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PHYSICOCHEMICAL CHARACTERISTICS OF RED WINES (CABERNET SAUVIGNON AND TEMPRANILLO) FROM ENSENADA, BAJA CALIFORNIA

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ABSTRACT

Ensenada wine country, in the State of Baja California, Mexico, accounts for approximately 70–80 % of Mexico's wine production. Despite its significance, detailed knowledge of the physical and chemical properties of wines remains limited. In this study, we examined nine physicochemical properties of 69 commercial red wines produced from the Tempranillo and Cabernet Sauvignon varietals in the San Vicente, Santo Tomás, and Guadalupe valleys. The pH, total acidity, acetic acid, lactic acid, malic acid, total polyphenols, glucose/fructose ratio, alcohol content, and red color intensity were all analyzed. Tempranillo wines showed significantly higher levels of acetic acid, lactic acid, and total acidity, but lower levels of total polyphenols and malic acid than Cabernet Sauvignon wines. Furthermore, wines from the Santo Tomás region have significantly higher alcohol content, glucose/fructose ratio, total polyphenols, red color intensity, and total acidity, distinguishing them from the wines of San Vicente and Guadalupe. Our results highlight the influence of the grape variety on wine chemistry, emphasizing the possibility for further optimization of the winemaking processes for the benefit of vine growers, enologists, and wine production in the region.

Keywords: *Vitis vinifera* L., viticulture, San Vicente Valley, Santo Tomás Valley, Guadalupe Valley.

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INTRODUCTION

Wine terroir refers to the combination of environmental factors and cultural practices that give wine its unique characteristics. These are shaped by several factors, including the variety of fermented grapes, the vineyard's geographical setting (including mesoclimate, topoclimate, and microclimate), soil geology and composition, as well as agronomic management practices (Alexandre, 2020). Climate, particularly temperature, is a crucial determinant of vine physiology and wine quality (Cabello-

Pasini *et al*., 2017), making climatic variation a key factor in the establishment of successful vineyards and the characteristics of grapes and wines produced in a region (Anderson *et al*., 2012). As such, climate is considered one of the most important factors influencing wine terroir.

About 70–80 % of wine production in Mexico occurs in the municipality of Ensenada, in the State of Baja California (Buendía-Muñoz and del Valle-Sánchez, 2017). There are more than 60 wineries in the region, ranging from very small businesses producing approximately 500 cases per year to considerably larger companies generating more than 15 million cases per year (Covarrubias and Thach, 2015; González-Andrade, 2015). According to state data, there are 3 359.75 ha of vines for winemaking in Ensenada. Approximately 87 % of state production is concentrated in three major wine-producing regions: Guadalupe (46 %), San Vicente (34 %), and Santo Tomás (7 %) (OEIDRUS, 2011).

Due to its Mediterranean climate (rainfall in winter and hot, dry summers), Baja California is regarded as the premier region for high-quality wine production in Mexico (Davis *et al*., 1996). This is primarily attributed to an average temperature of 19.8 °C from April to October, which corresponds to the growth cycle of *Vitis vinifera* L., and an average temperature of 20.4 °C in September, when the fruit ripens (Meraz-Ruiz and Ruiz-Vega, 2016). Although viticulture is practiced in several wine valleys in Baja California, Guadalupe, Santo Tomás, and San Vicente stand out as three of the most important due to their distinct climatic characteristics.

Valenzuela-Solano and Tonietto (2012) studied the viticultural climate of the main wine production areas in Baja California and found climatic diversity between regions, resulting in different viticultural potentials (Table 1). According to Macías-Carranza and Cabello-Pasini (2021), San Vicente and San Antonio de las Minas are classified as Region IV (temperate-warm) and Santo Tomás and Guadalupe as Region V (warm and very warm zones). Additionally, evapotranspiration in San Vicente and San Antonio de las Minas was 15 % lower than in Santo Tomás and Guadalupe. Nonetheless, climate forecasts for Baja California are predicted to change over the next 30 years, posing a threat to the region's ability to produce high-quality wines (Valenzuela-Solano *et al*., 2018).

Table 1. Average yearly total precipitation, minimum temperature, maximum temperature, mean temperature, and evaporation of the studied winemaking regions in Baja California, Mexico (SMN, 2019).

