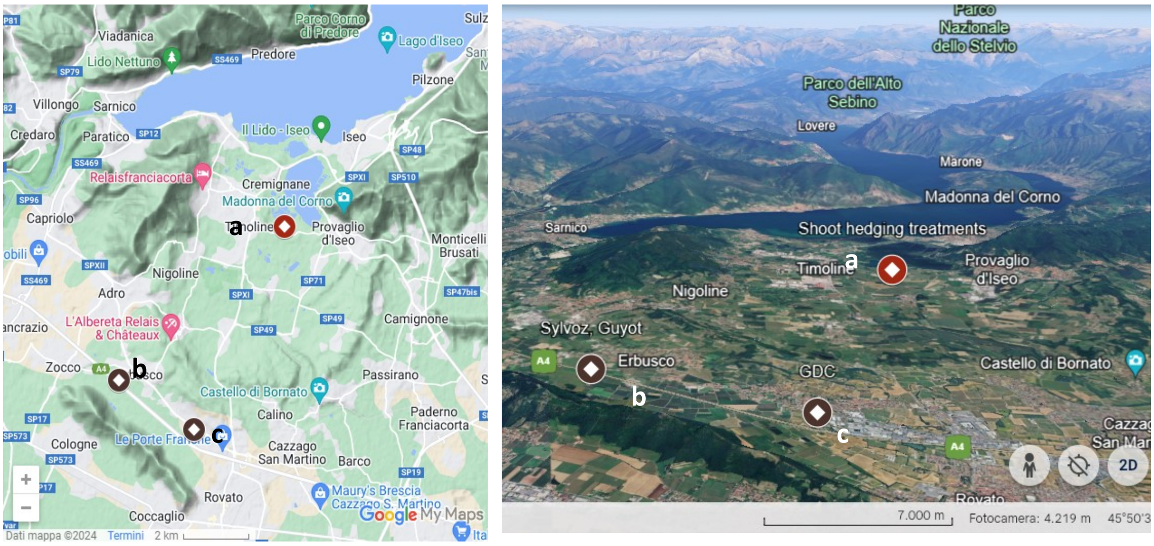
## 4.1. Location and experimental set up

Field experimental activities were carried out along the year 2023 in order to assess the effect of: shoot hedging treatments and training systems on growth, yield and berry quality aspects.

The vineyards used in the trials are located in the vine growing region of Franciacorta, in Lombardy, north of Italy. Plants of the *Vitis vinifera* L. cv "Chardonnay" are grafted on SO4 rootstock.

Vineyard A (figure 4A, 4B) was used to study the impact of the shoot hedging treatments (coordinates: 45.6367, 10.0229) and a total of 48 plants were considered.

Vineyards B and C (figure 4A, 4B) were assigned for the training system experiment (coordinates: 45.598, 9.960; 45.586, 9.989). These two vineyards were close and had homogeneous soil properties and vine ages (fifteen years). A total of 36 vines were taken into consideration to test three training system.



*A)* *B)*

*Figure 4 - Location of the shoot hedging experimental field(red dots), and of the experimental fields dedicated to training systems (brown dots). A) 2D view (Google Mymaps, 2024). B) 3D view (Google earth, https://earth.google.com/web). The letters a, b, c indicate the location of the three vineyards used in the trial.*

### 4.1.1. Shoot hedging trial

Shoot hedging was performed on single Guyot trained plants with an inter-row distance of 2.5 m, inner-row distance of 1.00 m, planting density of 4000 vines per ha, NE-SW oriented. Four treatments were applied: 1) Long hedging (LH) performed at 1.45 m from the fruiting cane, 2) Short hedging (SH) performed at 1.10 m, 3) Hedging/topping at veraison (TV) at 1.45 m and 4) No hedging but only shoot wrapping (SW) at 1.45 m. In the first two treatments, the treatments were applied 3 times along the vegetative season (on 30 June 77-BBCH berries beginning to touch, on 15 July 79-BBCH majority of berries touching, and on 4 August 81-BBCH beginning of ripening). In TV, the treatment was applied just once at veraison (4 August, 81-BBCH), and no headging was applied in last treatment, where the tops of the shoots were wrapped on the last wire of the trellis system at 1,45 m.

The experimental design was a complete block design (figure 5A, 5B) with four blocks, and taking into account three rows each treatment. Focusing on the middle raw, twelve plants for each treatment were considered, with four plants selected near the start of the row, four in the middle, and four at the end of the row, totalling forty-eight plants.

### 4.1.2.Training system trial

Three training systems were compared:

1) Sylvoz inter-row distance of 2.9 m, inner-row distance of 2.5 m, planting density of 2760 (Twin row) vines per ha N-S oriented. Figure 5D show the twin rows planting, where the vines are planted in pairs, close to each other.

2) Geneva Double Curtain (GDC) with an inter-row distance of 4 m, inner-row distance of 1.25m, planting density of 4000 vines per ha (Twin row), NE-SW oriented. Figure 5E show the twin rows planting, where the vines are planted in pairs, close to each other.

3) Guyot inter-row distance of 2.3 m, inner-row distance of 0.9 m, planting density of 4830 vines per ha, N-S oriented

The experimental design was a complete block design with four blocks and considering 12 plants for each treatment, mainly chosen focusing on the phytosanitary condition of the plants, with a total of 36 plants.

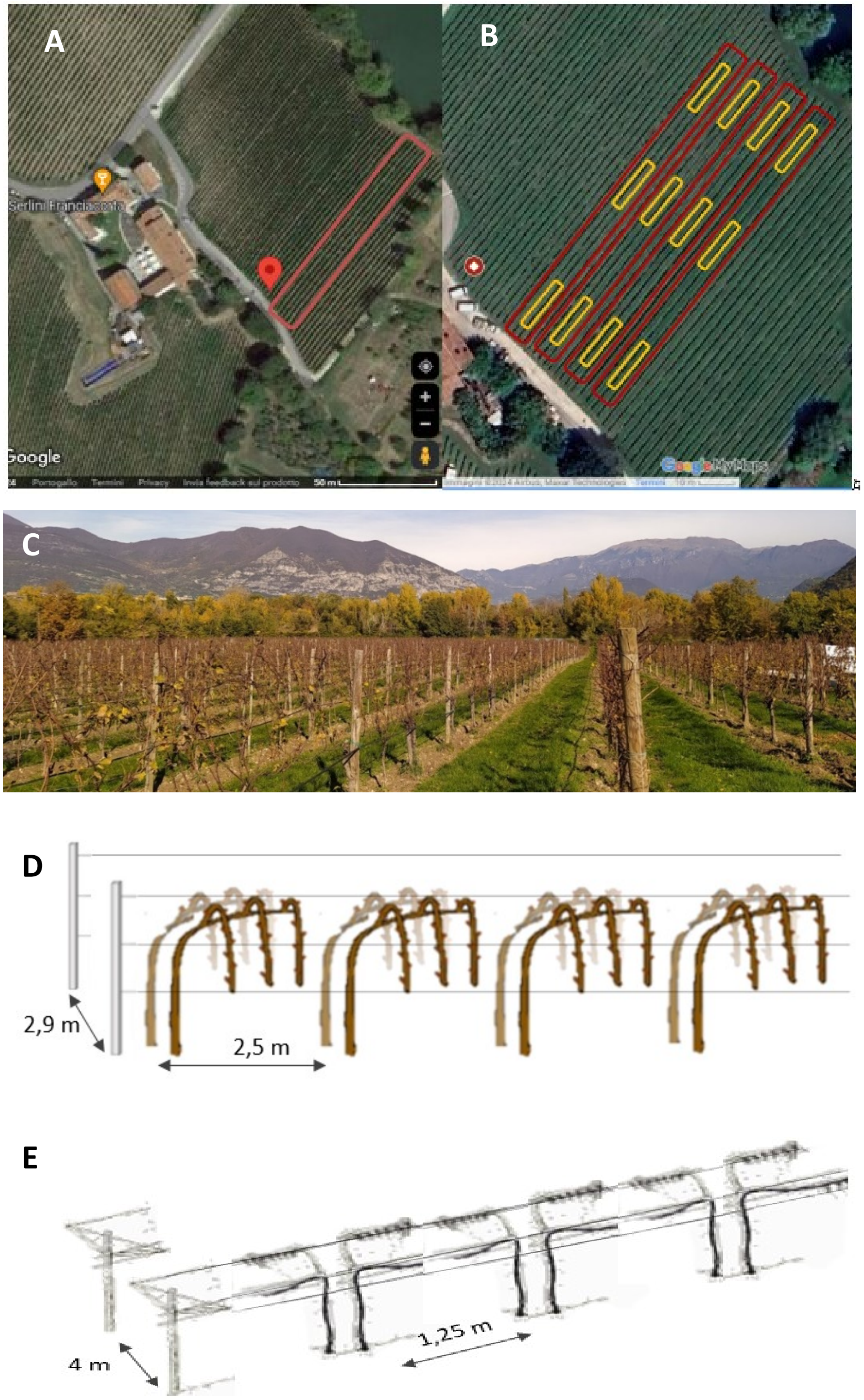


*Figure 5 - **A**): Experimental field location: 45.6367, 10.0229 (Google Maps, 2024). **B)** detail of experimental design (Google maps, 2024). **C)** Overview of the Shoot hedging experimental field (DiSAA University of Milan, 2023). D) Schematic representation of a twin row in Sylvoz training system (Adapted from DiSAA University of Milan, 2024) ; **E)**: Schematic representation of a twin row in GDC training system (Adapted from DiSAA University of Milan, 2024)*

## 4.2. Materials and measurements

Climate data analysis and related charts are based on the historical series 1997-2023 retrieved from the weather station located in Cortefranca, province of Brescia (Province of Brescia - Agrometeorological Network, 2024), it is located 4 Km from the farthest trial.
Vine phenology was measured through BBCH scale according to Lorenz et al (1995).

The vines' canopy architecture was evaluated by using the point quadrat analysis (Smart and Robinson, 1991) on 16 August in both trials (Training system: 89-BBCH, shoot hedging: 85-BBCH).
The Leaf Area Index (LAI) was measured by using LAI-2200 Plant Canopy Analyzer (Li-cor, USA) following the manufacturer's recommended protocol.

At harvest (17 August in the training system fields and 21 August in the shoot trimmed vineyard), data related to vegetative parameters were collected. We observed the number of buds left during pruning, the number of shoots as well as productivity parameters (number of clusters per plant, average cluster weight, and yield per plant). The pruning wood weight was measured in winter, considering primary wood and lateral shoots wood separately. The number of lateral shoots per plant and the shoots internodes number per each plant were also measured. Vegetative-reproductive balance can be assessed through many indexes. In the present research work has been decided to focus on five indexes as reported by Palliotti et al. (2018) and presented in table 2.

Table 2 - Vegetative-reproductive indexes and their optimal range. (Palliotti et al. 2018).

| **Indexes** | **Description** | **Optimal range values** |
|---|---|---|
| Shoot density | It implies the number of shoots per canopy linear meter | 12-16 N°/m |
| Pruning wood weight | it is expressed as kg of pruning wood per canopy linear meter | 0.4 - 0.8 kg |
| Yield per canopy linear meter | it varies depending on the oenological purpose. | 3.5 - 4.5 kg/m. |
| Ravaz index | it is given by the ratio of yield to pruning wood weight | 4 - 8 kg/kg |
| Lateral shoots development | Number of laterals per shoot. It is highly dependent on genetic factors. | 6 - 8 N° |

In both experiments the grape ripening was monitored during four sampling dates as described in tables 3 and table 4.The first three samplings were carried out by collecting 100 berries from the experimental plants, selecting the berries in a spiral pattern along the bunch. At harvest the samples were collected picking 3 whole bunches per plant.

Table 3 - Shoot hedging working timeline. DOY: Day of Year. BBCH scale according to Lorenz et al (1995)

| Date | DOY | BBCH scale | Activity |
|---|---|---|---|
| **15/01/2024** | 15 | 00-BBCH | Winter pruning. Pruning wood analysis. |
| **30/06/2023** | 181 | 77-BBCH | Hedging |
| **15/07/2023** | 196 | 79-BBCH | Hedging |
| **01/08/2023** | 213 | 81-BBCH | Grape sampling |
| **04/08/2023** | 216 | 81-BBCH | Hedging |
| **08/08/2023** | 220 | 83-BBCH | Grape sampling |
| **16/08/2023** | 228 | 85-BBCH | Point quadrat analysis |
| **16/08/2023** | 228 | 85-BBCH | Grape sampling |
| **21/08/2023** | 233 | 89-BBCH | Harvest. Vegetative e productive parameters collection. |

Table 4 - Training system working timeline. DOY: Day of Year. BBCH scale according to Lorenz et al (1995)

| Date | DOY | BBCH scale | Activity |
|---|---|---|---|
| **15/01/2024** | 15 | 00-BBCH | Winter pruning. Pruning wood analysis. |
| **25/07/2023** | 206 | 81-BBCH | Grape sampling |
| **01/08/2023** | 213 | 83-BBCH | Grape sampling |
| **08/08/2023** | 220 | 85-BBCH | Grape sampling |
| **16/08/2023** | 228 | 89-BBCH | Point quadrat analysis |
| **17/08/2023** | 229 | 89-BBCH | Harvest. Vegetative e productive parameters collection. |

After the collection, the samples were squeezed in a plastic bag. The juice was collected in a small plastic container where subsequently the qualitative parameters (sugar content, pH, total acidity, malic acid, tartaric acid, citric acid and succinic acid) were analysed. For the determination of sugar content, a Hanna digital refractometer model HI 96811 was used.

Total acidity and must pH were analysed using an automatic titrator FLASH (Steroglass, Italy). Identification and characterization of malic acid, tartaric acid, citric acid and succinic acid were performed at harvest using high-pressure liquid chromatography (HPLC) techniques through Orbitrap Exploris 240 MS (Thermofisher, Italy) according to the protocol described by Baccichet et al. (2021).

The sensorial evaluation of wines was performed by a panel of 11 experts, considering visual characters (Intensity, Tonality), olfactory characters (Intensity, Floreal, White fruit, Tropical fruit, Citrus, Dry fruit, Honey, Vegetal, Spicy, Balsamic), gustatory characters (Acidity, Alcohol, Sweetness, bitter, sapidity, structure, persistence) and overall quality.

The results were likewise analysed by testing principal components through the instrument FOSS WineScan (FOSSAnalytics, Denmark). Sugar: Fourier Transform Infrared Spectroscopy: MIFTIR, Alcohol: densimeter MITV, pH potentiometric method MIPH, volatile acidity: steam distillation, total acidity titration MIAT, Malic acid: Fourier Transform Infrared Spectroscopy: MIFTIR.

### 4.2.1. Statistical analysis

For statistical analyses, the IBM SPSS software was used. The variance analysis was performed using the ANOVA test (p value ≤ 0.05); homogeneous subsets were identified with Duncan's test.

## 4.3. Experimental Micro-vinification

Berries were harvested for the experimental micro-vinification. About 100 kg of grapes were harvested for each experimental trial to carry out separate micro-vinification.

All micro-vinifications followed the same winemaking protocol with the minimal intervention of adjuvants and additives in order to evaluate the oenological potential of the individual thesis.

Once the grapes arrived in cellar whole grape pressing was conducted. The free-run juice was collected in a stainless-steel tank where pre fermentative treatments were conducted.

The pre fermentative steps included the addition of enzyme 2 g/hl, PVPP 10 g/hl and Sulphur dioxide 5 g/hl. After enzyme addition, the must was left to settle for 24 hours allowing the gross lees to create a layer on the bottom of the tank and after 24 hours, the separation of the must from the gross lees were carried out. The liquid was pumped into the fermentation tank and after the addition of yeast (20 g/hl) and activators, fermentation started. The fermentation took place at 19-23°C and it lasted 13 days. Once fermentation was completed, racking and sulphur dioxide addition (4 g/hl) were carried out. Racking was carried out three more times, the first one after three days, then after 15 days, and finally after one month. The process ended with the last $SO_2$ addition (4 g/hl) and bottling.

The biochemical (alcohol content, residual sugar, total acidity, volatile acidity, pH, malic acid) and sensory characteristics were determined for each resulting wine as described above.

# 5. Results and discussion

## 5.1. Agrometeorology

### 5.1.1. Agroclimatic characterization

This chapter describes the study area at regional level to provide a climatic context for the area of study. For detailed considerations on the 2023 season, refer to Chapter 5.1.2. Meteorological season:2023. Figure 6 shows yearly average temperature and yearly precipitation from 1997 to 2023, measured by the Cortefranca weather station, located in the middle Franciacorta DOCG (Province of Brescia - Agrometeorological Network, 2024). In the figure are presented the annual average air temperature (green line), minimum temperature (blue line), and maximum temperature (red line). The histograms represent the cumulative annual precipitation.

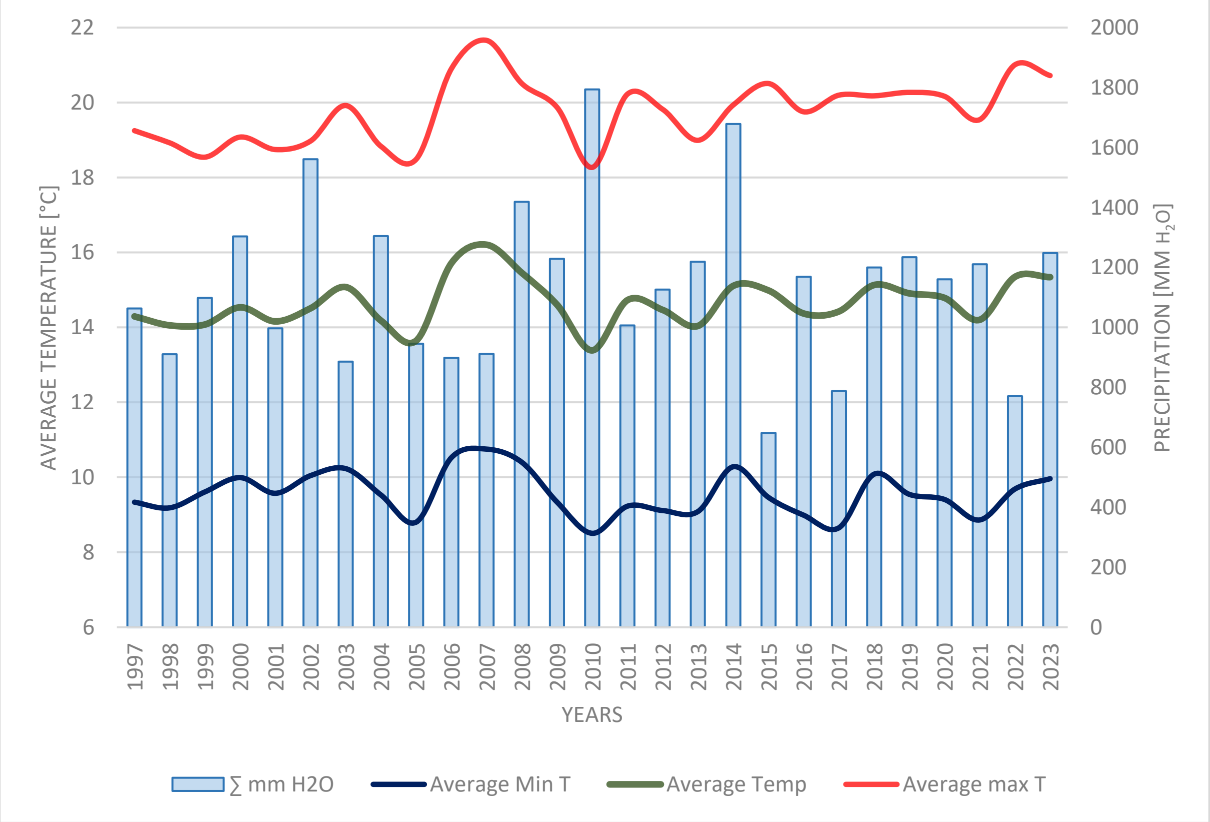


*Figure 6 - Annual minimum, maximum and average air temperature and rainfall (1997-2023)*

In Figure 7, starting from the 1997-2023 July and August average temperature (25,04 °C), each year deviation is presented. The annual deviation from the mean is expressed as a percentage. The 2023 did not shows deviation from the average value.

