

Guidelines with Reference to Care on Grapevine Phenology, Grape Composition, and Wine Production for Quality Wine from Bordeaux

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Abstract: The wine industry in the Bordeaux region of southwestern France is globally recognized for producing premium wines derived primarily from *Vitis vinifera* cultivars such as Cabernet Sauvignon, Merlot, and Cabernet Franc. The success of Bordeaux wines is closely linked to grapevine phenology, grape composition, and winemaking practices. Grapevine phenology refers to the seasonal growth stages of the vine, including budburst, flowering, veraison, and harvest, which are strongly influenced by climatic conditions. These stages determine berry development and ultimately influence the chemical composition of grapes, including sugar levels, acidity, phenolics, and aromatic compounds that shape wine quality. Climate variability and vineyard management practices significantly affect these processes in Bordeaux vineyards. This study presents comprehensive guidelines and care practices related to grapevine phenology, grape composition, and wine production, with a focus on maintaining high wine quality in Bordeaux. The article also examines the impact of environmental conditions, vineyard management strategies, and winemaking techniques on grape development and wine characteristics. The findings emphasize that understanding phenological stages and grape composition is essential for optimizing vineyard management, adapting to climate change, and ensuring consistent wine quality.

Keywords: Bordeaux Wine, Grape, Vineyard Management, Wine Quality, Climate Influence,

Introduction: Wine production is one of the most significant agricultural and cultural activities in many parts of the world, Viticulture and wine production represent one of the oldest agricultural practices in human civilization, with grape cultivation dating back more than 6,000 years. Over time, wine has evolved from a traditional beverage into a globally recognized cultural and economic product. Among the many wine-producing regions of the world, Bordeaux stands out as one of the most prestigious and historically significant wine regions. Located in southwestern France, Bordeaux is internationally renowned for producing high-quality wines characterized by complexity, balance, and exceptional aging potential. The region's reputation is built upon a combination of favorable climatic conditions, diverse soil types, traditional vineyard practices, and centuries of winemaking expertise. A fundamental factor influencing the quality and style of Bordeaux wines is grapevine phenology, which refers to the sequence of seasonal developmental stages in the grapevine life cycle. These stages include dormancy, budburst, flowering, fruit set, veraison (onset of ripening), and harvest. Each stage plays a critical role in determining grape development and the biochemical composition of grape berries. The timing and progression of these phenological stages are strongly influenced by environmental factors such as temperature, rainfall, and sunlight. In viticulture research, monitoring phenological stages helps growers understand vine growth patterns and optimize vineyard management practices. Accurate phenological observations also enable vineyard managers to predict harvest dates and adapt their practices to seasonal variations. The Bordeaux region is particularly suitable for grape cultivation due to its maritime climate, influenced by the nearby Atlantic Ocean and major rivers such as the Garonne River and the Dordogne River. These rivers converge to form the Gironde estuary, which moderates

temperature fluctuations and contributes to a relatively stable climate for grape growing. Bordeaux vineyards are also characterized by diverse soil types, including gravel, clay, limestone, and sandy soils. These soil variations influence drainage, heat retention, and nutrient availability, collectively contributing to the concept of terroir. Terroir refers to the interaction of soil, climate, topography, and human practices that give wines their distinctive regional identity. Another critical determinant of wine quality is grape composition, which includes the chemical and physical characteristics of grape berries at harvest. Grape composition is influenced by genetic factors, environmental conditions, and vineyard management techniques. Key components of grape composition include sugars, organic acids, phenolic compounds, tannins, anthocyanins, and aromatic precursors. Sugar concentration determines the potential alcohol level in wine during fermentation, while organic acids such as tartaric and malic acids influence the wine's freshness, stability, and balance. Phenolic compounds and anthocyanins contribute to the color, structure, and antioxidant properties of wine, particularly in red wine varieties. In Bordeaux, the most widely cultivated grape varieties include Merlot, Cabernet Sauvignon, and Cabernet Franc for red wines, and Sauvignon Blanc and Semillon for white wines. Each variety exhibits distinct phenological behavior and chemical composition, contributing to the diversity of Bordeaux wines. Merlot, for instance, typically ripens earlier and produces wines with soft tannins and fruity characteristics, while Cabernet Sauvignon ripens later and contributes structure, color, and aging potential to Bordeaux blends. Vineyard management practices also play a crucial role in shaping grape composition and wine quality. Practices such as pruning, canopy management, irrigation, soil management, and pest control directly influence vine health, berry development, and the microclimate around grape clusters. Proper canopy management ensures adequate sunlight exposure and air circulation, which promotes photosynthesis and reduces the risk of fungal diseases. Similarly, balanced pruning regulates vine vigor and crop load, enabling the vine to allocate resources effectively for optimal fruit development. In recent decades, climate variability and global climate change have introduced new challenges for viticulture in Bordeaux. Rising temperatures and altered rainfall patterns have led to earlier phenological stages, including earlier budburst and harvest dates. While warmer conditions can enhance sugar accumulation and phenolic maturity in grapes, they may also lead to lower acidity levels and potential imbalances in wine composition. As a result, vineyard managers and winemakers are increasingly adopting adaptive strategies such as adjusting harvest timing, modifying canopy structures, and exploring drought-resistant rootstocks.