Region	Total precipitation (mm)	Min. Temp. (°C)	Max. Temp. (°C)	Mean Temp. (°C)	Evaporation (mm)
San Vicente	18.0	9.1	25.9	17.6	131.8
Santo Tomás	21.4	8.6	27.3	18.0	151.5
Guadalupe	25.2	8.3	24.8	16.6	130.8

Despite their importance, little is known about the physical and chemical properties of Baja California wines (Covarrubias and Thach, 2015; Castillo-Sánchez *et al.*, 2018). Espitia-López *et al*. (2015) found differences in the content of wood phenolic compounds in a Mexican red Merlot wine from the Guadalupe Valley matured in barrels compared to wood chips. Likewise, Cabello-Pasini *et al*. (2013) evaluated the concentration of Ca, Mg, K, and Na in wines produced in Baja California. In a recent study, Espinoza-Cruz *et al*. (2020) determined major and minor trace elements (K, Na, Mg, Ca, Rb, Sr, Mn, Fe, Al, Cu, and Cr) in Mexican red wines, including five wines from Guadalupe Valley. Chávez-Márquez *et al*. (2022) described the validation of an untargeted metabolomics method for the characterization of Cabernet Sauvignon wines from two vineyards and two vintages in Mexico. Similarly, information on the physicochemical characteristics of grapes and wines, as well as their relationship to the climate factors that prevail in Baja California's grape-growing valleys, is still scarce. To our knowledge, only one study has investigated the relationship between mesoclimatic variability within the Guadalupe Valley and the concentration of total soluble solids, titratable acidity, and pH of Nebbiolo grapes (Cabello-Pasini *et al.*, 2017).

In this context, the objective of this study was to contribute to the decision-making process for winemaking in Baja California through the description of nine physicochemical characteristics (pH, total acidity, acetic acid, lactic acid, malic acid, alcohol content, total polyphenols, glucose/fructose ratio, and red color intensity) of commercial monovarietal red wines of Cabernet Sauvignon and Tempranillo varietals produced in three of the most important wine-producing areas of Baja California (Santo Tomás, San Vicente, and Guadalupe valleys). We also explored whether there are differences in red wines produced from the Cabernet Sauvignon and Tempranillo varietals, as well as in the wine regions of Santo Tomás, Guadalupe, and San Vicente, depending on the analyzed characteristics. Generating such information is one of the first steps in the search for the chemical identity of Baja California wines.

MATERIALS AND METHODS

We sampled 69 different commercial red wines of Tempranillo and Cabernet Sauvignon varietals produced in the San Vicente (SV), Santo Tomás (ST), and Guadalupe (GV) valleys from the 2012–2017 vintage. A sample size of 10 mL was obtained directly from each bottle. We followed an enzymatic approach, using a Y15 Biosystem enological analyzer (Biosystems, Barcelona, Spain) to measure the physicochemical characteristics (pH, total acidity, acetic acid, lactic acid, malic acid, total polyphenols, and glucose/fructose ratio). Alcohol content at 20 °C was measured using a Dujardin-Salleron 160000 ebulliometer (Dujardin-Salleron, France). All analyses were performed in duplicate, then averaged.

The Principal Component Analysis (PCA) is a multivariate technique used to reduce dimensionality in original data while retaining as much information as possible (Syms, 2008). This allows for a two-dimensional study of the wines and the determination of the directions in which the majority of the information is stored. Thus, using the main factors derived from the original data, it is possible to investigate the differences between different wines and determine which variables contribute the most to such variances (Câmara *et al*., 2006). As a result, we conducted a PCA using the physicochemical properties of the wines and retrieved the first four main component scores from the analysis.

We used ANOVA models to determine the main component differences between Cabernet Sauvignon and Tempranillo, as well as the wine-producing regions (ST, SV, and GV). The models PC1, PC2, PC3, and PC4 score as response factors, and the terms Varietal, Region, and Vintage (as covariates to compensate for storage time and environmental differences across years) serve as predictive factors. When the term Region showed significant results in an ANCOVA model, a Tukey-Kramer *post hoc* test was used to assess differences between variable levels ($\alpha = 0.05$). All statistical analyses were carried out using JMP version 14 (JMP Statistical Discovery; NC, USA).

RESULTS AND DISCUSSION

The sampled wines exhibited analytical values within the normal range observed in the global wine industry (Buendía-Muñoz and del Valle-Sánchez, 2017), indicating appropriate vinification techniques and standard quality measures (Table 2). Variations in the physicochemical parameters were found. PC1, PC2, PC3, and PC4 accounted for 75.96 % of the total multivariate variation from the original data (27.4 and 23.8 %, respectively). Variables with higher loading contributions to PC1 were acetic acid (0.883), lactic acid (0.8001), total acidity (0.721), total polyphenols (-0.481), and

Table 2. Summary statistics of nine physicochemical variables evaluated for Cabernet and Tempranillo red wines produced in the San Vicente, Santo Tomás, and Guadalupe valleys in Baja California, Mexico.