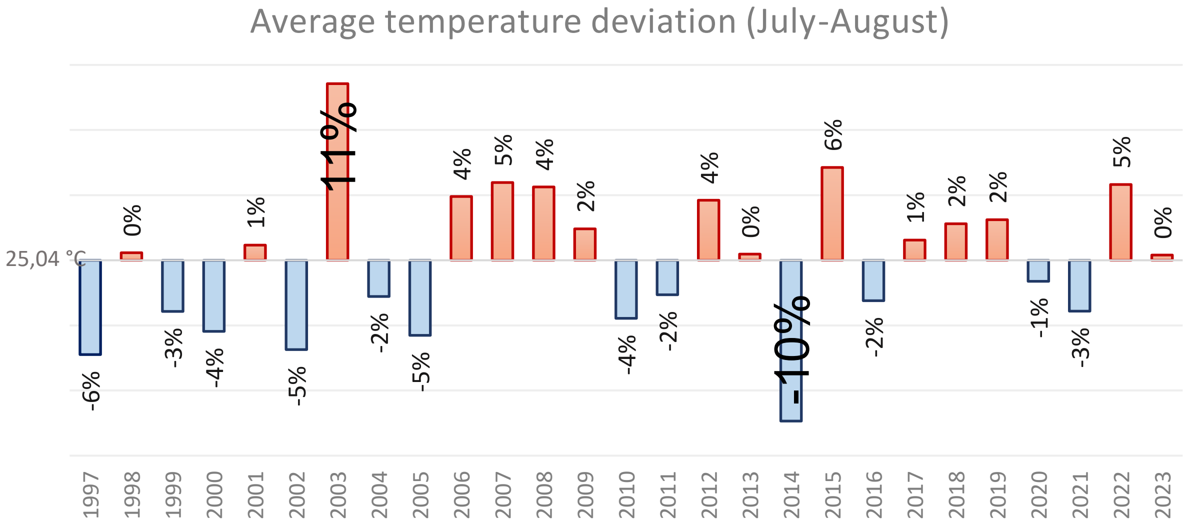


*Figure 7 - July and August average temperature deviation from the mean expressed as a percentage (1997-2023)*

In Figure 8 maximum temperature were analysed considering the yearly number of hot days (maximum temperature above 32°C – Modina et al. 2023; Zhu et al, 2020). The black line indicates the average days number, 32 (historical series 1997-2023) and, on each histogram the annual deviation from the average is expressed as a percentage. 2023 present -3% compared to the historical series 1997-2023.

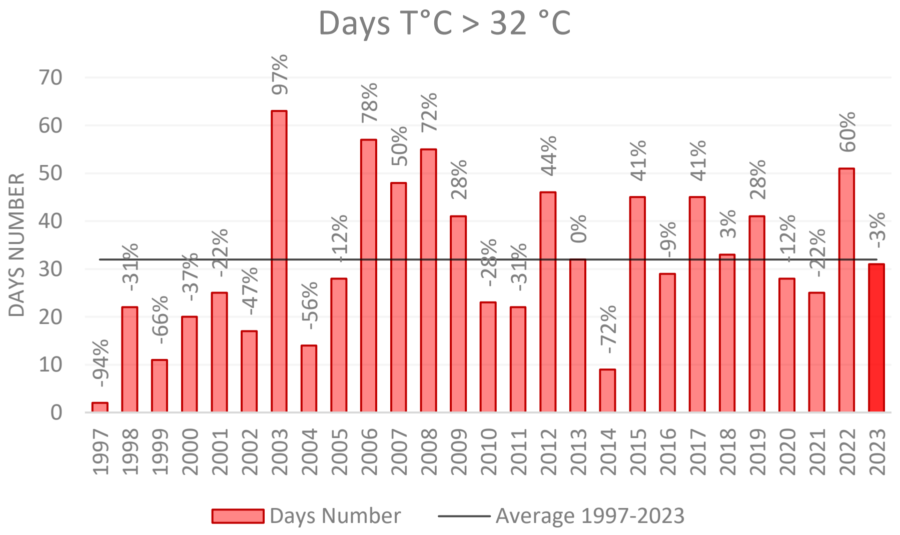


*Figure 8 - Number of Days with temperature > 32°C and annual deviation from the mean expressed as a percentage (1997-2023)*

In Figure 9, the number of annual rainy days is shown. The black line indicates the average (87 days), and the annual deviation from the mean is expressed as a percentage.

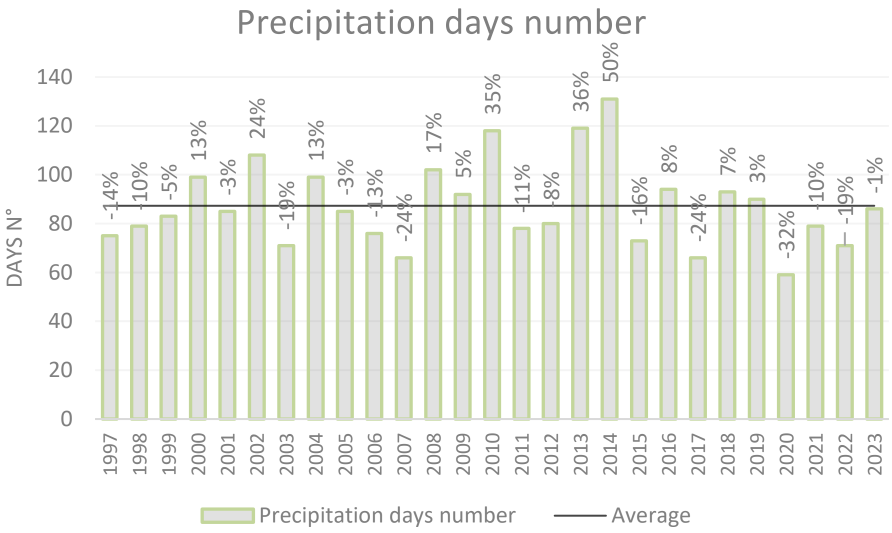


*Figure 9 - Precipitation days number and annual deviation from the mean express as percentage (1997-2023)*

### 5.1.2. Meteorological season: 2023

In figure 10, the rainfall pattern from October 2022 to September 2023 is presented. To better interpretate the viticultural season, the graph also shows the historical average from 1997 to 2023 ± standard deviation. October 2022 exhibits significantly below-average rainfall, returning to average levels in November, December, and January. February and March 2023 are characterized by much lower-than-average precipitation. The growing season begins with a rise in rainfall, which remains well above average throughout the viticultural year. In July, rainfall exceeds the standard deviation with 241 mm of precipitation, followed by August and September, where values return to be below average.

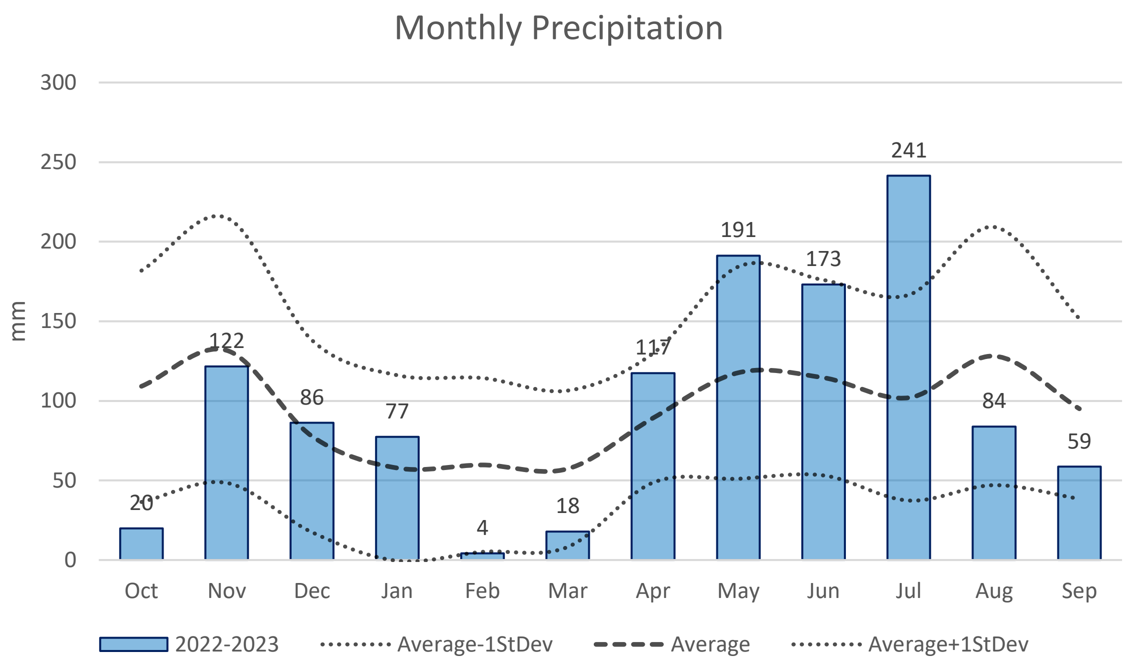


*Figure 10 - Average monthly precipitation (October 2022 – September 2023)*

In figure 11, the number of precipitation days is presented. In 2023 (blue histogram), the months of January, May, and July stand out with a higher precipitation frequency, while February, March, April, June, and August show a lower frequency compared to the 1997-2023 average (empty black histogram, figure 11). Regarding the cumulative number of rainy days from January to April 2023 (green area) experienced fewer rainy days than the historical series (black line), while from May onwards, the trend reverses with a higher cumulative number of rainy days for 2023, primarily due to the high number recorded in May.

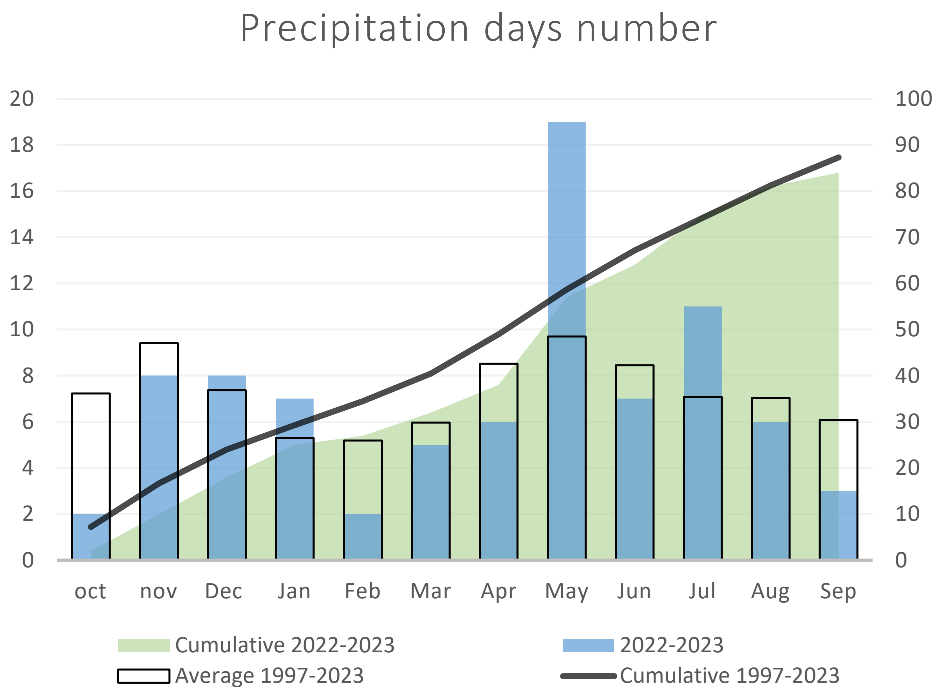


*Figure 11 - Precipitation days number (Oct 2022- Sep 2023 – Historical series 1997-2023)*

In figure 12 the average temperatures ± standard deviation of the historical series 1997-2023 are shown. The black line represents the trend from September 2022 to August 2023. From September to January, the measured temperatures are higher than the average + standard deviation, except for November, where temperatures are close to the average. Between February and March, temperatures oscillate between the average and the average + standard deviation, with a decrease in April where the blue line (average minus the standard deviation) is reached. From May to August, the 2023 temperature trend is within the average. Summarizing, the viticultural year was characterized by a warm autumn and winter (except for November), a cool April, and subsequently, temperatures from May to August were back to average.

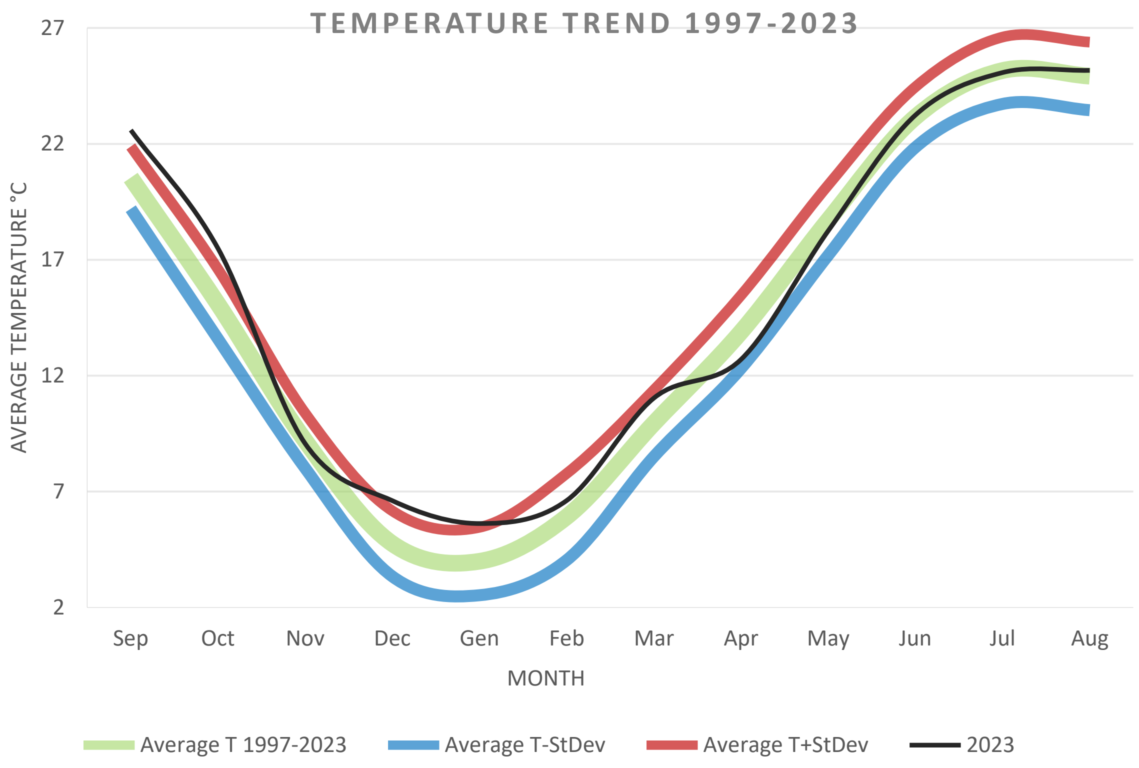


*Figure 12 - Temperature trend (2023 – Historical series 1997-2023)*

# 5.2. Shoot hedging effect

## 5.2.1. Agronomic parameter

### *5.2.1.1. Canopy architecture*

Point quadrat analysis was used to evaluate the canopy architecture, in figure 13 A it can be observed that a long hedging treatment corresponds to more 24% leaf layers in comparison with the average. The long hedging treatment also has the lowest number of external leaves and clusters (figure 13 B,C). The Ravaz index (figure 20 D) is inversely proportional to the leaf area index (figure 13 D), indicating a vegetative-reproductive imbalance as the leaf area index (LAI) increases.