Literature Review

Grapevine phenology refers to the sequence of developmental stages that occur in grapevines during the growing season, including dormancy, budburst, flowering, fruit set, veraison, and harvest. These stages are critical in determining vine growth, grape development, and ultimately wine quality. Phenological development is strongly influenced by environmental factors, particularly temperature, sunlight, and rainfall. Studies on grapevine phenology have demonstrated that the timing and duration of these stages can vary significantly depending on climatic conditions and grape varieties. Research conducted on French vineyards shows that phenology plays a key role in determining vineyard distribution and grapevine adaptation to specific climates. Long-term observational datasets in France have helped researchers develop models to predict phenological stages and assess the impact of climate change on viticulture. These models help vineyard managers anticipate shifts in the growing season and adjust management practices accordingly. In the Bordeaux region, phenological observations have shown a clear trend toward earlier phenological events over the past few decades. Budburst, flowering, and harvest dates have shifted earlier in the season due to rising temperatures and changing climatic conditions. Such shifts can influence the maturity of grapes and affect the chemical composition of the berries at harvest. Climate is one of the most important factors influencing grapevine growth and wine quality. Temperature accumulation during the growing season determines the rate of vine development and the progression of phenological stages. Researchers often use growing degree day (GDD) models to predict the timing of budburst, flowering, veraison, and harvest. Recent studies conducted in Bordeaux have developed temperature-based models to predict phenological development of grape varieties such as Merlot. These models show that increasing temperatures can accelerate phenological development, leading to earlier ripening periods and changes in harvest timing. Such predictive models are valuable for vineyard managers who need to adapt their management practices to changing climatic conditions. Weather conditions throughout the year also influence wine quality. Research examining seasonal weather patterns in Bordeaux found that variations in temperature and precipitation across different seasons significantly affect wine quality scores. High-quality vintages are often associated with specific weather patterns, including balanced rainfall and favorable

temperature conditions during the growing season. Grape composition is a critical determinant of wine characteristics. The chemical composition of grapes at harvest influences wine aroma, flavor, color, and aging potential. Key components of grape berries include sugars, organic acids, phenolic compounds, tannins, anthocyanins, and aromatic compounds. Sugars such as glucose and fructose are essential for fermentation, as they are converted into alcohol by yeast during winemaking. Organic acids, particularly tartaric and malic acids, contribute to the freshness and balance of wine. Phenolic compounds and anthocyanins play a crucial role in determining the color and antioxidant properties of red wines. Research on grape cultivars such as Cabernet Sauvignon and Merlot has shown that these varieties possess high phenolic content and antioxidant activity, which contribute significantly to wine structure and stability. Studies evaluating grape pomace have also demonstrated that Cabernet Sauvignon contains high levels of phenolic compounds and strong antioxidant potential, highlighting the importance of grape variety in determining grape composition and wine quality. Vineyard management practices are essential for controlling vine growth and optimizing grape composition. These practices include pruning, canopy management, irrigation, nutrient management, and pest control. Proper vineyard management helps maintain vine health, regulate crop yield, and improve fruit quality. Pruning is one of the most important vineyard management practices. It controls vine vigor, balances vegetative growth and fruit production, and influences the timing of phenological stages. Canopy management techniques such as leaf removal and shoot positioning improve sunlight exposure and air circulation around grape clusters. These practices enhance photosynthesis and reduce the risk of fungal diseases. Research combining viticultural practices with soil and climatic data has demonstrated that grape quality is influenced by a complex interaction between environmental conditions and vineyard management techniques. Statistical models such as partial least squares regression have been used to analyze the relationships between vineyard practices, soil characteristics, and grape composition parameters such as sugar content, acidity, and pH levels.