	Cabernet Sauvignon (mean ± SE)			Tempranillo (mean ± SE)		
	San Vicente	Santo Tomás	Guadalupe	San Vicente	Santo Tomás	Guadalupe
Glucose-fructose (g L^{-1})	2.85±1.37	2.39±0.43	2.38±0.50	4.26±1.79	2.45±0.75	1.90±0.34
Alcohol content (g L^{-1})	14.3±0.96	13.6±0.97	14.5±0.95	14.8±1.58	14.27±1.28	14.66±1.09
pH	3.83±0.12	3.93±0.05	3.82±0.18	3.85±0.14	3.89±0.20	3.86±0.17
Lactic acid (g L^{-1})	1.29±0.23	1.45±0.19	1.25±0.42	1.65±0.34	1.63±0.36	1.66±0.63
Malic acid (g L^{-1})	0.13±0.06	0.10±0.30	0.26±0.25	0.13±0.04	0.20±0.18	0.14±0.19
Acetic acid (g L^{-1})	0.87±0.23	0.99±0.19	0.76±0.21	0.97±0.16	1.14±0.12	0.95±0.34
Total acidity (g L^{-1})	5.28±0.62	4.82±0.31	5.06±0.61	5.36±0.62	5.22±0.21	5.19±0.14
Total polyphenols (mg L^{-1})	1985.00±327.49	1954.80±201.19	1057.81±199.86	1992.67±293.11	1975.50±278.60	1889.39±195.20
Red color intensity	9.82±2.37	8.05±1.19	9.57±1.89	12.32±4.51	9.03±2.06	8.78±1.14

SE: standard error.

malic acid (-0.559). On the other hand, variables that loaded higher into PC2 were red color intensity (0.882), total polyphenols (0.638), glucose/fructose ratio (0.619), ethanol content (0.554), and total acidity (0.347). Variables with higher loading contributions to PC3 were pH (0.928) and total acidity, while malic acid (0.635) and the glucose/fructose ratio (-0.406) contributed the most to PC4.

ANCOVA analysis for PC1 detected a significant effect of the term Varietal (F = 7.29, df (degrees of freedom) = 1, p = 0.0089). The mean PC1 scores were lower for Cabernet Sauvignon compared to Tempranillo wines (Figure 1). On the other hand, ANCOVA analysis for PC2 found a significant effect of the term Region (F = 3.95, df = 2, p = 0.024). Tukey-Kramer HSD *post hoc* analysis found that mean PC2 scores were significantly higher in ST compared to SV and VG, which did not differ between each other (Figure 1). ANCOVA analysis for PC3 detected a significant effect of the term Vintage (F = 4.15, df = 1, p = 0.0044), and a posterior regression analysis showed a positive relationship between Vintage values and PC3 scores (y = -364.5 + 0.1805 × Vintage, R^2 = 0.1, p = 0.0074).

ANCOVA of PC1 scores revealed that Tempranillo wines had significantly greater levels of acetic acid, lactic acid, and total acidity but lower levels of total polyphenols and malic acid than Cabernet Sauvignon wines (Figure 1). This indicates that grape variety is an important factor contributing to the differences in acidity profiles among the analyzed wines (Miao *et al*., 2022). Particularly, the Cabernet Sauvignon variety showed higher PC1 scores compared to Tempranillo, reflecting a more pronounced acidity profile (Figure 1). However, the acidity is not just determined by the type of grapes used but also by the winemaking process itself, including fermentation conditions and techniques (Jakabová *et al*., 2021).

Likewise, the lower levels of malic acid observed in Cabernet Sauvignon compared to Tempranillo wines might be the result of vinification decisions intended to achieve a "rounder and creamier mouthfeel" throughout an extensive malolactic fermentation (Virdis *et al*., 2021). On the other hand, polyphenol levels could be attributed to the thickness of the grape skins of each variety. Cabernet Sauvignon grapes are renowned for their thick skins, which may impede the extraction of phenolic compounds, resulting in lower polyphenol content (Apolinar-Valiente *et al*., 2016; Gombau *et al*., 2020). The obtained acidity profile and total phenol content may be the result of different factors such as canopy management, extraction techniques, winemaking practices, and grape thickness (Jakabová *et al*., 2021). Further research is warranted to elucidate the specific mechanisms underlying these differences and to explore the potential implications for wine production in the region.