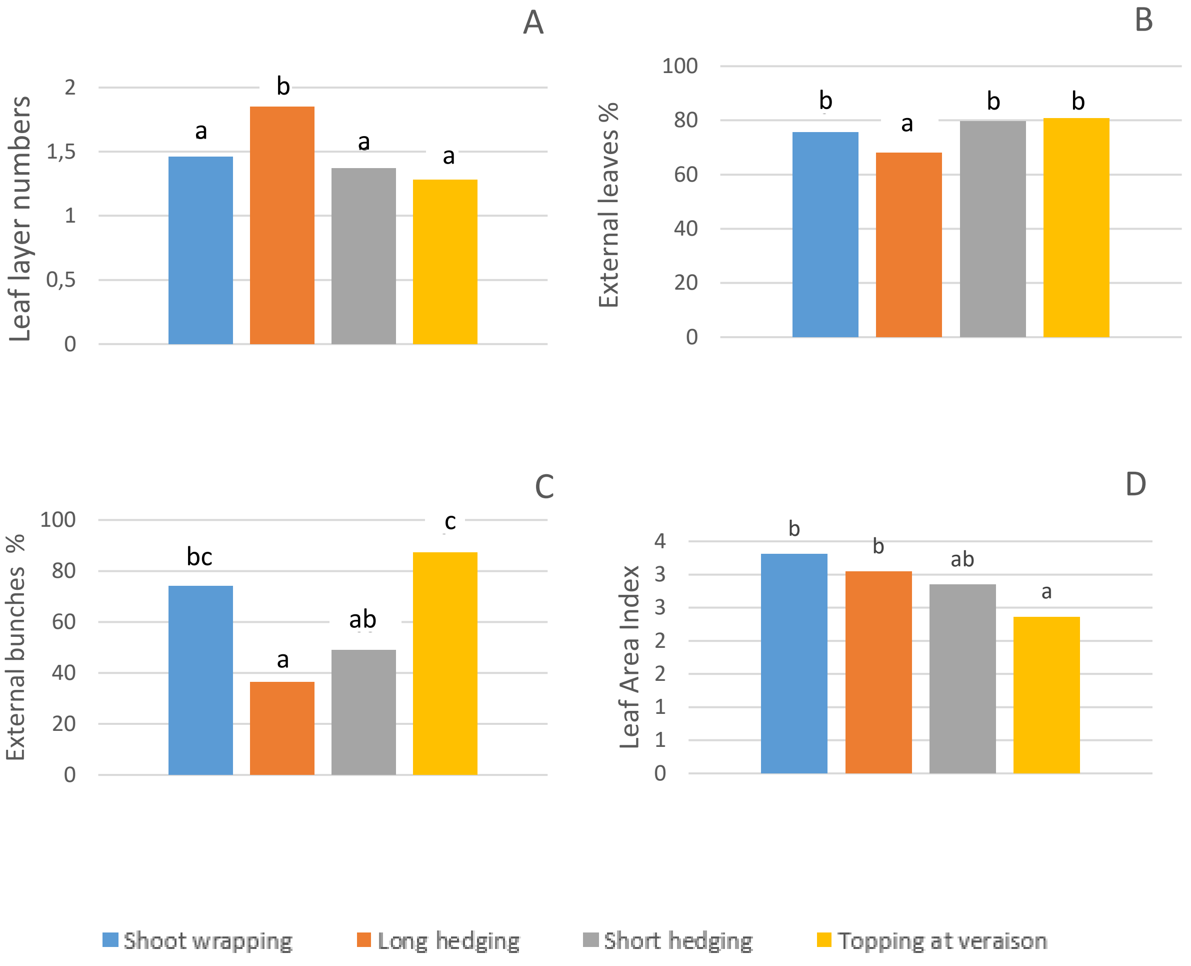


*Figure 13 - Canopy architecture parameters. A: leaf layer number. B: external leaves %. C: external bunches %. D: leaf area index. Statistical analyses performed using the ANOVA test (p value ≤ 0.05); homogeneous subsets were identified through letters with Duncan's test. Values are means (n=12). Different letters indicate significant differences.*

#### *5.2.1.2. Winter pruning weight*

Shoot wrapping treatment shows more 24% of primary wood as compared to the average (Figure 14 A). Similar result (+21%) is maintained in the measures of the total wood. Lateral shoot wood does not show difference. The treatments involve the removal of biomass and photosynthetically active tissue, and the vines responded by emitting lateral shoots, which need to grow and become photosynthetically autonomous. In this way the vines use energy to laterals growth, and it lose the tissue that should have been the most efficient in the next weeks (Poni et al. 2004). As figure 14 C shows, that results in a lower total pruning wood in the treated plants. Besides, non-topped treatment benefited from larger leaf area, which is linked to higher photosynthetic capacity and to a greater evapotranspiration potential (Munitz et al. 2019). This drew more water and allowed for greater vigour leading to a higher pruned wood weight.

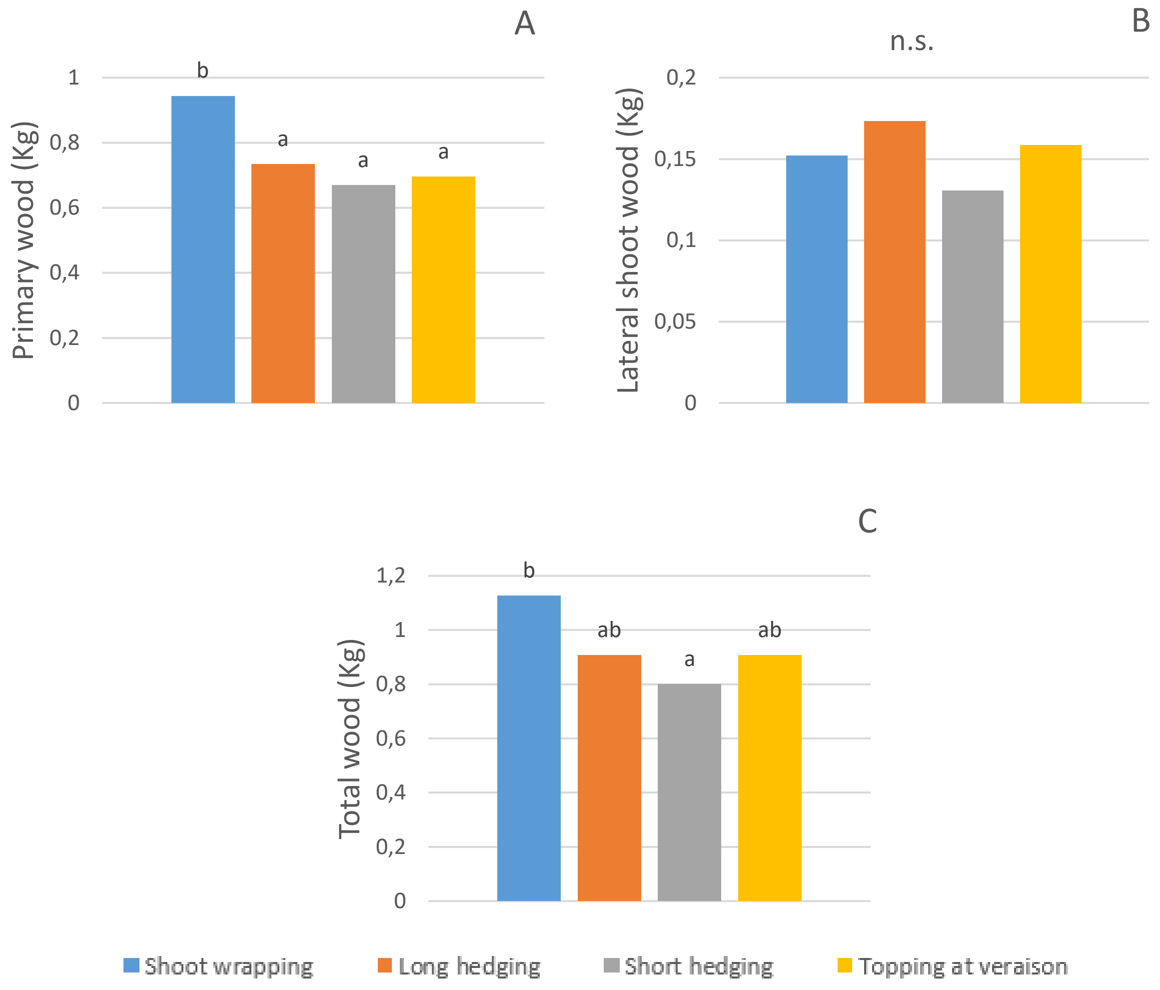


*Figure 14 - Winter pruning weight. A: Primary wood (Kg). B: Lateral shoot wood (Kg) C: Total wood (Kg). Statistical analyses performed using the ANOVA test (p value ≤ 0.05); homogeneous subsets were identified through letters with Duncan's test, n.s. indicates not significance (p > 0.05).*

Data of winter pruned wood is shown in figure 15. It is possible to distinguish the percentage of primary wood and of lateral shoot wood. The amount of wood attributable to the laterals reflects their growth dynamics under different summer pruning treatments. Differently from what expected for a dry season that limits vigour and in accordance with literature (Abad et al., 2019, Poni et al., 2023), the 2023 vintage allowed significant growth of lateral shoots, particularly in the hedging at veraison treatment, which shows the highest percentage of lateral shoots. This indicates a pronounced vegetative growth deriving by favourable environmental conditions even after veraison.

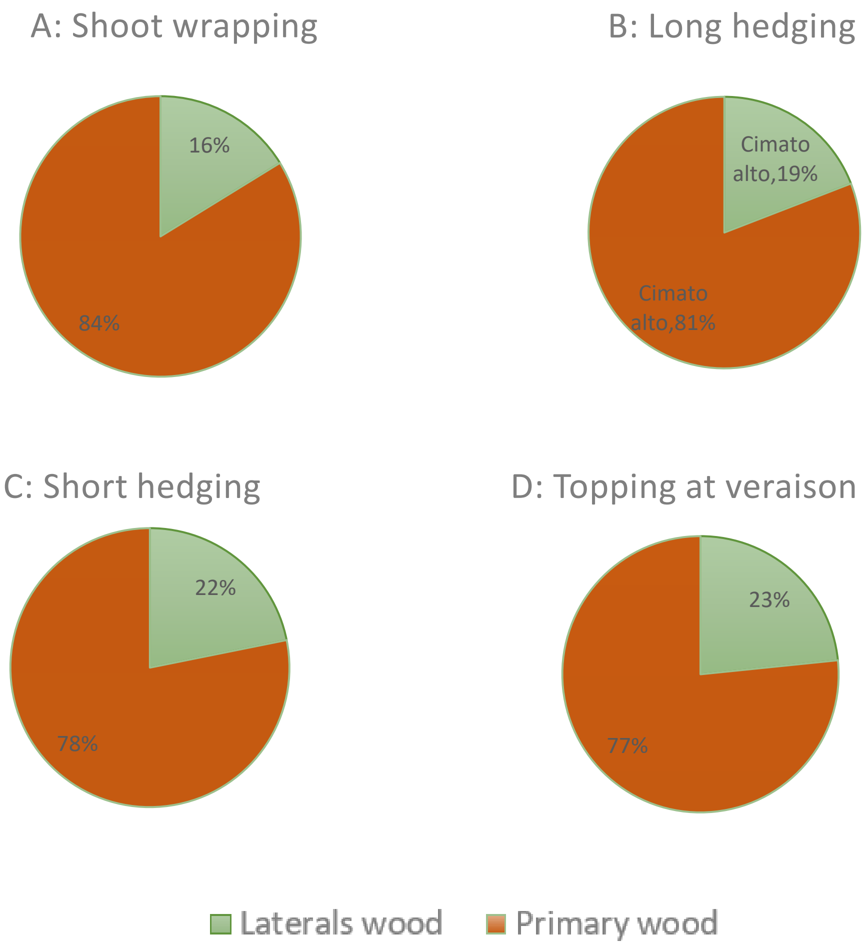


*Figure 15 - Pruned wood partition between primary wood and laterals expressed as percentage. A: Shoot wrapping. B: Long hedging. C: Short hedging. D: Topping at veraison*

#### *5.2.1.3. Laterals vigour*

Results show that the wood weight for the topping at veraison is 35% higher than the average weight (Figure 16). This can be related to the meteorological conditions and trend of 2023 season. Five days before the treatment (04/08/2023), the cumulative precipitation was 56.8 mm (figure 10), which favoured vegetative growth and high vigour of the lateral shoots. That was especially perceived in the topped at veraison treatment as compared to the others. Additionally, the average maximum and minimum air temperatures in the 10 days following the hedging were favourable to the growth (30°C and 16°C, respectively) leading to a high vegetative expression.

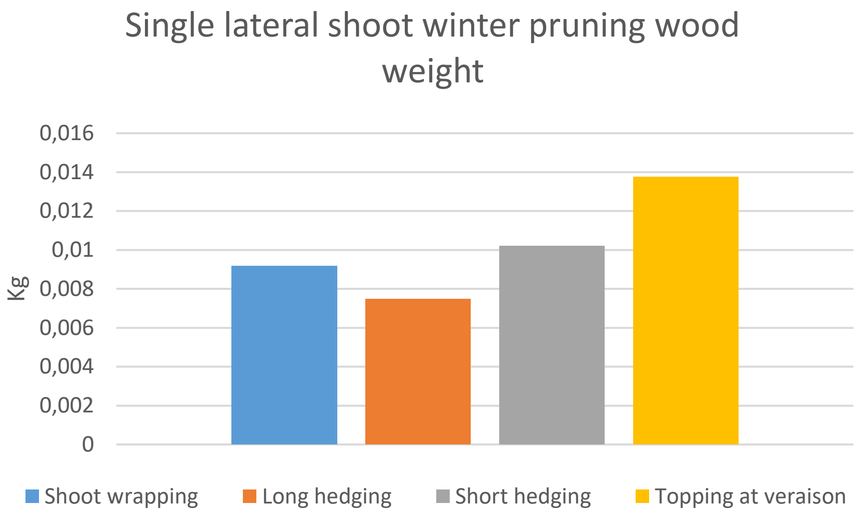


*Figure 16 - Single lateral shoot winter pruning wood weight*

### *5.2.1.4. Laterals formation dynamic*

The average number of lateral shoots observed in all the treatments result high (from 16 of the treated at veraison trial to 23 of the long hedging treated, figure 17), it is probably due to the meteorological context in which the plant developed which was characterized by moderate temperatures and high precipitation amount. The high soil water availability conditions during the plant growth leads to an increase vigour with a subsequent greater amount of lateral shoots formed (Abad et al., 2019). Further, the studied treatments imply the removal of the apical shoot that changes the hormonal balance in the shoot and promotes lateral shoot formation (Reynolds and Wardle 1989).

Also in the non-hedged treatment, the number of lateral shoots observed were medium-high, reaching an average of 20 lateral shoots per plant. Here, apical dominance is mainly maintained in the upper part of the shoot, the further we move from the vegetative apex, the less the lateral shoot is influenced by the apical dominance (the vegetative apex remains more distal, and by wrapping the shoot, auxins are more difficultly translocated via PIN carriers) (Lovisolo et al. 2002), allowing the lateral shoots to develop. That can explain the high number of laterals observed.

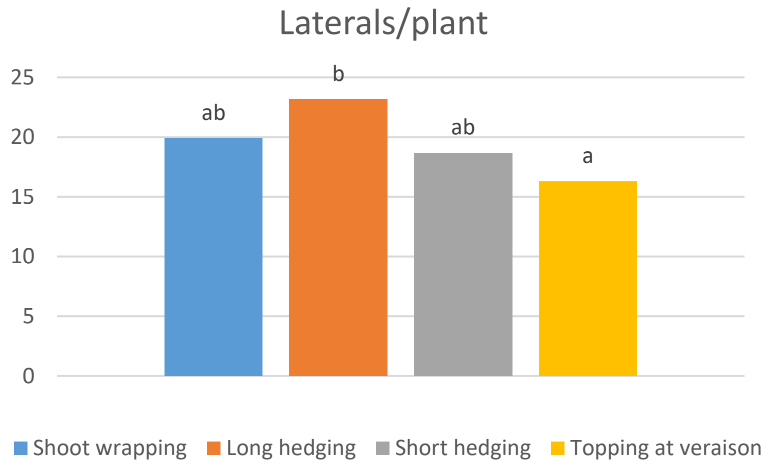


*Figure 17 - Number of lateral shoots per plant. Statistical analyses performed using the ANOVA test (p value ≤ 0.05); homogeneous subsets were identified through letters with Duncan's test.*

Figure 18 show the laterals internode number. In the shoot wrapped treatment, the plant shows more internodes on the lateral shoots. This number is in relation with the ages of the laterals. The results can be explained by the climatic trend of 2023, where high rainfall pushed vegetative growth from the start of the season. Moreover, the hedging treatments push lateral shoots formation (Reynolds and Wardle 1989), increasing their number along the growing season and thereby decreasing the average age of the laterals.

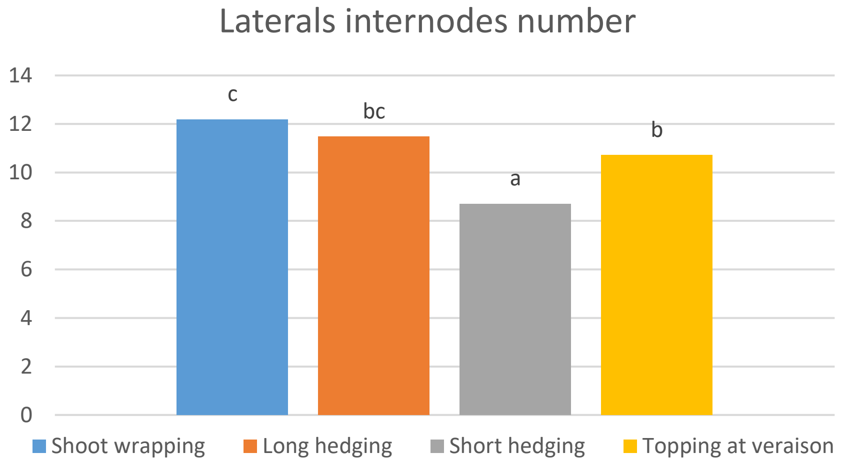


*Figure 18 - Lateral shoot internode number. Statistical analyses performed using the ANOVA test (p value ≤ 0.05); homogeneous subsets were identified through letters with Duncan's test.*

### 5.2.2. Yield parameters

As reported in the chapter 4.1 Agrometeorology, the 2023 season was characterized by elevated precipitation, which favoured the development of major vine fungal diseases (Downy mildew: causal agent *Plasmopara Viticola* and powdery mildew: causal agent *Erysiphe Necator*). The pattern can be seen especially in May with 19 days of rain (figure 11) that significantly impacted the spraying possibility and, as a result the production. It is therefore believed that the production data might have been affected by this issue. The results could thus be influenced by this problem; however, hypotheses related to vine physiology will be discussed, which will seek confirmation in subsequent years of study.

The yield per plant (figure 19 A) was higher for the treatment applied at veraison, with a 21% increase compared to the average. Additionally, the average cluster weight (figure 19 B) differs in all treatments. Indeed the cluster weight was 22 % higher in the plants treated at veraison (August 4) and which can be supposed that before hedging, the plant has an efficient canopy with a generally young average leaf age respect to the other treatments (because the plant never undergo the treatment) at the moment of hedging, the treatment remove the competition from a sink that could have given a growth boost to the cluster. As reported by Keller M. (2015), berry size may increase to compensate for the low number of berries relative to leaf area. This increase may be a result of elevated rates of sugar import due to a low sink/source ratio. Further studies would be needed to support this thesis. However, the Ravaz index (figure 20 D) results higher for the topped at veraison treatment, indicating a better vegetative-reproductive balance that can have acted on the productive parameter.