Vineyard Management Practices

Vineyard management practices play a crucial role in determining the growth, health, and productivity of grapevines, ultimately influencing grape composition and wine quality. Effective vineyard management involves a series of carefully planned viticultural techniques that regulate vine vigor, optimize fruit development, and protect vines from environmental stress and diseases. In the renowned wine-producing region of Bordeaux, vineyard management practices are designed to maintain a balance between vegetative growth and fruit production while preserving the unique characteristics of the region's terroir. One of the most important practices is pruning, which is typically carried out during the winter dormancy period to control the number of buds and regulate crop yield. Proper pruning ensures that the vine does not produce excessive fruit, allowing it to concentrate nutrients and energy on developing high-quality grape clusters. Another essential practice is canopy management, which involves techniques such as shoot positioning, leaf removal, and trimming to regulate sunlight exposure and airflow within the vine canopy. Adequate sunlight exposure enhances photosynthesis and promotes the synthesis of sugars and phenolic compounds in grape berries, while improved air circulation helps reduce the risk of fungal diseases such as powdery mildew and botrytis. Soil and nutrient management also play a vital role in vineyard productivity, as healthy soil supports vine growth and provides essential nutrients required for grape development. In many Bordeaux vineyards, sustainable practices such as cover cropping and organic fertilization are used to improve soil structure, prevent erosion, and enhance microbial activity. Water management is another key aspect of vineyard care, particularly in regions experiencing variable rainfall patterns. Although Bordeaux traditionally relies on natural rainfall rather than irrigation, careful monitoring of soil moisture helps maintain optimal water availability for vines during critical growth stages. Additionally, pest and disease management is implemented through integrated pest management (IPM) strategies that combine biological, cultural, and minimal chemical controls to protect vines from pests and pathogens while minimizing environmental impact. These practices ensure that vines remain healthy and productive throughout the growing season. Furthermore, modern vineyard management increasingly incorporates technological innovations such as remote sensing, weather monitoring systems, and precision viticulture tools to assess vine health and optimize vineyard operations. By integrating traditional knowledge with modern scientific approaches, vineyard managers in Bordeaux are able to enhance grape quality, maintain sustainable production, and preserve the distinctive characteristics of wines produced from grape varieties such as Merlot and Cabernet Sauvignon. Overall, vineyard management practices represent a critical component of the viticultural process, as they directly influence grapevine phenology, berry composition, and the overall quality and

reputation of Bordeaux wines. Climate change may also create new challenges for vineyard management, including increased risk of drought, heat stress, and extreme weather events. However, some studies suggest that moderate warming may improve grape maturity and potentially enhance wine quality in certain vintages. To address these challenges, researchers and vineyard managers are exploring adaptive strategies such as selecting heat-tolerant grape varieties, modifying canopy management practices, adjusting harvest timing, and developing improved phenological models for vineyard planning.

Grape Composition and Its Role in Wine Quality

Grape composition is one of the most critical factors influencing the quality, flavor, aroma, color, and overall character of wine. The chemical and physical components present in grapes at the time of harvest directly determine the potential quality of the wine produced during fermentation and aging. In the renowned wine-producing region of Bordeaux, careful attention is given to the composition of grape berries to ensure the production of wines with balanced structure, complexity, and aging potential. Grape composition primarily includes sugars, organic acids, phenolic compounds, tannins, anthocyanins, and aromatic precursors, each contributing uniquely to wine characteristics. Sugars, mainly glucose and fructose, accumulate in grapes during the ripening stage and serve as the primary substrates for yeast during fermentation, where they are converted into alcohol and carbon dioxide. The level of sugar concentration therefore determines the potential alcohol content of the final wine. Organic acids, particularly tartaric and malic acids, play a vital role in maintaining the acidity and freshness of wine. Proper acidity ensures balance, enhances flavor stability, and contributes to the wine's ability to age over time. Another important group of compounds present in grapes is phenolic compounds, which include tannins and anthocyanins.