On the other hand, ANCOVA of PC2 scores showed that wines produced in the Santo Tomás region had significantly higher alcohol content, glucose/fructose ratio values, total polyphenols, red color intensity, and total acidity than wines from San Vicente and Guadalupe, which did not differ between each other (Figure 1). This suggests that the geographic origin of the wines influenced the evaluated variables related to PC2. Elevated temperatures have been observed to increase alcohol content, glucose/

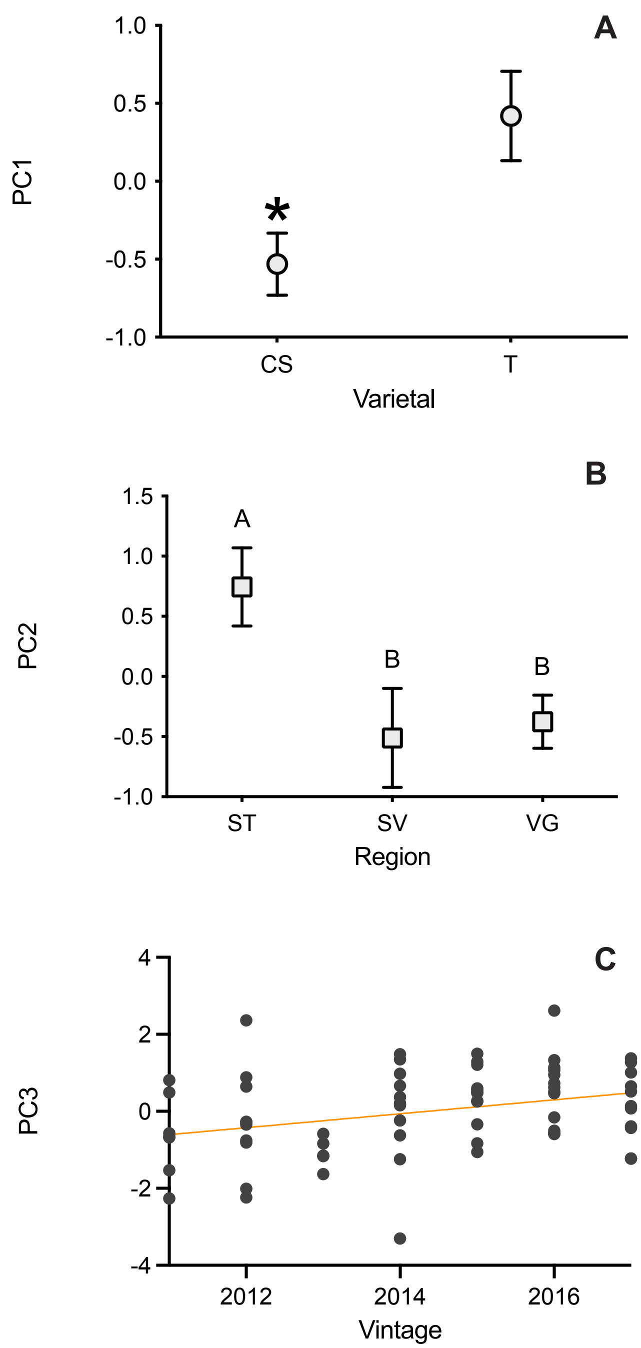

Figure 1. Principal component analysis score means (± SE). A: Principal Component 1 (PC1) of Cabernet Sauvignon and Tempranillo varietals; B: Principal Component 2 (CP2) of red wines produced on San Vicente, Santo Tomás, and Guadalupe valleys; C: relationship between Principal Component 3 (PC3) scores and Vintage values of studied wines. Means not sharing the same letter differ significantly after a Tukey-Kramer LSD *post hoc* test. *Significant differences between levels.

fructose levels, total polyphenols, and red color intensity while increasing total acidity (Delrot *et al*., 2020).

Finally, analyses revealed a significant relationship with Vintage, indicating that annual harvest variations have a significant influence on the chemical profiles of the studied wines. This suggests that interannual differences in climate conditions, cultivation practices, and grape maturity at the time of harvest can have considerable effects on the physicochemical characteristics of wines, specifically on parameters associated with PC3, such as pH and total acidity.

Temperatures in the various wine valleys of Baja California have risen significantly in recent years (Valenzuela-Solano *et al*., 2018). Given that Santo Tomás is already a warm valley, it can be expected that wines produced in this region will be among the first to experience the consequences of temperature surges. Winemakers in the region could benefit from the use of non-*Saccharomyces* yeasts, such as *Lachancea thermotolerans*, in co-culture with *Saccharomyces* strains as adaptation strategies to control pH, ethanol, and volatile acidity resulting from high temperatures (Benito, 2018; Pérez-Muñoz *et al*., 2023). They can also implement strategies such as irrigation and canopy management to reduce the effects of increasing temperatures (Delrot, 2020).

CONCLUSIONS

Based on their physicochemical characteristics, we were able to detect significant multivariate differences between varieties and regions. The analyzed wines exhibit standard values in all analytical measurements of the final product, suggesting proper winemaking practices were employed while highlighting the significant influence of grape variety on the chemical composition of wines in the region. However, in the face of the challenges derived from climate change, there is still room for monitoring, control, and improvement in the winemaking process.

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