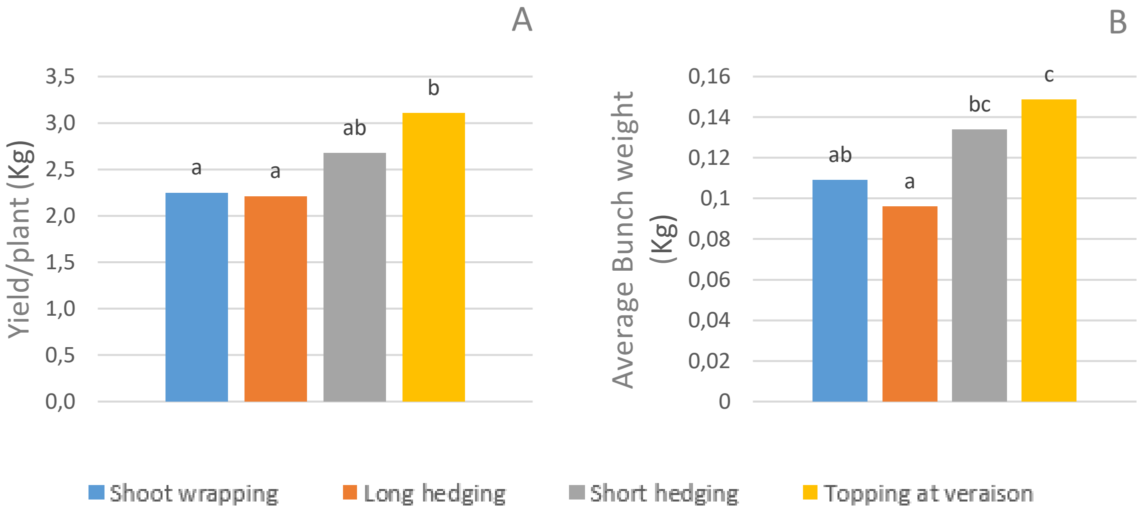


*Figure 19 – Effect of the treatment on A: Yield per plant (Kg). B: Average bunch weight (Kg). Different letters mean significant differences. Statistical analyses performed using the ANOVA test (p value ≤ 0.05); homogeneous subsets were identified through letters with Duncan's test.*

### 5.2.3. Vegetative-reproductive balance

Vegetative-reproductive balance can be assessed through many indexes. In the present research work has been decided to focus on five indexes as reported by Palliotti et al. (2018). The estimated indexes presented in Figure 20, show that vegetative growth was promoted with a higher expression of the vegetative organs. Non-optimal values of those indexes may result in excessive shading and related consequences in terms of berry quality and eventually diseases problems. Also, in figure 20 we can verify that hedging affected vegetative-reproductive balance which can be also occurring in parallel with modified sink-source relations. Our results are in accordance with Palliotti and Poni (2011) as the treatments reduced the ratio between vegetative area and yield.

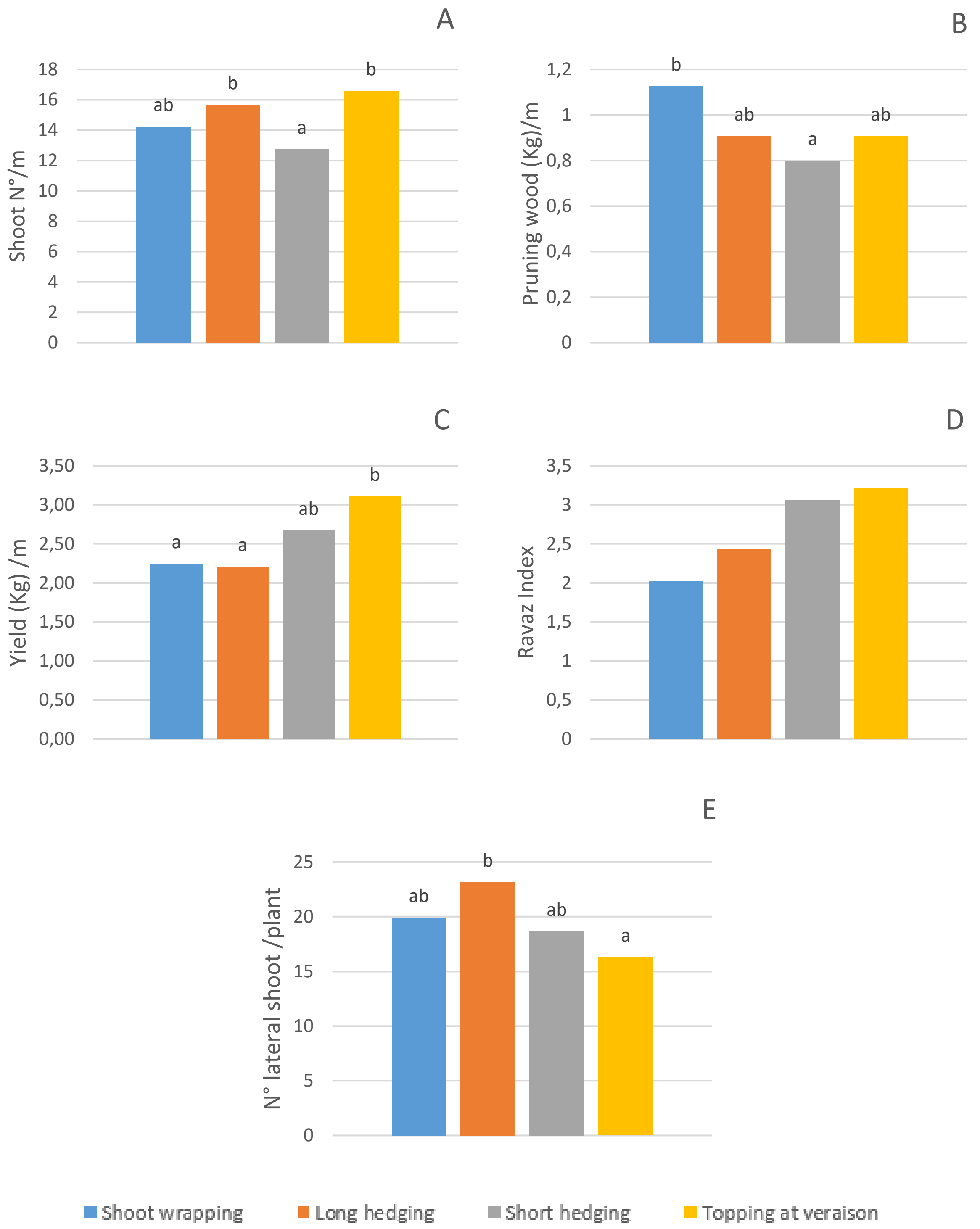


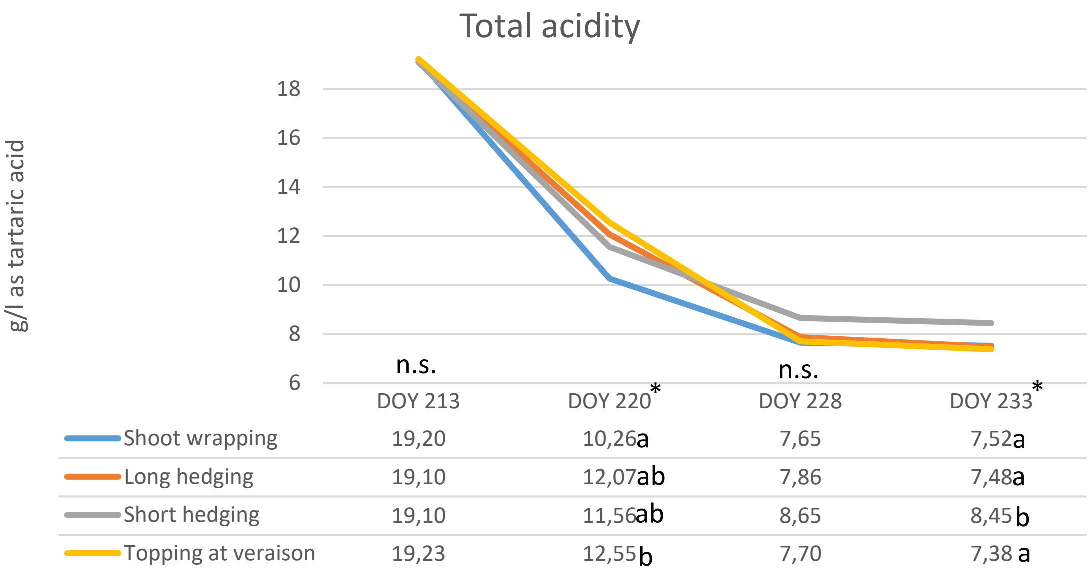
*Figure 20. Effect of the four treatments on - A: Shoot N°/m. B: Pruning wood (Kg)/m. C: Yield (Kg)/m. D: Ravaz Index Kg/Kg. E: N° lateral shoot/plant. Statistical analyses performed using the ANOVA test (p value ≤ 0.05); homogeneous subsets were identified through letters with Duncan's test.*

## 5.2.4. Berry composition

### *5.2.4.1. Total acidity, pH and organic acids*

Short hedging resulted in 0,74 g/l of titrable acidity higher than the other treatments. The results are in accordance with literature (Pulko et al 2022, Poni et al 2004) that reports that higher severity of the treatment can postpone maturation from the technological point of view.

In the case of the short hedging treatment, the reduction of the leaf wall height slowed down the decomposition of the organic acids in grape juice, which resulted in the higher total acidity. The same trend can also be observed for the malic acid content measured on the grape must.



| | DOY 213 | DOY 220* | DOY 228 | DOY 233* |
|---|---|---|---|---|
| Shoot wrapping | 19,20 | 10,26a | 7,65 | 7,52a |
| Long hedging | 19,10 | 12,07ab | 7,86 | 7,48a |
| Short hedging | 19,10 | 11,56ab | 8,65 | 8,45 b |
| Topping at veraison | 19,23 | 12,55b | 7,70 | 7,38 a |

*Figure 21. Effect of the four treatments on - total acidity expressed as g/l of tartaric acid measured during the sampling dates (01/08/2023 to 21/08/2023). Statistical analyses performed using the ANOVA test (* indicate p value ≤ 0.05, n.s. indicate not significance p value > 0.05); homogeneous subsets were identified through letters with Duncan's test.*

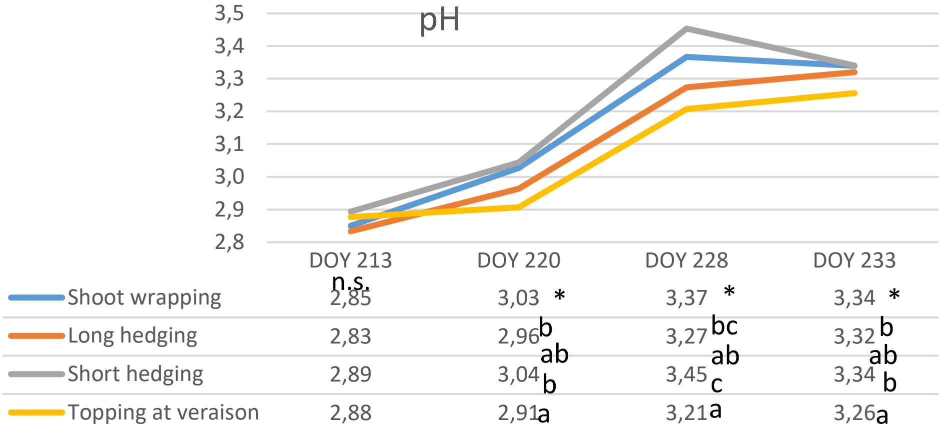


*Figure 22. Effect of the four treatments on - pH measured during the sampling dates (01/08/2023 to 21/08/2023). Statistical analyses performed using the ANOVA test (* indicate p value ≤ 0.05, n.s. indicate not significance p value > 0.05); homogeneous subsets were identified through letters with Duncan's test.*

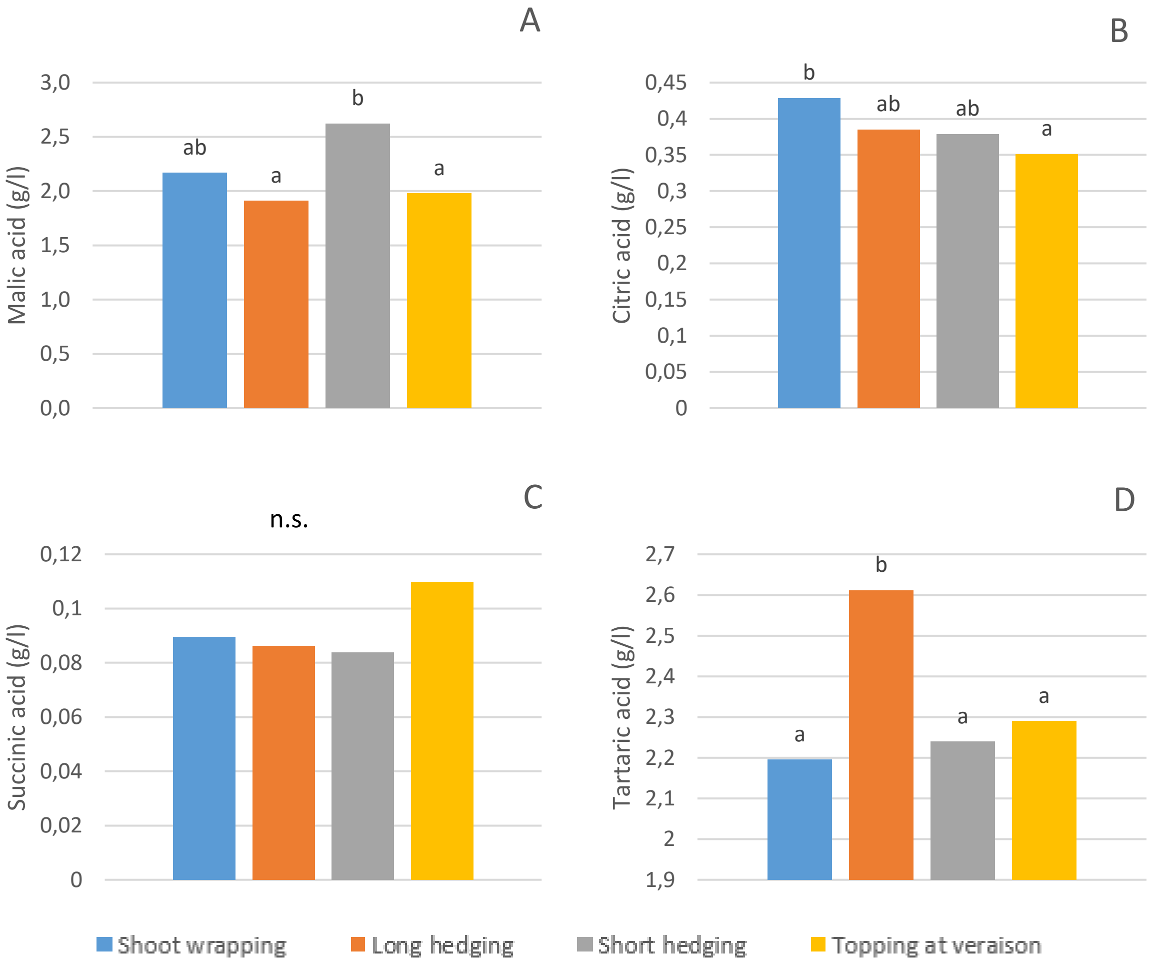


*Figure 23. Effect of the four treatments on - Organic acids measurements in the grape must. A: Malic Acid (g/l). B: Citric acid (g/l). C: Succinic acid (g/l). D: Tartaric acid (g/l). Statistical analyses performed using the ANOVA test (* indicate p value ≤ 0.05, n.s. indicate not significance p value > 0.05); homogeneous subsets were identified through letters with Duncan's test.*

Figure 24 shows the partition of the organic acids. The major difference is presented in the short hedging treatment, where the 49% of the organic acids is represented by the malic acid. As observed by Pulko et al. (2022) and previously reported, the difference can be attributed to a general delay in maturation caused by the treatments, which has postponed malic acid consumption. The other treatments report similar results among themselves.

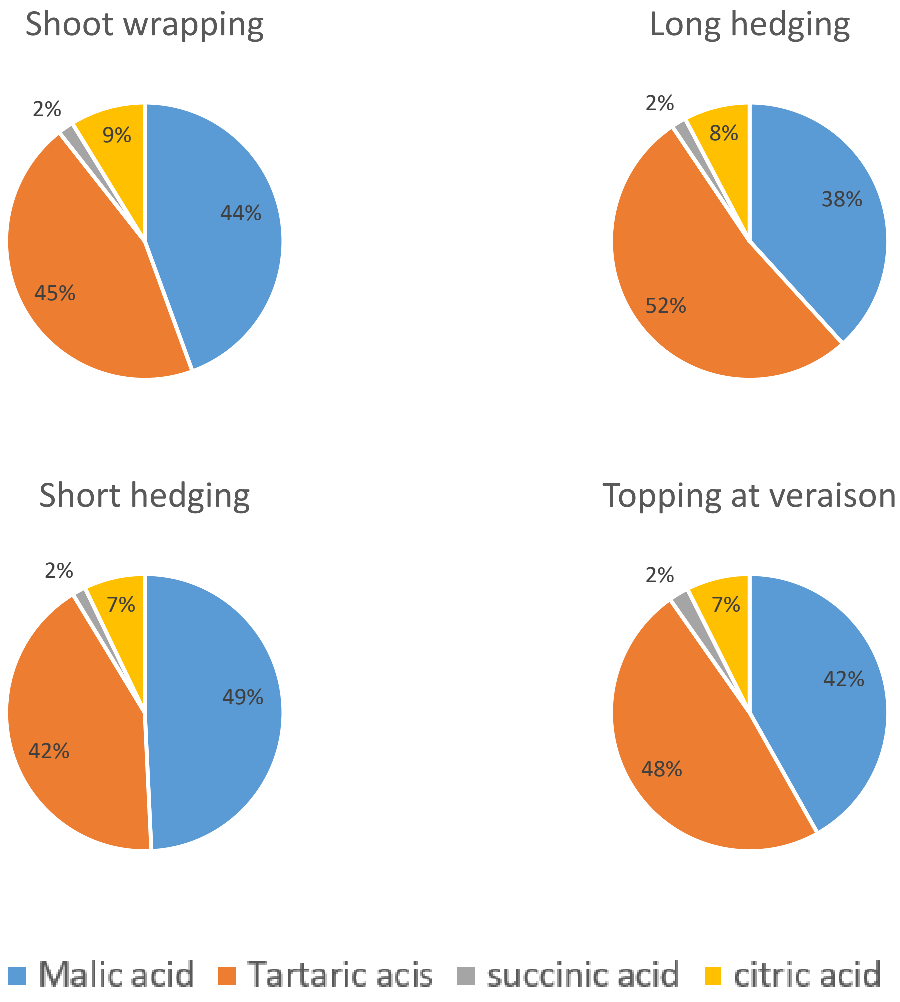


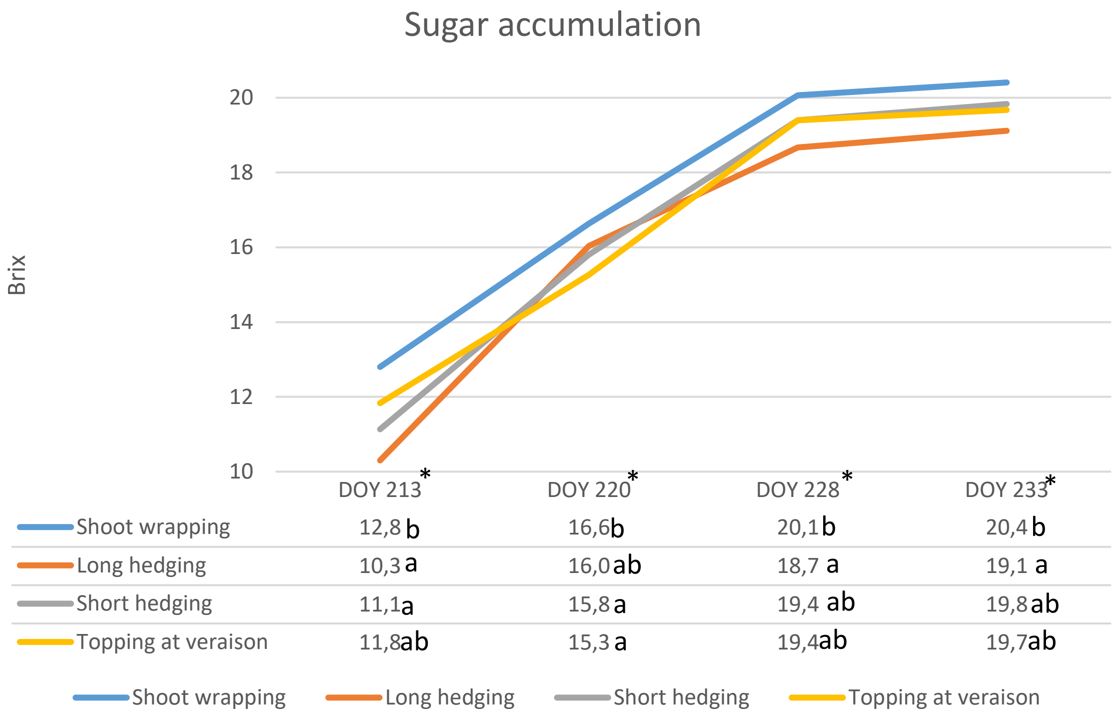
*Figure 24 – Effect of the different treatments on organic acids partition expressed as percentage.*

### *5.2.4.2. Sugar accumulation*

All the treatments involving hedging, showed lower sugar accumulation compared with non-hedged treatment (Figure 25). This is line with the previous finding (Caccavello et al. 2017, Poni et al. 2004, Pulko et al. 2022), and it can be attributed to multiple factors, including a reduction in leaf area expressed by -8% of LAI in long hedging, -14% in short hedging and -29% in topping at veraison treatments respect to the non-hedged treatment.