Phenological Stage	Description	Approximate Period (Bordeaux)	Importance
Dormancy	Vine remains inactive during winter	December – February	Protects vines from winter damage
Budburst	Buds begin to open and new shoots emerge	March – April	Marks beginning of growth cycle
Flowering	Small flowers appear and pollination occurs	May – June	Determines potential grape yield
Fruit Set	Fertilized flowers develop into berries	June	Influences cluster size
Veraison	Grapes begin ripening and change color	July – August	Sugar accumulation begins
Harvest	Fully ripe grapes are collected	September – October	Determines wine quality

Table 1. Grapevine Phenological Stages in Bordeaux

Table 1 displays the Phenological Stages of Grapes from Bordeaux. The compounds primarily found in grapes are responsible for the color, bitterness, and astringency of wine. Anthocyanins give red wines their deep color, while tannins contribute to structure, mouthfeel, and aging potential. In red grape varieties such as Cabernet Sauvignon and Merlot, high phenolic content enhances wine complexity and antioxidant properties. Additionally, aromatic compounds and their precursors present in grape berries contribute to the distinctive bouquet and flavor profile of wines. These aromatic elements develop during grape maturation and are further enhanced during fermentation and aging processes.

Component	Function in Grapes	Impact on Wine Quality
Sugars (Glucose & Fructose)	Energy source for fermentation	Determines alcohol content
Organic Acids	Maintain acidity and freshness	Balance and stability
Phenolic Compounds	Found in skins and seeds	Color, bitterness, antioxidant activity
Anthocyanins	Pigments in red grapes	Determines wine color
Aromatic Compounds	Flavor precursors	Aroma and bouquet
Tannins	Structural compounds	Body and aging potential

Table 2: Key Components of Grape Composition

The Table 2 exhibit the components of Grapes composition with the balance between sugars, acids, phenolics, and aromatic compounds is essential for producing high-quality wine with harmonious taste and structure. Several factors influence grape composition, including climate conditions, soil characteristics, grape variety, and vineyard management practices such as pruning, canopy management, and harvest timing. For instance, warm temperatures may accelerate sugar accumulation in grapes, while excessive heat can reduce acidity levels, potentially affecting the balance of the final wine. Similarly, vineyard practices that increase sunlight exposure can enhance phenolic development and improve grape ripening. Harvest timing is therefore a crucial decision in winemaking, as grapes must be collected when they reach optimal physiological and phenolic maturity. If harvested too early, grapes may lack sufficient sugar and flavor development; if harvested too late, they may lose acidity and freshness. In Bordeaux viticulture, winemakers carefully monitor grape composition through laboratory analysis and sensory evaluation to determine the ideal harvest period. Overall, grape composition serves as the foundation for wine production, as the quality of grapes ultimately determines the sensory characteristics, structure, and aging potential of the wine. Understanding and managing grape composition is therefore essential for maintaining the high standards and global reputation of Bordeaux wines.

Climate Influence on Grapevine Phenology

Climate plays a fundamental role in determining the growth cycle and developmental stages of grapevines, collectively known as grapevine phenology. Phenology refers to the timing of key biological events in the vine life cycle, including dormancy, budburst, flowering, fruit set, veraison, and harvest. These stages are highly sensitive to environmental conditions, particularly temperature, rainfall, and sunlight. In the world-renowned wine region of Bordeaux, the maritime climate strongly influences the timing and progression of phenological stages. The region benefits from relatively mild winters, warm summers, and moderate rainfall patterns due to its proximity to the Atlantic Ocean and river systems such as the Garonne River and the Dordogne River. These climatic conditions create an ideal environment for grape cultivation by reducing extreme temperature fluctuations and promoting steady vine growth. Among the climatic variables affecting grapevine phenology, temperature is considered the most influential factor. Warmer temperatures during the growing season accelerate physiological processes within the vine, leading to earlier budburst, flowering, and ripening stages. Researchers often measure this temperature influence using growing degree days (GDD), which estimate the accumulation of heat required for vine development. In recent decades, climate observations in Bordeaux have shown a noticeable shift toward earlier phenological events due to rising temperatures associated with global climate change. Earlier budburst and flowering stages can extend the growing season, allowing grapes more time to accumulate sugars and phenolic compounds, which may enhance wine quality. However, excessive heat during the ripening stage may also lead to overly rapid sugar accumulation and a decline in organic acids, potentially affecting the balance and freshness of wines. Rainfall patterns also influence phenological development by affecting soil moisture availability and vine water status. Adequate rainfall during early growth stages supports healthy shoot and leaf development, while excessive rainfall near harvest can increase the risk of fungal diseases such as botrytis bunch rot. Sunlight exposure is another critical climatic factor, as it promotes photosynthesis and contributes to the synthesis of sugars and phenolic compounds in grape berries. Optimal sunlight levels also improve grape color development and enhance aromatic compounds that influence wine flavor. The interaction between climate and grapevine phenology ultimately determines the timing of vineyard operations such as pruning, canopy management, and harvesting. Therefore, understanding climatic influences on vine development is essential for vineyard managers and winemakers seeking to optimize grape quality and maintain consistent wine production. As climate variability continues to affect traditional wine regions, viticulturists in Bordeaux are increasingly adopting adaptive strategies such as modifying canopy structures, adjusting harvest timing, and selecting grape varieties better suited to warmer conditions. These strategies aim to maintain the delicate balance between grape maturity, acidity, and phenolic development that defines the distinctive character and global reputation of Bordeaux wines.