Moreover, the presence of older canopy leaves during ripening, decreased the photosynthetic capacity of the existing leaf area, and resulted in lower sugar accumulation at harvest (21 August) in the hedged plants. Specifically, the long hedging treatment showed a lower Brix value (less 1,3 Brix) than non-treated plants, which could be attributed to higher number of lateral shoots (figure 20 E). These shoots demand energy when they are young (hedging dates June 30, July 15, August 4) and, during berry development they acted as strong sinks, drawing photosynthates and maintaining a lower sugar concentration in the berries (Poni et al. 2023, Poni et al. 2004).

On the other hand, berries from plants subjected to shoot wrapping shows a higher value (20,4 Brix); if we correlate the total wood with a larger leaf area, it is possible to notice that the shoot wrapping resulted in greater sugar biosynthesis due to a wider leaf area that allows higher brix value (more 0,6 Brix than the average sugar accumulation).



| | DOY 213* | DOY 220* | DOY 228* | DOY 233* |
|---|---|---|---|---|
| Shoot wrapping | 12,8 b | 16,6 b | 20,1 b | 20,4 b |
| Long hedging | 10,3 a | 16,0 ab | 18,7 a | 19,1 a |
| Short hedging | 11,1 a | 15,8 a | 19,4 ab | 19,8 ab |
| Topping at veraison | 11,8 ab | 15,3 a | 19,4 ab | 19,7 ab |

*Figure 25 – Effect of treatments on sugar accumulation expressed as Brix measured during the sampling dates (01/08/2023 to 21/08/2023). Statistical analyses performed using the ANOVA test (* indicate p value ≤ 0.05); homogeneous subsets were identified through letters with Duncan's test.*

### 5.2.5. Shoot hedging remarks

The 2023 growing season was particularly rainy (figure 10), favouring vegetative growth. The high temperatures without heat waves allowed for a progression of the phenological stages. As consequence, vines showed an expressive growth of the shoots, leading to a vegetative-reproductive imbalance (figure 20) skewed towards the vegetative apparatus.

Moreover in 2023, there was a high pathogens pressure from powdery mildew and downy mildew that strongly affected the shoot hedging experimental field, increasing the unbalanced conditions of the plants.

All these factors have contributed to stress the plant with the outcome of having lower quantity and a less qualitative production. Therefore, a careful management becomes important to ensure the plant an optimal condition to growth in function of its vegetative reproductive balance.

As already reported, the path is open in three directions: short-, medium- and long-term strategies.

In the precise context of short-term adaptation strategies, it is important to underline that climate change introduces unpredictability in environmental conditions, during which the viticulturist must make the most suitable choices by adjusting vineyard management strategies according to the yearly environmental conditions.

Following the presented logic, vineyard management strategies are proposed based on meteorological pattern and the demonstrated vigour of the 2023 season:

Modulating the organic matter availability, with reference to nitrogen, less intensive nutrition allows to contain vigour in water availability season. Increasing the bud load during pruning can have a dual function: increase production and decrease the shoots development. Since the field under consideration is within a denomination of origin and therefore, subject to production limits, other techniques can be employed. For instance, avoid herbicide use, avoid mulching, and avoid continuous mechanical tillage under the row that eliminate the water competition of weeds. With the same aim, the use of cover crops can increase competitiveness and reduce water availability.

Other strategies can be discussed during vineyard implantation, such as the choice of clone and rootstock, planting density, and training system.

## 5.3. Training systems effect

### 5.3.1. Agronomic parameters

In figure 26, the parameters related to the spatial distribution of the canopy are shown. It can be observed that GDC exhibits 34% of porosity compared to Guyot 8,5% and Sylvoz 9,5%. There are no differences in the number external leaves and external clusters. GDC has a single leaf layer, while Guyot and Sylvoz have 44% and 47% more than GDC, respectively, the same trend is also reported by the leaf area index. The high porosity value of GDC indicates a low leaf light interception capacity and consequently a lower photosynthetic potential.

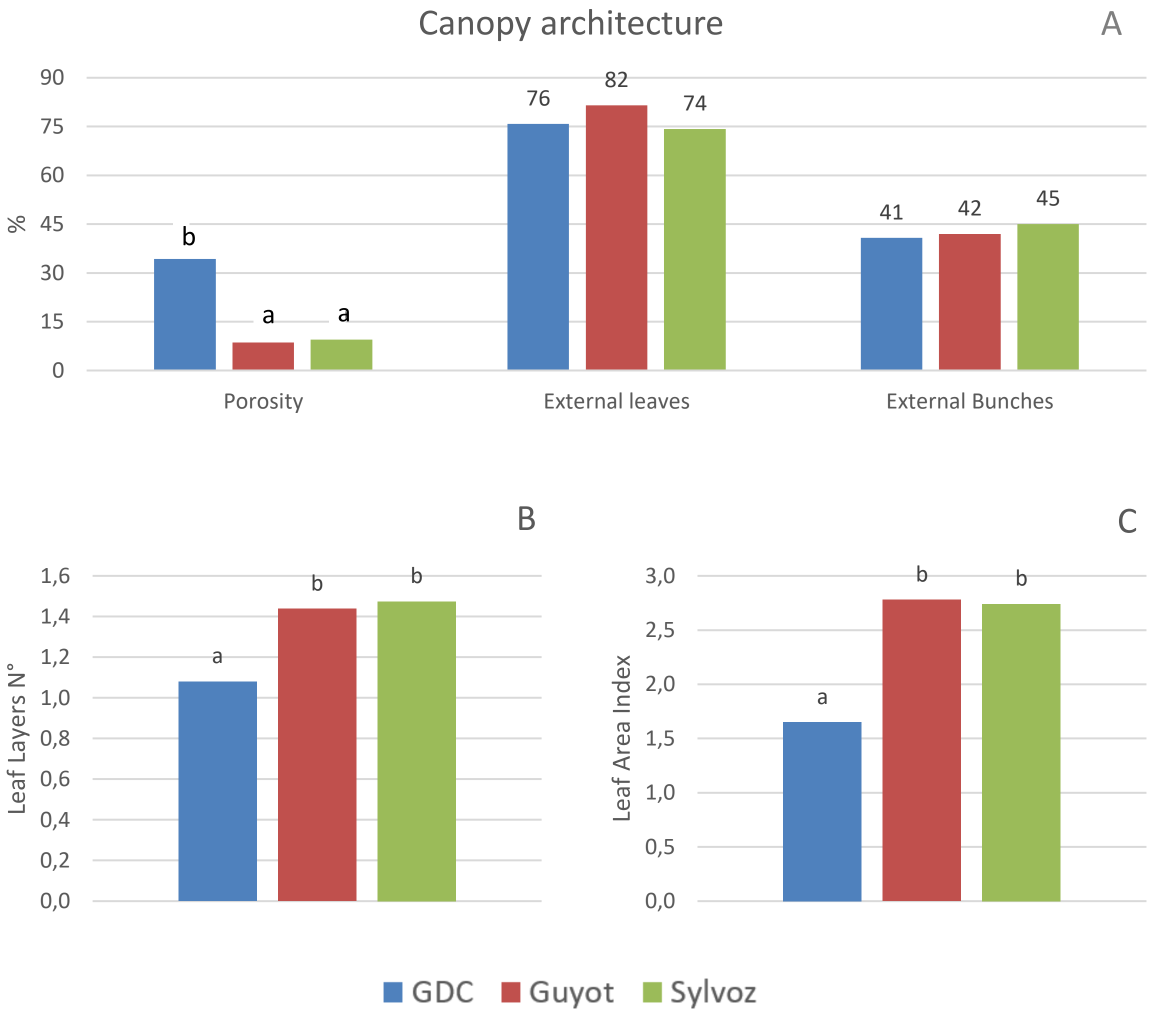


*Figure 26 - Canopy architecture and spatial distribution. A: Porosity %. External leaves %. External bunches %. B: leaf layer number. C: leaf area index. Statistical analyses performed using the ANOVA test (p value ≤ 0.05); homogeneous subsets were identified through letters with Duncan's test.*

In figure 27 the pruning wood weight is shown. It indicates a higher vegetative growth in Sylvoz, which has 21% more wood than the average, +8% in Guyot and GDC is the least vigorous -30%.

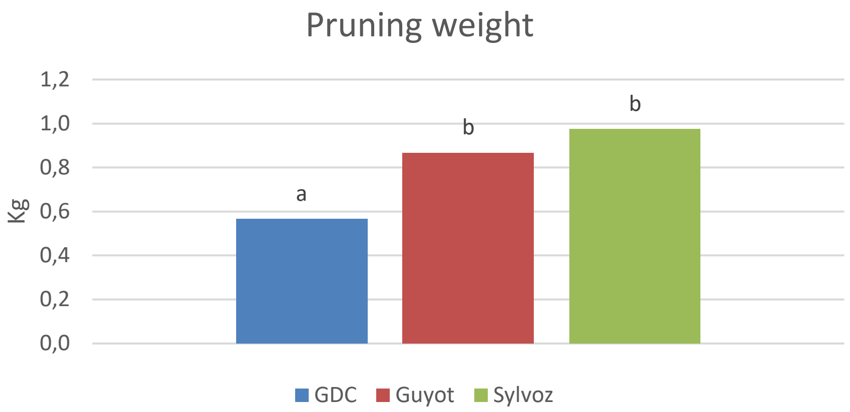


*Figure 27 - Pruning wood weight (Kg). Statistical analyses performed using the ANOVA test (p value ≤ 0.05); homogeneous subsets were identified through letters with Duncan's test.*

In figure 28 are shown the bud load and the shoot load per plant. Guyot presents 13 leaved buds while GDC has 2.4 times more bud than Guyot (+141%) and Sylvoz has 2 times more bud than Guyot (+100%). The shoot per plant maintains the same trend but with lower proportion where Guyot shows 18 shoot per plant, GDC +68% and Sylvoz +80%.

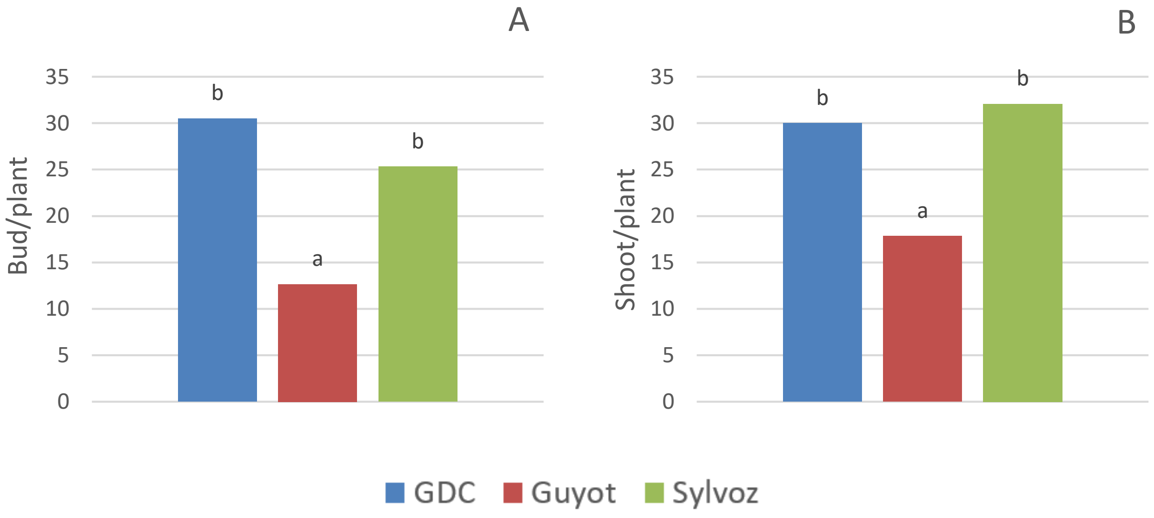


*Figure 28 - A: Leaved bud per plant. B: developed shoot per plant. Statistical analyses performed using the ANOVA test (p value ≤ 0.05); homogeneous subsets were identified through letters with Duncan's test.*

As reported in previous literature by del Zozzo and Poni (2024), GDC offer a good control on vine vigour. In figure 29, it is possible to observe that the high bud load of GDC manage the double shoot pushing, expressed by the plants. GDC has one shoot burst per bud, Guyot 1,4 shoot/bud and Sylvoz 1,3 shoot/bud.

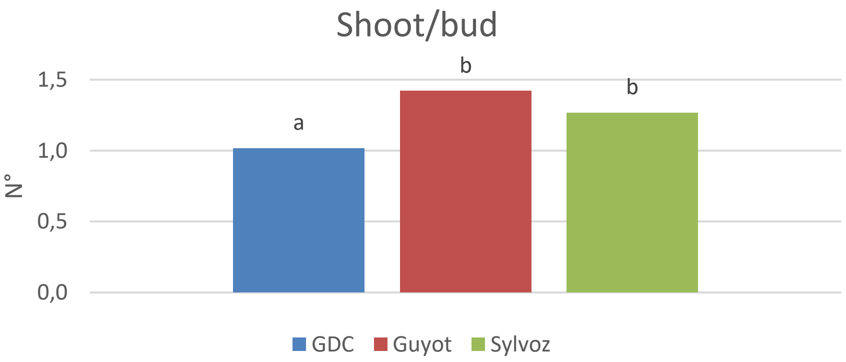


*Figure 29 - Number of shoots burst on primary bud leaved during winter pruning. Statistical analyses performed using the ANOVA test (p value ≤ 0.05); homogeneous subsets were identified through letters with Duncan's test.*

### 5.3.2. Yield parameters

In figure 30 the yield parameters are reported. Yield per plant results in GDC and Sylvoz being 30% and 52% higher than guyot, respectively. However, the planting density shows a marked difference in production per hectare where GDC (4000 plants/ha) reported +8% production more than Guyot (4830 plants/ha), while Sylvoz, due to its wider planting density (2760 plants/ha), reported -13% of yield.

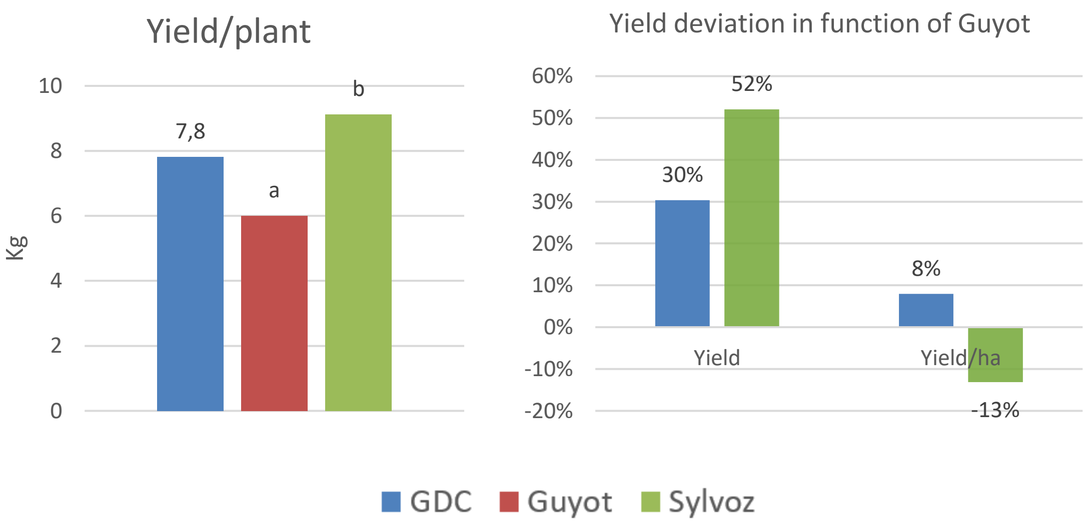


*Figure 30 - Yield per plant and yield deviation from Guyot on plant and on hectares (%). Statistical analyses performed using the ANOVA test (p value ≤ 0.05); homogeneous subsets were identified through letters with Duncan's test.*

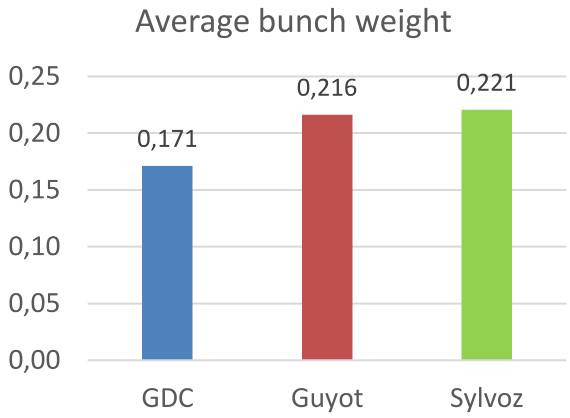


*Figure 31 - Average bunch weight. Statistical analyses performed using the ANOVA test (p value ≤ 0.05); homogeneous subsets were identified through letters with Duncan's test.*

### 5.3.3. Vegetative-reproductive balance

Vegetative-reproductive balance can be assessed through many indexes. As in case of the short-term adaptation strategy, the four indexes as reported by Palliotti et al. (2018) have been investigated.