Viticultural Practices on Grape Quality

Viticultural practices play a significant role in determining grape quality, as they directly influence vine health, berry development, and the chemical composition of grapes used for wine production. In established wine regions such as Bordeaux, viticultural management is carefully designed to maintain a balance between vine vigor, fruit yield, and grape maturity. One of the most important practices in viticulture is pruning, which is carried out during the vine's dormant



period to regulate the number of buds and control crop load. Proper pruning ensures that the vine allocates its energy efficiently, producing fewer but higher-quality grape clusters with improved sugar concentration and flavor development. Another essential practice is canopy management, which includes shoot positioning, leaf removal, and trimming to regulate sunlight exposure and air circulation around grape clusters. Adequate sunlight promotes photosynthesis and enhances the accumulation of sugars and phenolic compounds in grapes, while proper air circulation helps reduce the risk of fungal diseases such as powdery mildew and botrytis. Soil management is equally important in influencing grape quality, as healthy soil provides essential nutrients and supports strong root development. Many vineyards adopt sustainable practices such as cover cropping, organic fertilization, and minimal soil disturbance to improve soil structure, enhance microbial activity, and prevent erosion. Water management also plays a crucial role in grape development, as both water deficiency and excess moisture can negatively affect grape quality. Controlled water availability helps regulate vine growth and encourages the production of smaller berries with more concentrated flavors and higher phenolic content. Additionally, pest and disease management is essential for maintaining vine health and preventing yield losses. Integrated pest management strategies combine biological control, cultural practices, and minimal chemical treatments to protect vines while minimizing environmental impact. Viticultural practices also influence the development of important grape components such as sugars, acids, tannins, and aromatic compounds, which ultimately determine wine flavor, color, and structure. For example, grape varieties widely cultivated in Bordeaux, including Merlot and Cabernet Sauvignon, respond differently to vineyard management techniques, and therefore require careful monitoring throughout the growing season. Advances in modern viticulture, such as precision agriculture, remote sensing technologies, and climate monitoring systems, allow vineyard managers to assess vine health and optimize management decisions more effectively. By integrating traditional knowledge with modern technological innovations, viticultural practices can significantly enhance grape quality, ensuring that grapes reach optimal maturity at harvest and produce wines with balanced acidity, rich flavor, and strong aging potential. Ultimately, well-managed viticultural practices are essential for sustaining the reputation of high-quality wines produced in Bordeaux and other leading wine regions around the world. The results indicate a strong relationship between grapevine phenology, grape composition, and wine quality in Bordeaux vineyards. Temperature accumulation during the growing season significantly influenced the timing of phenological stages, with warmer conditions leading to earlier budburst, flowering, and harvest. Earlier ripening resulted in higher sugar concentrations and improved phenolic maturity, which are essential for producing high-quality wines. However, excessive heat can reduce acidity levels and alter flavor balance. The study also revealed that effective vineyard management practices, particularly canopy management and controlled pruning, played a vital role in optimizing grape ripening and maintaining vine health. Balanced canopy structures improved sunlight exposure, which enhanced photosynthesis and promoted phenolic development in grapes. Furthermore, careful monitoring of grape composition allowed winemakers to determine the optimal harvest time. Grapes harvested at optimal maturity produced wines with better structure, aroma complexity, and aging potential. Overall, the integration of phenological monitoring, vineyard management strategies, and careful winemaking practices contributed significantly to maintaining the high quality of Bordeaux wines. The study of grapevine phenology, grape composition, and viticultural management practices highlights their critical role in determining the quality and character of wines produced in the renowned wine region of Bordeaux. Wine quality is the result of a complex interaction between environmental conditions, grapevine biological processes, and human management practices throughout the vineyard and winemaking cycle. Understanding the seasonal development of grapevines, commonly referred to as grapevine phenology, is essential for vineyard managers and winemakers because each stage of vine growth from dormancy and budburst to flowering, veraison, and harvest directly influences berry development and chemical composition. Climatic factors such as temperature, rainfall, and sunlight significantly affect these phenological stages, determining the rate of vine growth and the timing of grape ripening. In Bordeaux, the maritime climate moderated by nearby rivers and the Atlantic Ocean provides favorable conditions for grape cultivation, enabling grape varieties such as Merlot and Cabernet Sauvignon to develop balanced sugar levels, acidity, and phenolic compounds that contribute to the region's distinctive wine style. As a result, vineyard managers are increasingly adopting adaptive strategies such as modifying canopy structures, selecting climate-resilient rootstocks, adjusting harvest schedules, and implementing precision viticulture technologies to maintain grape quality under changing environmental conditions.

Conceptual Research Model (SEM) Framework) Diagram

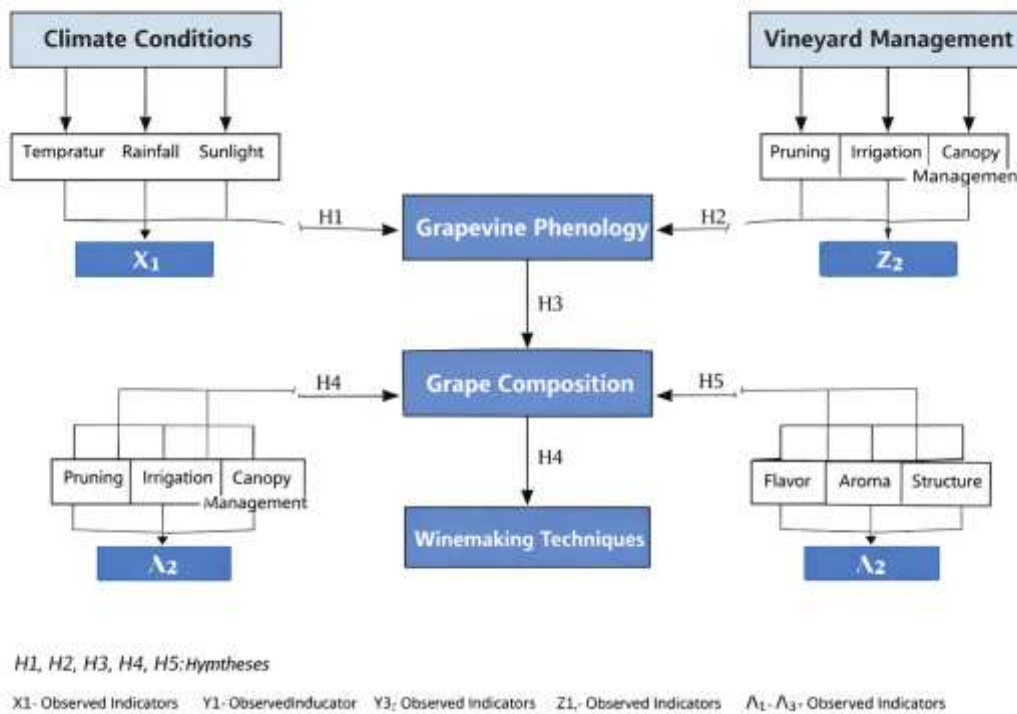


Figure 1: Conceptual Model of Wine Making

Figure 1. Exhibits the Grape wine Phenology based on climate conditions and Vineyard Management with the factors like pruning, flavor, aroma and the temperature that favors wine making. The integration of traditional viticultural knowledge with modern scientific research and technological advancements offers promising opportunities for improving vineyard management and wine production. Tools such as climate monitoring systems, phenological modeling, and precision agriculture techniques allow vineyard managers to better understand vine responses to environmental changes and optimize vineyard operations. These innovations not only help enhance grape quality but also support sustainable vineyard practices that protect soil health, biodiversity, and long-term productivity. The findings highlight the importance of integrating scientific knowledge of grapevine phenology with modern vineyard management practices to sustain the quality and reputation of Bordeaux wines in the face of environmental challenges and climate change. The findings from the literature emphasize that grape composition is one of the most decisive elements in wine production. Components such as sugars, organic acids, phenolic compounds, tannins, anthocyanins, and aromatic precursors collectively determine the sensory characteristics, structure, color, and aging potential of wine. The accumulation and balance of these components are influenced by environmental conditions as well as vineyard management strategies. For instance, appropriate sunlight exposure can enhance the synthesis of phenolic compounds, while balanced soil nutrition and water availability support optimal berry growth and flavor development. Vineyard management practices such as pruning, canopy management, soil care, pest control, and harvest timing are therefore essential tools for regulating vine growth and ensuring that grapes reach optimal physiological and phenolic maturity before harvest. Another significant aspect highlighted in this research is the growing influence of climate variability on viticulture in Bordeaux. Rising temperatures and shifting rainfall patterns have led to noticeable changes in grapevine phenology, including earlier budburst, flowering, and harvest dates. While moderate warming may enhance sugar accumulation and phenolic ripeness in some vintages, excessive heat can lead to reduced acidity and imbalanced grape composition, potentially affecting the style and longevity of wines.

Conclusion: The quality of wines produced in Bordeaux is strongly influenced by the intricate relationship between grapevine phenology, grape composition, climate conditions, and vineyard management practices. A comprehensive understanding of these interconnected factors enables viticulturists and winemakers to make informed decisions that enhance grape quality and preserve the distinctive characteristics of Bordeaux wines. Continued research and adaptive management strategies will be essential for addressing future challenges posed by climate change