From the evaluation of the vegetative-reproductive indexes (figure 32), it is noted that Sylvoz presents values within the optimal range, GDC shows values strongly inclined towards high production, and Guyot has high vegetative values, which are balanced by a high production.

In the GDC treatment, such a high imbalance can lead to a shortage of carbohydrates and can negatively affect vine fertility in the subsequent year due to the decreased carbohydrate availability for bunch and flower initiation/differentiation (Bennett al. 2005).

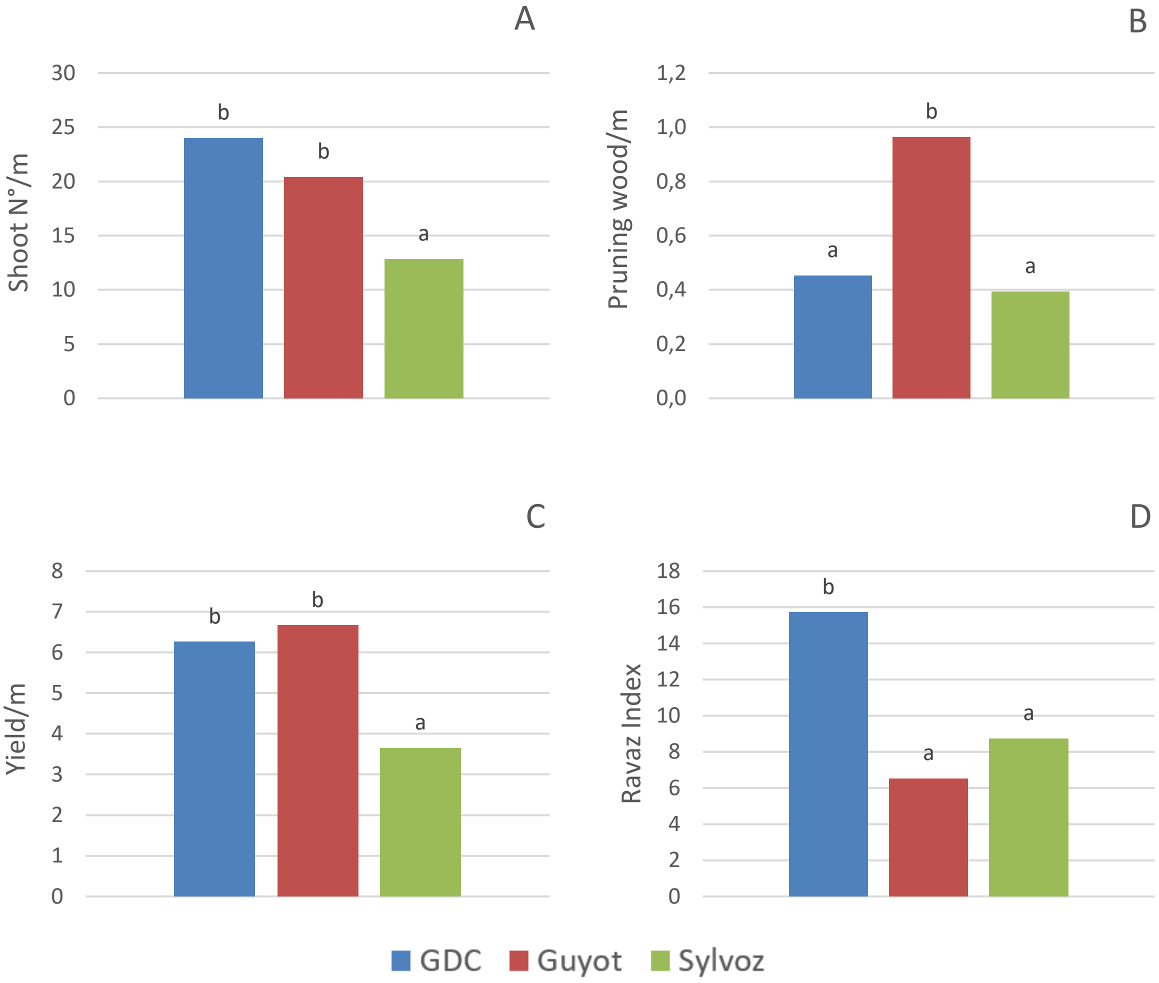
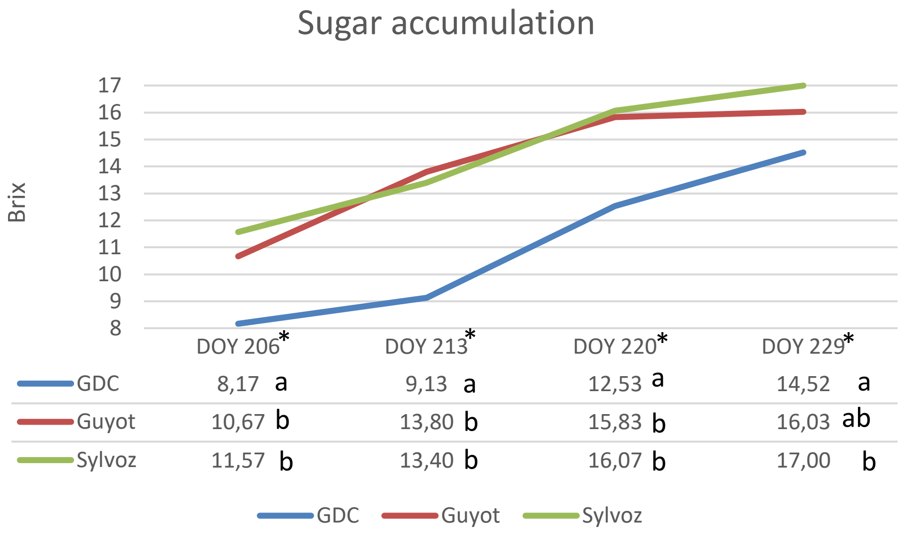


*Figure 32 - Vegetative-reproductive indexes. A: Shoot N°/m. B: Pruning wood/m. C: Yield/m. D: Ravaz Index. Statistical analyses performed using the ANOVA test (p value ≤ 0.05); homogeneous subsets were identified through letters with Duncan's test.*

## 5.3.4. Berry composition

### *5.3.4.1. Sugar accumulations*

As shown in figure 33, during all ripening period, Guyot and Sylvoz maintain the same sugar accumulation trend, while GDC shows consistently lower sugar level. At harvest, Guyot reaches 16 Brix, while Sylvoz reaches 17 (+6%) and GDC 14.5 (-9%). The lower sugar accumulation in the GDC treatment could be attributed to a higher bud load, yield, and number of clusters compared to Guyot. In accordance with Del Zozzo and Poni (2024), these factors have resulted in delayed maturation. Moreover, the point quadrat analysis showed that GDC has less canopy expansion, leading to a smaller photosynthetic area and consequently lower sugar accumulation at harvest.

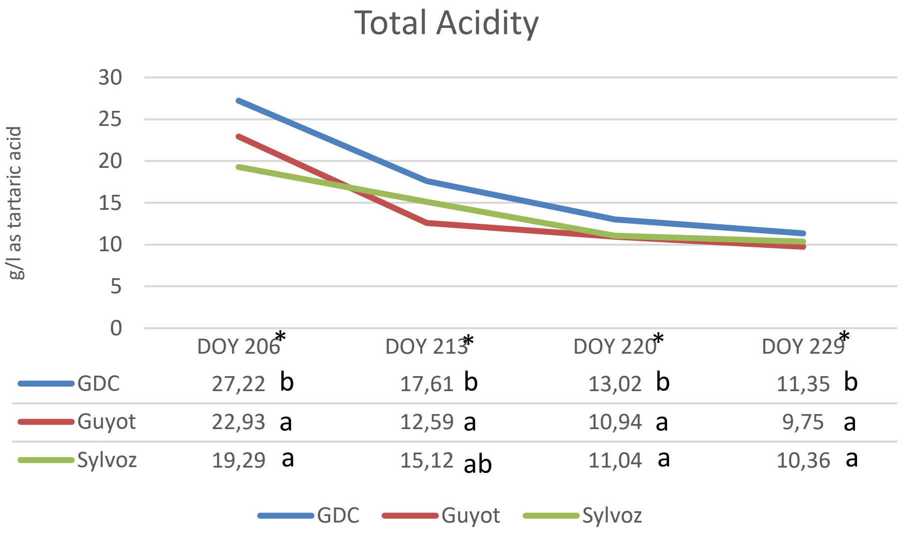


| | DOY 206* | DOY 213* | DOY 220* | DOY 229* |
|---|---|---|---|---|
| GDC | 8,17 a | 9,13 a | 12,53 a | 14,52 a |
| Guyot | 10,67 b | 13,80 b | 15,83 b | 16,03 ab |
| Sylvoz | 11,57 b | 13,40 b | 16,07 b | 17,00 b |

*Figure 33 - Sugar accumulation expressed as Brix measured during the sampling dates (25/07/2023 to 17/08/2023). Statistical analyses performed using the ANOVA test (* indicate p value ≤ 0.05) homogeneous subsets were identified through letters with Duncan's test.*

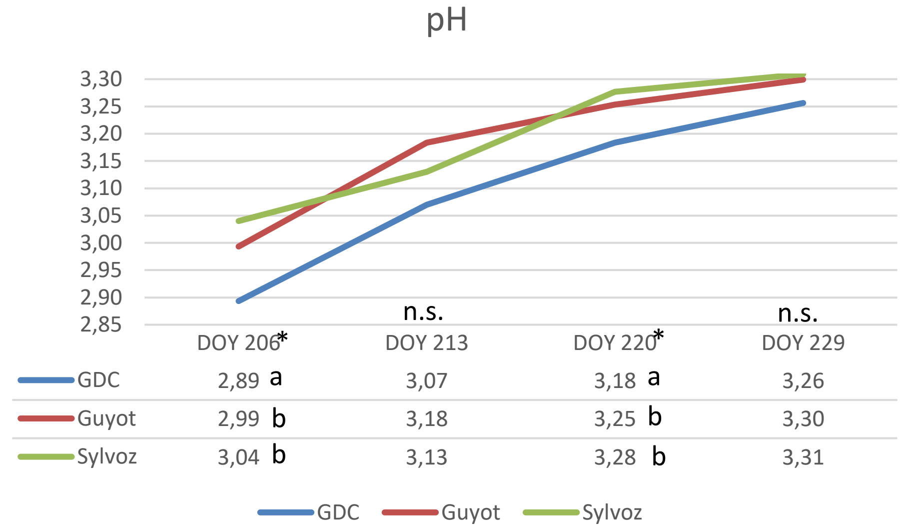
#### *5.3.4.2. Total acidity, pH and organic acids*

The trend in total acidity (figure 34) during all the samplings remained the same for Guyot and Sylvoz, with a faster decrease for Guyot. On 25/07/2023, Guyot displays 22.9 g/l as tartaric acid and reached 9.75 g/l at harvest, while Sylvoz exhibits 19.3 g/l on the first day of sampling and reached 10.4 g/l at harvest. This indicates a faster degradation for Guyot and a +6% higher acidity for Sylvoz. GDC benefited from a higher initial acidity value of 27.2 g/l as tartaric acid and, it has been degraded to 11.35 g/l by August 17. Thus, GDC maintained higher acidity, with a +16% compared to Guyot. These results can be attributed to a general delay in maturation of GDC due to the heavy crop load (figure 30) and less developed vegetative apparatus (figure 26).



| | DOY 206* | DOY 213* | DOY 220* | DOY 229* |
|---|---|---|---|---|
| GDC | 27,22 b | 17,61 b | 13,02 b | 11,35 b |
| Guyot | 22,93 a | 12,59 a | 10,94 a | 9,75 a |
| Sylvoz | 19,29 a | 15,12 ab | 11,04 a | 10,36 a |

*Figure 34 - total acidity expressed as g/l of tartaric acid measured during the sampling dates (25/07/2023 to 17/08/2023). Statistical analyses performed using the ANOVA test (* indicate p value ≤ 0.05); homogeneous subsets were identified through letters with Duncan's test.*



| | DOY 206* | n.s.<br>DOY 213 | DOY 220* | n.s.<br>DOY 229 |
|---|---|---|---|---|
| GDC | 2,89 a | 3,07 | 3,18 a | 3,26 |
| Guyot | 2,99 b | 3,18 | 3,25 b | 3,30 |
| Sylvoz | 3,04 b | 3,13 | 3,28 b | 3,31 |

*Figure 35 - pH measured during the sampling dates (25/07/2023 to 17/08/2023). Statistical analyses performed using the ANOVA test (* indicate p value ≤ 0.05, n.s. indicate not significance p value > 0.05); homogeneous subsets were identified through letters with Duncan's test.*

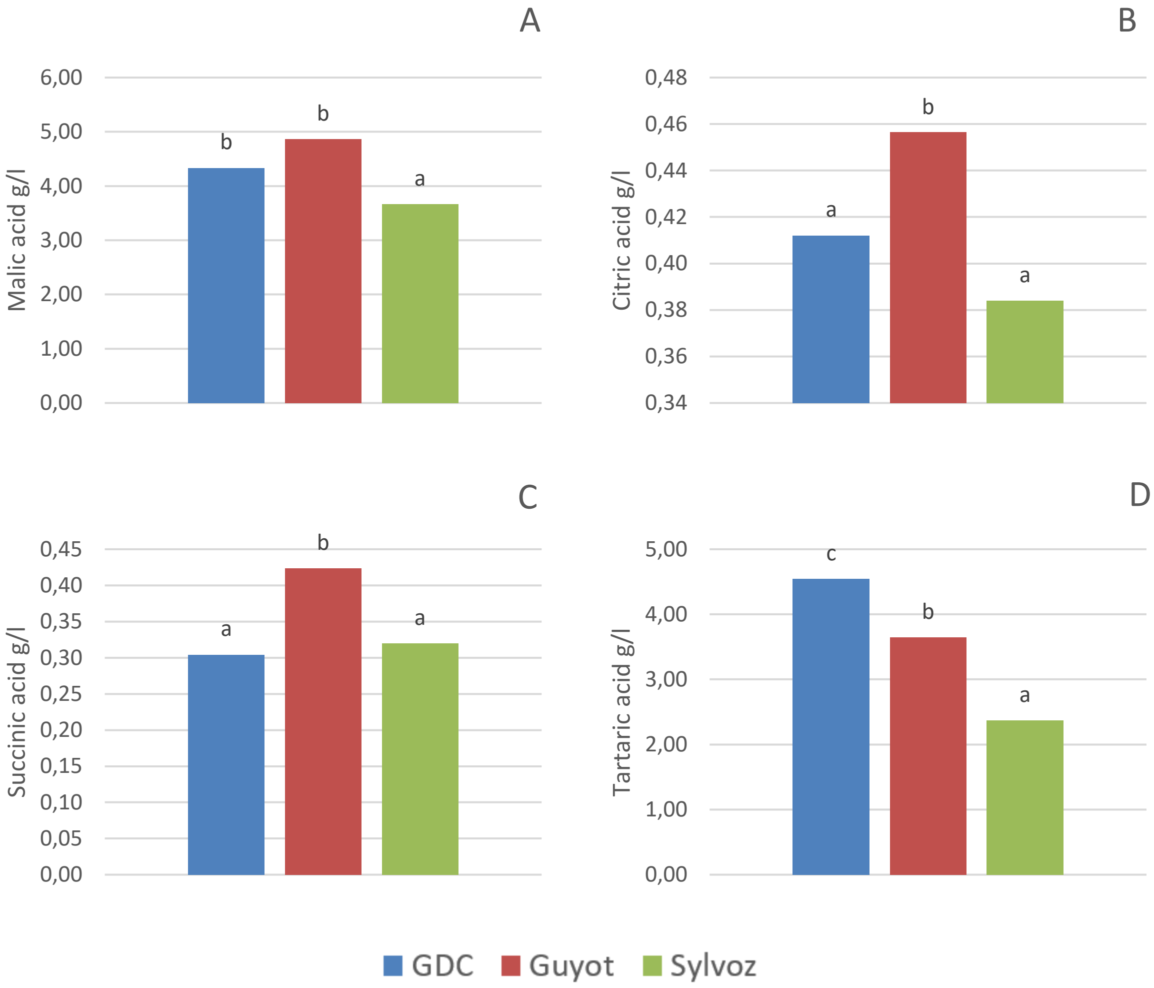


*Figure 36 - Organic acids measurements in the grape must. A: Malic Acid (g/l). B: Citric acid (g/l). C: Succinic acid (g/l). D: Tartaric acid (g/l). Statistical analyses performed using the ANOVA test (p value ≤ 0.05); homogeneous subsets were identified through letters with Duncan's test.*

As shown in Figure 34, GDC exhibits a delayed ripening process compared to the other treatments, maintaining higher acidity levels. Figure 36 displays the amount of tartaric acid in g/l, showing GDC with higher values than Guyot and Sylvoz. In Figure 37, it is observed that the percentage of tartaric acid accounts for 47% of the total acidity, which is higher compared to Guyot (39%) and Sylvoz (35%). In Guyot and Sylvoz, most of the acidity is composed of malic acid, representing 52% and 54%, respectively, with a similar distribution for the other main acids (tartaric, citric, and succinic).

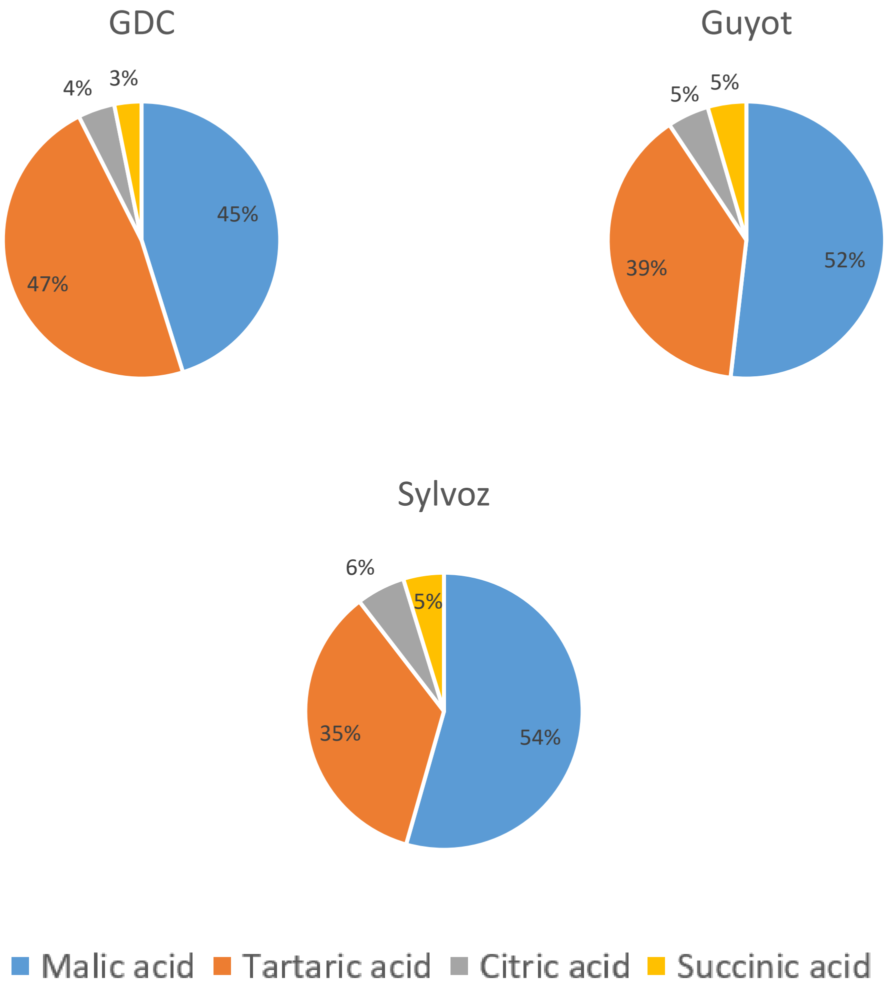


*Figure 37 - Organic acids partition among the treatments expressed as percentage.*

### 5.3.5. Training system remarks

Results obtained for the 2023 season, shows that the training systems can be grouped according to similar trend such as Guyot and Sylvoz. Harvest data shows that they have comparable technological parameters. Sylvoz maintains a better vegetative-reproductive balance but offers lower yields per hectare compared to Guyot.

As reported in literature (Del Zozzo and Poni, 2024), the GDC differs from the two other training system due to its delayed ripening, higher acidity, and lower sugar accumulation. These results are favoured by a high yield and a less developed vegetative apparatus compared to the other experimental trials.

The weather conditions of the 2023 season favoured vegetative growth due to the high rainfall during the growing season. In the case of the training system experiment, a high number of buds left at pruning help to control vigour. It offers a dual perspective: on one hand, that includes an increase in yield, and on the other, the possibility to delay maturation while maintaining good acidity, which is particularly interesting for sparkling wine production that characterized the studied area. However, technological parameters are not the only ones that drives wine overall quality, it is also dependent by the sensorial analysis (Chapter 6).

# 6. Wine analysis

The vinification process followed the same winemaking protocol for both the experiments, with the minimal intervention of adjuvants and additives in order to evaluate the oenological potential of each experimental plot.

## 6.1. Impact of shoot hedging

Vinification was carried out for only 3 of the 4 treatments (Long hedging, Short hedging and shoot wrapping). Data from wine analysis (figure 38) shows similar level of malic acid for all the treatments considered. No differences in volatile acidity and an increase of 0,6 g/l of total acidity was shown by shoot wrapping treatment when compare with hedged treatment. The alcohol content was the same in shoot wrapping and long hedging, while present 0,5 v/v more in short hedging treatment.

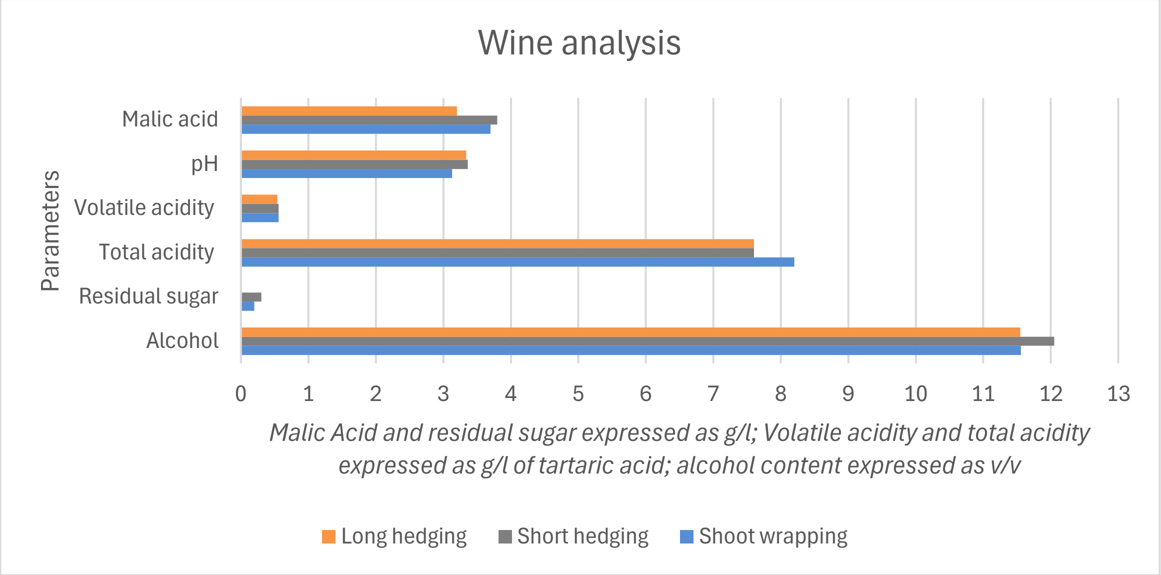


*Figure 38 Effect of the three treatments (Long hedging, Short hedging and Shoot Wrapping) on wine characteristic. Malic Acid and residual sugar expressed as g/l; Volatile acidity and total acidity expressed as g/l of tartaric acid; alcohol content expressed as v/v.*

In figure 39 the sensorial analysis in reported. The testing panels did not indicate a sharp difference in the considered parameters. Shoot wrapping shows a higher complexity and higher structure with an emphasized alcohol perception. Short hedging was characterised from higher bitterness with well-expressed honey, vegetal and citrus notes. Long hedging represents similar character but less expressed.

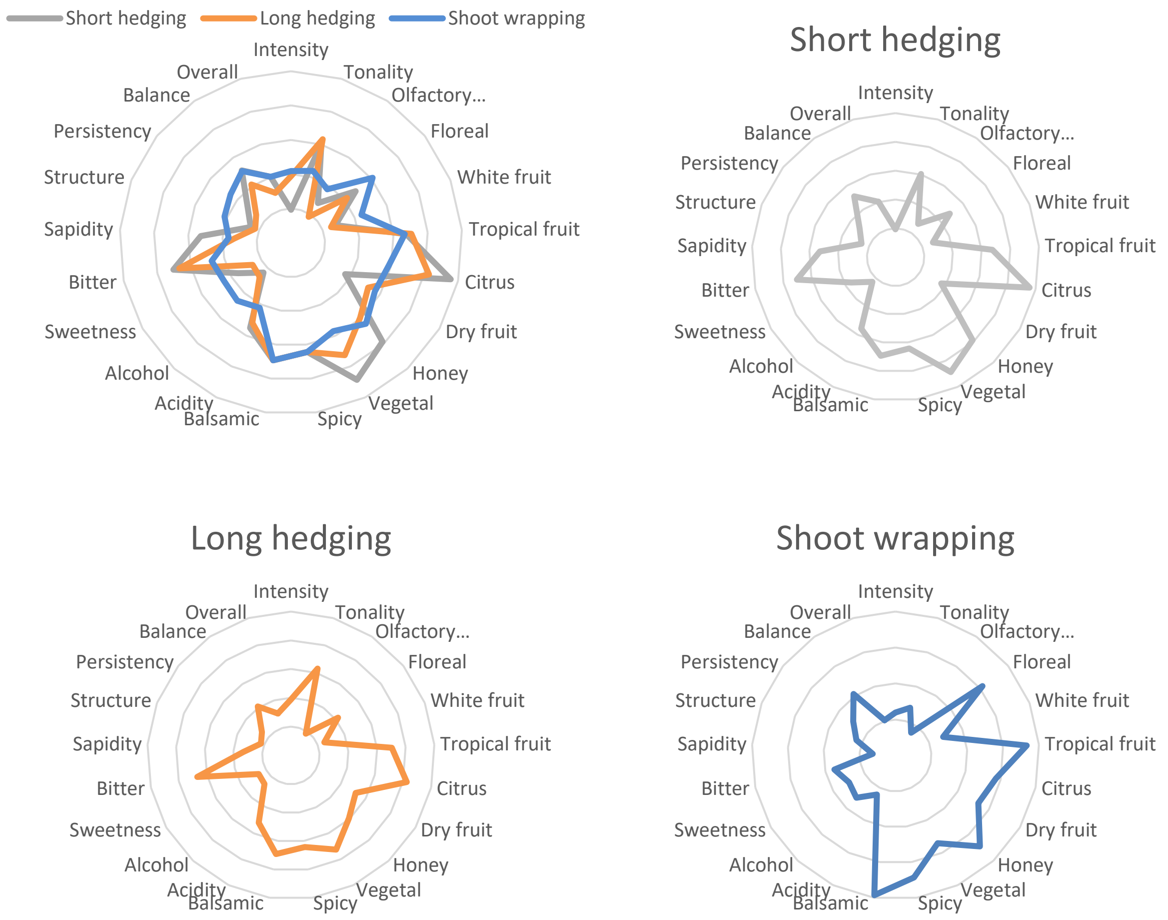


*Figure 39 – Effect of the three treatments (Long Hedging, Short Hedging and Shoot Wrapping) on diverse wine sensorial traits such as visual characters (Intensity, Tonality), olfactory characters (Intensity, Floreal, White fruit, Tropical fruit, Citrus, Dry fruit, Honey, Vegetal, Spicy, Balsamic), gustatory characters (Acidity, Alcohol, Sweetness, bitter, sapidity, structure, persistence) and overall quality.*

## 6.2. Impact of the training system

Results show 20% higher values of Total acidity for Guyot and Sylvoz training systems as compared to GDC. The alcohol content is higher for Sylvoz and Guyot and lower for GDC, mainly due to the different initial sugar content (GDC -9% Brix). The wine analysis shows amount of malic acid that strongly differs in GDC, which showed values below 1 g/l, whereas Guyot and Sylvoz training systems presented values above 5 g/l of malic acid. Furthermore, the volatile acidity where higher in GDC. These two factors indicate a possible microbiological contamination, which had as substrate malic acid, leading to a greater production of acetic acid.

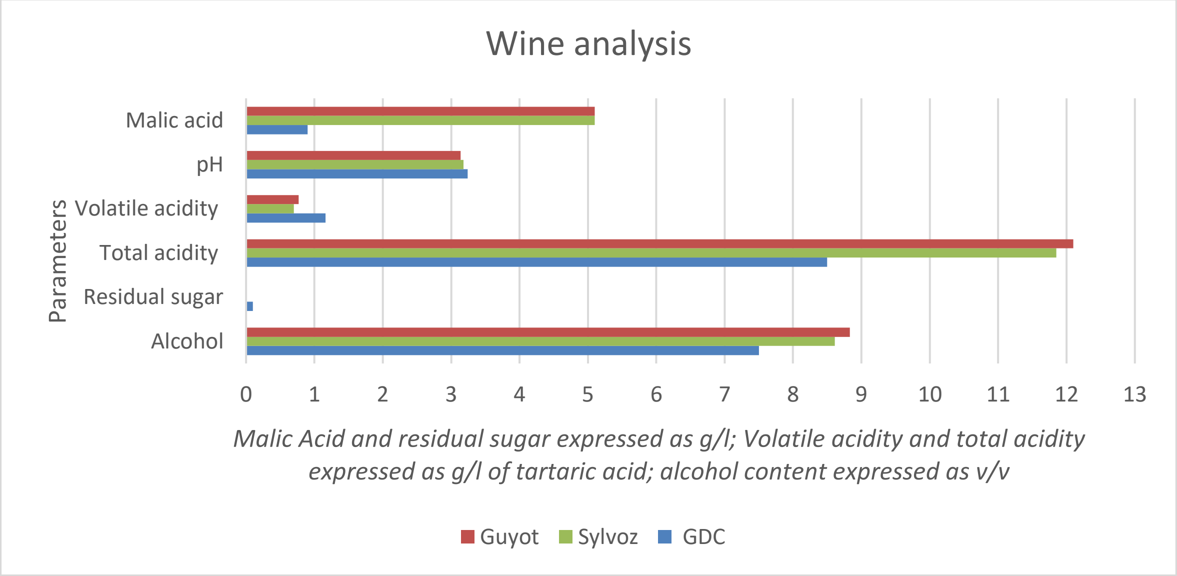
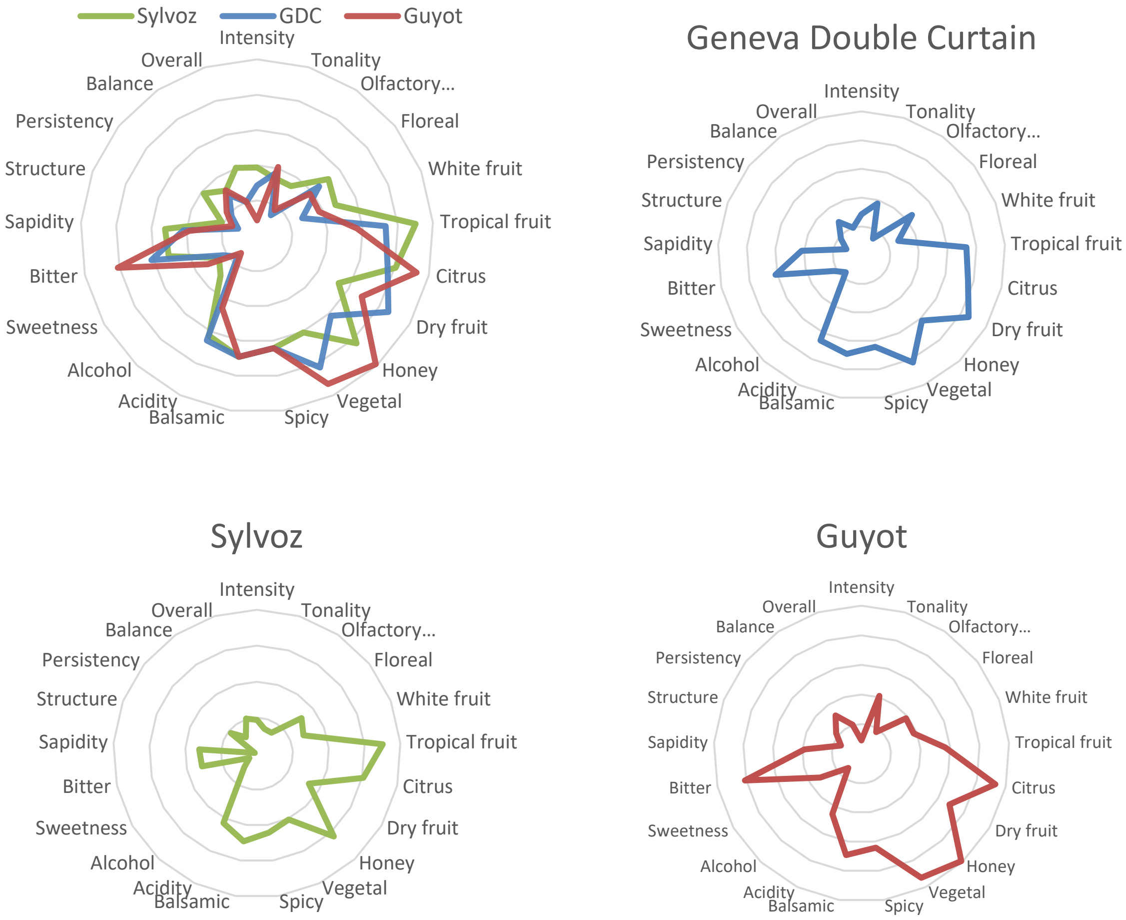


*Figure 40 - Effect of the three training systems (Guyot, Sylvoz and GDC) on wine sensorial analysis. Malic Acid and residual sugar expressed as g/l; Volatile acidity and total acidity expressed as g/l of tartaric acid; alcohol content expressed as v/v.*

Wine tastings did not reveal a clear preference. Wine sensorial analysis is reported in figure 41. Guyot stands out for resulting in wines with more vegetal, honey, and citrus notes, and also offering greater bitterness. GDC and Sylvoz maintained a more similar profile, where Sylvoz differentiated itself by a slightly greater aromatic intensity, with more pronounced floral and tropical notes, as well as better balance. GDC presented more vegetal and dried fruit notes compared to Sylvoz, with an overall assessment similar to Guyot but inferior to Sylvoz.



Geneva Double Curtain

Sylvoz

Guyot

*Figure 41 - Effect of the three training systems (Guyot, Sylvoz and GDC) on wine sensorial analysis. Parameter considered: visual characters (Intensity, Tonality), olfactory characters (Intensity, Floreal, White fruit, Tropical fruit, Citrus, Dry fruit, Honey, Vegetal, Spicy, Balsamic), gustatory characters (Acidity, Alcohol, Sweetness, bitter, sapidity, structure, persistence) and overall quality.*

# 7. Conclusions

The objective of a sustainable agricultural system is to enable the vine to express its productive and qualitative potential while maintaining efficiency over time without compromising the longevity of the plants. This can be achieved through a vegetative-reproductive balance in vineyard and in vines themselves.

A major limitation of the present study resides in comparing treatments with different planting density in the case of the training system experiment. This could have influenced the results obtained, and it is therefore recommended to take this limitation into account. For future research, it would be interesting to evaluate the results with the same number of plants per hectare.

In the context of the DOCG Franciacorta, this was not possible because the vineyards under study are commercial vineyards assigned for the production of Franciacorta DOCG, and they are subject to the product specifications that only allow training systems with vertical shoot positioning (VSP). For the purposes of this work, the study relied on the few vineyards with non-VSP training system that predate the product specifications, which allow their use for DOCG wine production.

However, considering the aforementioned limitation, the study shows how Guyot resulted the more balanced system from the vegetative reproductive and qualitative point of view. In case of GDC system, suboptimal conditions lead to unbalanced vegetative growth where the plants presented low vigour and excessive yield. This condition may lead to incomplete ripening (as was the case of the 2023 vintage) and a potentially low overall fitness of the plant, opening the door to multiple environmental stresses (pathogenic insects, viruses, fungi diseases, water stress) which can cause significant qualitative and productive decline.

On the other hand, as in the case of the hedging treatments experiments, excessive vigour resulted in too dense and shaded canopies, with a highly expanded leaf area. This could lead to unbalanced sink/source ratio and fungal diseases issues.

Moreover, all these complications can strongly affect vine longevity with significant repercussions on the economic sustainability of the vineyard.

Therefore, the study of the next seasons (with different meteorological features) is of primary importance to evaluate and understand the vine response depending on environmental conditions.

In this context, short term adaptation strategy results as deeply dynamic and easily implementable due to the possibility of the viticulturist to adapt the vineyard management based on the seasonal environmental conditions.

Differently, at the base of the training system choice, many other factors must be considered, not least of which is the climatic variability.

Unlike short-term adaptation strategies, training systems imply the long-term maintenance of the structure used. Thus, the choice becomes highly significant for subsequent years, which will be strongly influenced by it.It is therefore essential to study the productive and qualitative stability of the training systems in different weather patterns evaluating the best choice in a specific terroir.