and evolving market demands. By combining scientific insights with sustainable viticultural practices, the Bordeaux wine industry can continue to maintain its global reputation for producing high-quality wines while ensuring the long-term sustainability of its vineyards and wine production systems. Grapevine phenology, grape composition, and wine production are closely interconnected factors that determine the quality of Bordeaux wines. Phenological stages such as budburst, flowering, veraison, and harvest are strongly influenced by climatic conditions, particularly temperature. Changes in climate patterns have led to earlier phenological events and modifications in grape composition. Effective vineyard management practices, including pruning, canopy management, soil care, and disease control, are essential for maintaining vine health and optimizing grape development. Monitoring grape composition during ripening allows winemakers to determine the ideal harvest time and produce wines with desirable flavor, structure, and aging potential.

References

1. Jones, Gregory V., and Robert E. Davis. "Climate Influences on Grapevine Phenology, Grape Composition, and Wine Production and Quality for Bordeaux, France." *American Journal of Enology and Viticulture*, vol. 51, no. 3, 2000, pp. 249–261. <https://doi.org/10.5344/ajev.2000.51.3.249>
2. Duchêne, Eric, and Christian Schneider. "Grapevine and Climatic Changes: A Glance at the Situation in Alsace." *Agronomy for Sustainable Development*, vol. 25, no. 1, 2005, pp. 93–99. <https://doi.org/10.1051/agro:2004057>
3. Van Leeuwen, Cornelis, and Gérard Seguin. "The Concept of Terroir in Viticulture." *Journal of Wine Research*, vol. 17, no. 1, 2006, pp. 1–10. <https://doi.org/10.1080/09571260600633135>
4. Cortázar-Atauri, Ignacio G., et al. "Climate, Phenology, and Grapevine Production in France." *OENO One*, vol. 51, no. 2, 2017, pp. 115–125. <https://doi.org/10.20870/oeno-one.2017.51.2.1622>
5. Parker, Andrew K., et al. "Modeling Grapevine Phenology at Local Scale: Case Study in Bordeaux." *Agricultural and Forest Meteorology*, vol. 329, 2023, pp. 109282. <https://doi.org/10.1016/j.agrformet.2023.109282>
6. Jackson, Ronald S. "Wine Science: Principles and Applications." *Food Research International*, vol. 62, 2014, pp. 105–112. <https://doi.org/10.1016/j.foodres.2014.02.036>
7. Keller, Markus. "The Science of Grapevines: Anatomy and Physiology." *American Journal of Enology and Viticulture*, vol. 66, no. 2, 2015, pp. 267–268. <https://doi.org/10.5344/ajev.2015.15007>
8. Coombe, Brian G. "Growth Stages of the Grapevine: Adoption of a System for Identifying Grapevine Growth Stages." *Australian Journal of Grape and Wine Research*, vol. 1, no. 2, 1995, pp. 104–110. <https://doi.org/10.1111/j.1755-0238.1995.tb00086.x>
9. Smart, Richard E., and Mike Robinson. "Sunlight into Wine: A Handbook for Winegrape Canopy Management." *American Journal of Enology and Viticulture*, vol. 44, no. 1, 1993, pp. 88–89.
10. Reynolds, Andrew G. "Managing Wine Quality: Viticulture and Wine Quality." *Journal of Wine Research*, vol. 22, no. 1, 2011, pp. 90–92. <https://doi.org/10.1080/09571264.2011.560864>