# 8. Future prospects

As reported in Chapter 5.1, the 2023 meteorological season did not show extreme temperature differences compared to the historical series from 1997 to 2023, while it was characterized by high precipitation during the vegetative season.

Shoot hedging could potentially lead to a delayed sugar accumulation and it could lead to decreased canopy water usage (Poni et al., 2023). However, shoot hedging leads to different outcomes depending on the specific viticultural context in which it is applied. In hot and dry conditions, it led to water saving, while under non-limiting conditions, the results were not significant (Abad et al., 2019; Mirás-Avalos et al., 2017). Therefore, in the next years, it could be interesting the evaluation of the plant response under water limiting situation and with higher air temperature conditions. In the same way, it will be useful to study the different training system outcomes in more environmental stressful conditions as the one reported in chapter 2.1.

During 2023 season, data concerning predawn leaf water potential and midday leaf water potential were collected (data not showed) but their collection were interrupted because the plant never perceived water stress. In the next seasons these data will be collected and used as important integration of the meteorological data.

Furthermore, results should be improved with complementary data which can offer a broader framework of the plant physiological status. For instance, data relative to radiation, vapor pressure deficit and hydraulic resistance well describe the system soil-plant-atmosphere, and leaf gas exchange which could be useful to better interpretate results and explain vines' behaviour.

The ResilVine project is a multi-year project with the aim to provide viticulturists reliable and effective tools to contrast the challenges of modern viticulture, mostly related to climate change adaptation. This was the first year of research, and results are just preliminary and affected by the peculiar feature of the past meteorological season. As future perspective, the results need to be implemented with the next findings to provide a wider overview of the adaptation measures proposed.

# 9. References

1. Abad, F. J., Marín, D., Loidi, M., Miranda, C., Royo, J. B., Urrestarazu, J., & Santesteban, L. G. (2019). Evaluation of the incidence of severe trimming on grapevine (*Vitis vinifera* L.) water consumption. Agricultural Water Management, 213, 646-653.
2. Baccichet, I., Chiozzotto, R., Bassi, D., Gardana, C., Cirilli, M., & Spinardi, A. (2021). Characterization of fruit quality traits for organic acids content and profile in a large peach germplasm collection. Scientia Horticulturae, 278, 109865.
3. Bennett, J., Jarvis, P., Creasy, G. L., & Trought, M. C. (2005). Influence of defoliation on overwintering carbohydrate reserves, return bloom, and yield of mature Chardonnay grapevines. American Journal of Enology and Viticulture, 56(4), 386-393.
4. Bobeica, N., Poni, S., Hilbert, G., Renaud, C., Gomès, E., Delrot, S., & Dai, Z. (2015). Differential responses of sugar, organic acids and anthocyanins to source-sink modulation in Cabernet Sauvignon and Sangiovese grapevines. Frontiers in plant science, 6, 382.
5. Bucur GM, Dejeu L, (2022). Research on adaptation measures of viticulture to climate change: overview. Scientific Papers. Series B, Horticulture. Vol. LXVI, No. 2, 2022
6. Caccavello, G., Giaccone, M., Scognamiglio, P., Forlani, M., & Basile, B. (2017). Influence of intensity of post-veraison defoliation or shoot trimming on vine physiology, yield components, berry and wine composition in Aglianico grapevines. Australian Journal of Grape and Wine Research, 23(2), 226-239.
7. Cola, G., Mariani, L., Maghradze, D., & Failla, O. (2020). Changes in thermal resources and limitations for Georgian viticulture. Australian Journal of Grape and Wine Research, 26(1), 29-40.
8. Costa JM, Egipto R, Sánchez-Virosta A, Lopes CM, Chaves MM. (2019). Canopy and soil thermal patterns to support water and heat stress management in vineyards.Agricultural Water Management 216, 484-496.
9. Costa, J.M.; Catarino, S.; Escalona, J.M.; Comuzzo, P. (2022) Achieving a More Sustainable Wine Supply Chain – Environmental and Socioeconomic Issues of the Industry. In Improving sustainable viticulture and winemaking practices.; Costa, J.M., Catarino, S., Escalona, J.M., Comuzzo, P., Eds.; Academic Press, Elsevier, 2022; ISBN 9780323851503. pp. 1–24
10. Del Zozzo, F., & Poni, S. (2024). Climate Change Affects Choice and Management of Training Systems in the Grapevine. Australian Journal of Grape and Wine Research, 2024(1), 7834357.
11. Díaz-Losada E., Trigo-Córdoba E., Soto-Vázquez E., Bouzas-Cid Y., Mirás-Avalos J.M., Rego-Martínez F., 2013. Effects of training system on the agronomical and enological performance of Galician grapevine cultivars. Ciência e Técnica Vitivinícola, Volume 28, Proceedings 18th International Symposium GiESCO, Porto, 7-11 July 2013, 578-582.
12. Dokoozlian, N. (2012). The evolution of mechanized vineyard production systems in California. In I International Workshop on Vineyard Mechanization and Grape and Wine Quality 978 pp. 265-278..
13. Faralli M., Zanzotti R., Bertamini M. (2022). Maintaining canopy density under summer stress conditions retains PSII efficiency and modulates must quality in Cabernet franc. Horticulturae 8 (8), 679.
14. Fraga H, Molitor D, Leolini L, Santos JA. What Is the Impact of Heatwaves on European Viticulture? A Modelling Assessment. Applied Sciences. 2020; 10(9):3030. https://doi.org/10.3390/app10093030
15. Franciacorta Consortium (2024, June 28) Geologia e clima. https://franciacorta.wine/it/vino/geologia-clima/
16. Google earth (2024, 30 June) https://www.google.it/intl/it/earth/index.html
17. Google maps (2024, 30 June) https://www.google.it/maps/preview
18. Gouot JC, Smith JP, Holzapfel BP, Barril C. (2019). Grape Berry Flavonoid Responses to High Bunch Temperatures Post Véraison: Effect of Intensity and Duration of Exposure. Molecules. 24(23):4341. https://doi.org/10.3390/molecules24234341
19. Herrera, J. C., Bucchetti, B., Sabbatini, P., Comuzzo, P., Zulini, L., Vecchione, A., ... & Castellarin, S. D. (2015). Effect of water deficit and severe shoot trimming on the composition of *Vitis vinifera* L. Merlot grapes and wines. Australian Journal of Grape and Wine Research, 21(2), 254-265.
20. Howell, G. S. (2001). Sustainable grape productivity and the growth-yield relationship: A review. American Journal of Enology and Viticulture, 52(3), 165-174.
21. Insidewine (2024, June 28) Zona di produzione Franciacorta. https://www.insidewine.it/guida-al-franciacorta-aromi-abbinamenti-e-migliori-cantine/

22. IPCC, 2023: Sections. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35-115.
23. Ismea mercati, (2024, October 01). https://www.ismeamercati.it/vino
24. Jones, G. V., Edwards, E. J., Bonada, M., Sadras, V. O., Krstic, M. P., & Herderich, M. J. (2022). Climate change and its consequences for viticulture. In Managing wine quality Woodhead Publishing. pp. 727-778
25. Keller M. (2015). The science of grapevine. Anatomy and physiology. Secon edition. 6.3.6 Crop load. (pp. 261-264). Published by Elsevier Inc.
26. Kliewer, W. M., & Dokoozlian, N. K. (2005). Leaf area/crop weight ratios of grapevines: Influence on fruit composition and wine quality. American Journal of Enology and Viticulture, 56(2), 170-181.
27. Lorenz, D. H., Eichhorn, K. W., Bleiholder, H., Klose, R., Meier, U., & Weber, E. (1995). Growth Stages of the Grapevine: Phenological growth stages of the grapevine (*Vitis vinifera* L. ssp. vinifera)—Codes and descriptions according to the extended BBCH scale. Australian Journal of Grape and Wine Research, 1(2), 100-103.
28. Louarn, G., Lecoeur, J., & Lebon, E. (2008). A three-dimensional statistical reconstruction model of grapevine (Vitis vinifera) simulating canopy structure variability within and between cultivar/training system pairs. Annals of Botany, 101(8), 1167-1184.
29. Lovisolo, C., Schubert, A., & Sorce, C. (2002). Are xylem radial development and hydraulic conductivity in downwardly-growing grapevine shoots influenced by perturbed auxin metabolism?. *New Phytologist*, *156*(1), 65-74.
30. Mirás-Avalos, J. M., Buesa, I., Llacer, E., Jiménez-Bello, M. A., Risco, D., Castel, J. R., & Intrigliolo, D. S. (2017). Water versus source–sink relationships in a semiarid tempranillo vineyard: vine performance and fruit composition. American Journal of Enology and Viticulture, 68(1), 11-22.
31. Modina, D., Cola, G., Bianchi, D., Bolognini, M., Mancini, S., Foianini, I., ... & Brancadoro, L. (2023). Alpine viticulture and climate change: environmental resources and limitations for grapevine ripening in Valtellina, Italy. Plants, 12(11), 2068.
32. Mota, R. V. D., Souza, C. R. D., Silva, C. P. C., Freitas, G. D. F., Shiga, T. M., Purgatto, E., Lajolo F. M., & Regina, M. D. A. (2010). Biochemical and agronomical responses of grapevines to alteration of source-sink ratio by cluster thinning and shoot trimming. Bragantia, 69, 17-25.
33. Munitz, S., Schwartz, A., & Netzer, Y. (2019). Water consumption, crop coefficient and leaf area relations of a *Vitis vinifera* cv.'Cabernet Sauvignon' vineyard. Agricultural Water Management, 219, 86-94.
34. Novello V., de Palma L., 2013 Viticultural strategy to reduce alcohol levels in wine. 1st International Symposium alcohol level reduction in wine - oenoviti international network. Session I - Potential reduction in alcohol levels and viticulture pp 3-8. 6 September 2013 - Bordeaux
35. O. Garcia-Tejera, M. Bonada, P.R. Petrie, H. Nieto, J. Bellvert, V.O. Sadras (2023), Viticulture adaptation to global warming: Modelling gas exchange, water status and leaf temperature to probe for practices manipulating water supply, canopy reflectance and radiation load, Agricultural and Forest Meteorology, Volume 331, 109351, ISSN 0168-1923.
36. Palliotti, A., & Poni, S. (2011). Traditional and innovative summer pruning techniques for vineyard management. Advances in Horticultural Science, 25(3), 151-163.
37. Palliotti, A., Poni, S., and Silvestroni, O. (2018) Manuale di viticoltura. Equilibrio vegeto-produttivo ed analisi dell'efficienza Edagricole Calderini. pp. 269-275
38. Parker, A. K., Hofmann, R. W., van Leeuwen, C., McLachlan, A. R., & Trought, M. C. (2014). Leaf area to fruit mass ratio determines the time of veraison in Sauvignon Blanc and Pinot Noir grapevines. Australian Journal of Grape and Wine Research, 20(3), 422-431.
39. Parker, A. K., Hofmann, R. W., Van Leeuwen, C., McLachlan, A. R., & Trought, M. C. (2015). Manipulating the leaf area to fruit mass ratio alters the synchrony of total soluble solids accumulation and titratable acidity of grape berries. Australian Journal of Grape and Wine Research, 21(2), 266-276.
40. Poni, S., Bernizzoni, F., Civardi, S., & Libelli, N. (2009). Effects of pre-bloom leaf removal on growth of berry tissues and must composition in two red Vitis vinifera L. cultivars. Australian Journal of Grape and Wine Research, 15(2), 185-193.
41. Poni, S., Del Zozzo, F., Santelli, S., Gatti, M., Magnanini, E., Sabbatini, P., & Frioni, T. (2021). Double cropping in Vitis vinifera L. cv. Pinot Noir: agronomical and physiological validation. Australian Journal of Grape and Wine Research, 27(4), 508-518.

42. Poni, S., Frioni, T., & Gatti, M. (2023). Summer pruning in Mediterranean vineyards: is climate change affecting its perception, modalities, and effects? Frontiers in Plant Science, 14.
43. Poni, S., Giachino, E., & Magnanini, E. (2004). Cimatura dei germogli su Cabernet Sauvignon: fisiologia ed effetti agronomici. ENOLOGO-MILANO-, 40, 87-98.
44. Poni, S., Merli, M. C., Magnanini, E., Galbignani, M., Bernizzoni, F., Vercesi, A., & Gatti, M. (2014). An improved multichamber gas exchange system for determining whole-canopy water-use efficiency in grapevine. American Journal of Enology and Viticulture, 65(2), 268-276.
45. Province of Brescia - Agrometeorological Network, (2024, February 15). https://meteo.provincia.brescia.it/default.asp
46. Pulko, B., Frangež, M., & Valdhuber, J. (2022). The Impact of Shoot Topping Intensity on Grape Ripening and Yield of'Chardonnay'. Agricultura Scientia, 19(2), 29-35.
47. Reynolds, A. G., & Heuvel, J. E. V. (2009). Influence of grapevine training systems on vine growth and fruit composition: a review. American Journal of Enology and Viticulture, 60(3), 251-268.
48. Reynolds, A. G., & Wardle, D. A. (1989). Effects of timing and severity of summer hedging on growth, yield, fruit composition, and canopy characteristics of de Chaunac. I. Canopy characteristics and growth parameters. American journal of enology and viticulture, 40(2), 109-120.
49. Santesteban, L. G., Miranda, C., Urrestarazu, J., Loidi, M., & Royo, J. B. (2017). Severe trimming and enhanced competition of laterals as a tool to delay ripening in Tempranillo vineyards under semiarid conditions. OENO One, 51(2), 191–203.
50. Santos JA, Fraga H, Malheiro AC, Moutinho-Pereira J, Dinis L-T, Correia C, Moriondo M, Leolini L, Dibari C, Costa freda-Aumedes S, et al. (2020) A Review of the Potential Climate Change Impacts and Adaptation Options for European Viticulture. Applied Sciences; 10(9):3092.
51. Shaulis, N. J., & May, P. (1971). Response of'Sultana'vines to training on a divided canopy and to shoot crowding. American Journal of Enology and Viticulture, 22(4), 215-222.
52. Smart, R., and Robinson, M. (1991). Sunlight into wine: a handbook for winegrape canopy management.
53. Torres N., Martínez-Lüscher J., Porte E., Yu R., Kurtural S. K., (2021). Impacts of leaf removal and shoot thinning on cumulative daily light intensity and thermal time and their cascading effects of grapevine (*Vitis vinifera* L.) berry and wine chemistry in warm climates, Food Chemistry, Volume 343, 2021, 128447, ISSN 0308-8146.
54. van Leeuwen, C., & Destrac-Irvine, A. (2017). Modified grape composition under climate change conditions requires adaptations in the vineyard. OENO One, 51(2), 147–154.
55. Van Leeuwen, C., & Seguin, G. (2006). The concept of terroir in viticulture. Journal of wine research, 17(1), 1-10.
56. Van Leeuwen, C., Destrac-Irvine, A., Dubernet, M., Duchêne, E., Gowdy, M., Marguerit, E., ... & Ollat, N. (2019). An update on the impact of climate change in viticulture and potential adaptations. Agronomy, 9(9), 514.
57. Zhu, J., Fraysse, R., Trought, M. C., Raw, V., Yang, L., Greven, M., ... & Agnew, R. (2020). Quantifying the seasonal variations in grapevine yield components based on pre-and post-flowering weather conditions. Oeno One, 54(2).

# 10. Appendix

In figure I, a summary of the historical series 1997-2023 is presented, the years are classified considering temperature and precipitation levels. The central vertical lines in the chart represent the average annual precipitation of the historical series 1997-2024 (1140 mm) while the central horizontal one, the average annual temperature 1997-2023 (14.65 °C). This allows to identify of the following four sub-areas:

- Top right: years with annual temperature and annual precipitation above the average
- Bottom left: years with annual temperature and annual precipitation below the average
- Top left: years with annual temperature above the average and annual precipitation below the average
- Bottom right: years with annual temperature below the average and annual precipitation above the average.

It is noted that 2023 is in the top-right quadrant with an average temperature of 15.3 °C and annual precipitation of 1247 mm.

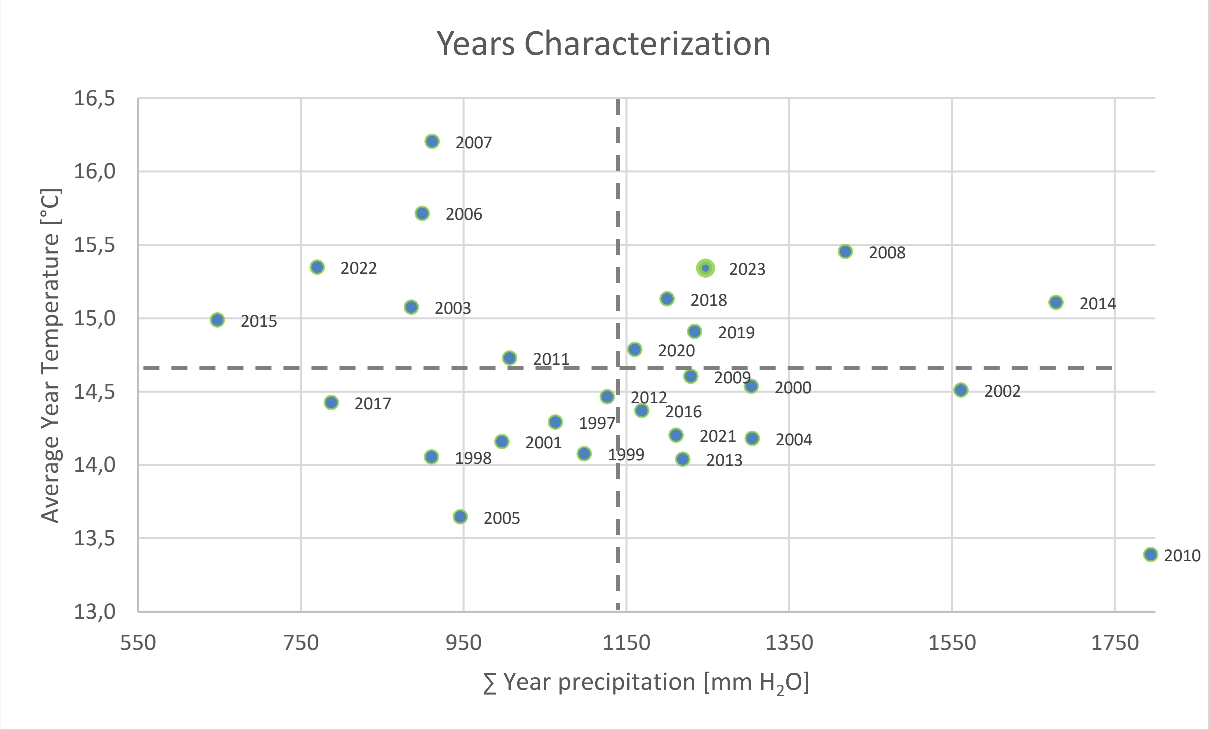


*Figure I - Annual average temperature and rainfall (1997-2023)*