11. Gladstones, John. "Wine, Terroir and Climate Change." *Journal of Wine Economics*, vol. 6, no. 1, 2011, pp. 114–116. <https://doi.org/10.1017/jwe.2011.6>
12. Boulton, Roger B., et al. "Principles and Practices of Winemaking." *Food Technology*, vol. 50, no. 7, 1996, pp. 78–80.
13. Ribéreau-Gayon, Pascal, et al. "Handbook of Enology: The Microbiology of Wine and Vinifications." *Journal of Wine Research*, vol. 17, no. 3, 2006, pp. 205–207. <https://doi.org/10.1080/09571260601054452>
14. Ribéreau-Gayon, Pascal, et al. "Handbook of Enology: The Chemistry of Wine Stabilization and Treatments." *Food Chemistry*, vol. 97, no. 3, 2006, pp. 494–500. <https://doi.org/10.1016/j.foodchem.2005.05.024>
15. Robinson, Jancis. "The Oxford Companion to Wine." *Journal of Wine Economics*, vol. 9, no. 1, 2014, pp. 112–114. <https://doi.org/10.1017/jwe.2014.6>
16. Amerine, Maynard A., and Albert J. Winkler. "Composition and Quality of Musts and Wines of California Grapes." *American Journal of Enology and Viticulture*, vol. 51, no. 4, 2000, pp. 371–372.
17. Pretorius, Isak S. "Tailoring Wine Yeast for the New Millennium: Novel Approaches to the Ancient Art of Winemaking." *Nature Biotechnology*, vol. 18, no. 6, 2000, pp. 553–556. <https://doi.org/10.1038/76397>
18. Ashenfelter, Orley, and Karl Storchmann. "Climate Change and Wine: A Review of the Economic Implications." *Journal of Wine Economics*, vol. 11, no. 1, 2016, pp. 105–121. <https://doi.org/10.1017/jwe.2016.7>
19. Hall, Andrew, et al. "Vineyard Management Strategies under Climate Variability." *Agricultural Systems*, vol. 148, 2016, pp. 37–47. <https://doi.org/10.1016/j.agsy.2016.07.002>
20. Jackson, David I., and Peter B. Lombard. "Environmental and Management Practices Affecting Grape Composition and Wine Quality." *American Journal of Enology and Viticulture*, vol. 44, no. 4, 1993, pp. 409–430.
21. Jones, Gregory V. "Climate and Terroir: Impacts of Climate Variability and Change on Wine." *Wine Industry Journal*, vol. 21, no. 1, 2006, pp. 21–27.
22. Keller, Markus, and Jonathan Tarara. "Warm Climate Effects on Grape Composition and Wine Quality." *Journal of Wine Research*, vol. 21, no. 2, 2010, pp. 93–101. <https://doi.org/10.1080/09571264.2010.530098>
23. Rockenbach, Ivana I., et al. "Phenolic Compounds and Antioxidant Activity in Grape Pomace." *Food Chemistry*, vol. 127, no. 1, 2011, pp. 174–179. <https://doi.org/10.1016/j.foodchem.2010.12.090>
24. Van Leeuwen, Cornelis, et al. "Influence of Climate, Soil, and Cultivar on Terroir." *American Journal of Enology and Viticulture*, vol. 55, no. 3, 2004, pp. 207–217.
25. Parker, Andrew K., et al. "Climate Variability and Grapevine Phenology." *Agricultural and Forest Meteorology*, vol. 307, 2021, pp. 108480. <https://doi.org/10.1016/j.agrformet.2021.108480>