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Sensory and Physicochemical Characterization of Three Oenological Products from Cameroon

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Abstract

In Cameroon's expanding eneological sector, local producers are responding to the rise of a middle-class consumer base with specific sensory expectations. Despite comparable pricing (~1300 FCFA/L) and similar packaging, commercial dry red wines show marked variability in consumer acceptance. This study sought to characterize and identify the physicochemical factors influencing consumer preferences among three popular locally produced red wines. Hedonic sensory and physicochemical evaluations were conducted. ANOVA, linear regression, and principal component analysis (PCA) were strategically applied to examine and interpret the results. Hedonic analysis revealed that wine 654 was significantly ($p<0.05$) more appreciated (mean score: 3.63 ± 0.94) than wines 886 and 587. Linear regression indicated that in-mouth volume, odor, acidity, and in-mouth warmth were the main sensory attributes driving overall liking. The most appreciated wine, wine 654, exhibited a distinct chemical profile: lower pH (2.97 ± 0.02), higher total acidity (5.58 ± 0.01 g/L), lower alcohol content (12.29 ± 0.09%), and greater color intensity (6.89 ± 0.02). It was also richer in total phenolics (TPI: 30.20 ± 0.03 AU), anthocyanins (40.40 ± 2.32 mg/L), and amino acids (AA: 1.21 ± 0.07 g/L), and showed moderate tannin (0.97 ± 0.01 g/L) and vitamin C levels (90.00 ± 10.00 mg/L). Except for dry extract in two samples, all parameters complied with OIV standards. Principal Component Analysis identified acidity, sugar, alcohol, AA, total proteins, total SO_2, and total phenolic compounds as the main physicochemical markers of sensory quality, thus providing avenues for optimizing wine quality to align with the specific palate of Cameroonian consumers. To further advance this work, future research will focus on detailed profiling of phenolic compounds, organic acids, and volatile aromatic compounds contributing to the overall sensory experience.

Introduction

Grapes, the fruit of the vine (*Vitis vinifera*), represent a strategic raw material for winemaking, a fermented product among the most widely consumed worldwide. Wine quality is intrinsically linked to grape quality, which itself is influenced by a wide range of factors, including the geographical location of the vineyard, climate, soil characteristics, viticultural practices, and the grape varieties used [1]. This quality is reflected in both sensory and physico-chemical properties, the expression of which is closely dependent on the initial composition of the grape.

Recent studies have highlighted the impact of the production method on sensory dimensions and, consequently, on the overall perception of wine quality [2]. In this context, the development of wine products with distinctive organoleptic profiles represents a major strategic lever for the growth of the wine industry, in response to the diverse expectations of consumers [3]. Accordingly, oenological research focuses on characterizing wine production, composition, and tasting modalities in order to optimize winemaking processes and ensure consistent quality [3].

The sensory quality of wine relies both on its aromatic expression and the perceived gustatory balance, the latter resulting from the interaction between sour, sweet, and bitter tastes, modulated by tannic structure. Major organic acids such as tartaric, malic, citric, and lactic acids play a central role in the perception of acidity [4], while the bitterness of red wines is partly attributed to plant-derived phenolic compounds, as well as to ellagitannins extracted from oak wood during barrel aging [5].

As a complex and evolving product, wine must meet physico-chemical standards defined by the International Organisation of Vine and Wine [6], which serve to characterize the quality of red wines based on criteria such as: pH (2.8 to 3.8), total acidity (≥ 3.5 g/L of tartaric acid or 3 to 6g/L sulphuric acid), volatile acidity (≤ 0.98 g/L), alcoholic strength by volume (8.5 to 15% vol), sugar content in the must (150 to 250 g/L), residual sugars (0 to 10 g/L for dry wines; 20 to 40 g/L for sweet wines), free SO_2 content (≤ 40 mg/L at consumption), total SO_2 (≤ 150 mg/L for wines with <5 g/L sugar), dry extract (≥17 g/L), colour (color intensity), and phenolic compound content [7,8].

Globally, European countries remain the leading wine producers, with Italy, France, and Spain at the top, producing 47.2, 43.9, and 37.5 million hectolitres per year, respectively. In Africa, South Africa stands as the primary producer, with an annual output of 10.4 million hectolitres [9].

In Cameroon, according to data collected at the General Directorate of Imports, wine operators in Cameroon have ordered large quantities of secure stickers to stamp wines in recent years. The data shows an increasing trend in orders for stickers over the years, with 47752220, 58739874, 31766968, 39634204 stickers ordered for the years 2022, 2021, 2019 and 2018 respectively, highlighting the growing importance of wine in local food culture and consumption habits.

Wine holds a special place in Cameroonian social practices, particularly during ceremonies and celebrations. The systematic introduction of wine lists in restaurants also reflects the valued nature of its consumption**.** Furthermore, red wine presents documented functional benefits. Indeed, moderate consumption may contribute to the nutritional prevention of various diseases, due to the presence of phenolic compounds with antioxidant properties [10]. These bioactive molecules are associated with anti-carcinogenic, anti-atherogenic, anti-inflammatory, immunomodulatory, and antimicrobial effects, among others [11]**.** Moreover, its high-water content makes wine a beverage that also contributes to hydration.

Numerous recent studies have focused on the physico-chemical and sensory characterization of wines or their raw materials, with a view to technological optimization through targeted choices related to grape varieties, enological inputs, or winemaking processes [12-14]**.**

In Cameroon, the wine sector is experiencing sustained growth, driven primarily by demand from the middle class. Many local production units are attempting to meet this demand by offering affordable and competitive wines while maintaining an acceptable level of quality. However, understanding consumer sensory preferences remains a complex challenge. On the local market, three brands of dry red wines sold in similar packaging and within the same price range (approximately 1300 FCFA per liter) are particularly popular. Despite this apparent homogeneity, certain brands are more appreciated than others, yet no study to date has identified the factors responsible for these sensory differences.

The present study aimed to identify the physico-chemical and sensory determinants responsible for the differences in perception among three popular local brands of dry red wines, in order to propose technological levers for improving the quality of wines produced in Cameroon, in line with consumer preference

Materials and Methods

Chemicals and reagents

Sodium hydroxide (NaOH), iodine (I_2), formaldehyde (CH_2O), sulfuric acid (H_2SO_4), purchased from An ITW company (Darmstadt, Germany), Folin-Ciocalteu reagent ($[PMo_{12}O_{40}]^{3-}$ and $[PW_{12}O_{40}]^{3-}$), hydrogen peroxide (H_2O_2), tartaric acid ($C_4H_6O_6$), calcium carbonate ($CaCO_3$), sodium metabisulfite ($Na_2S_2O_5$), hydrochloric acid (HCl), 3,5-dinitrosalicylic acid (DNS), zinc sulfate ($ZnSO_4$), potassium ferrocyanide ($K_4[Fe(CN)_6]$), ninhydrin (2,2-dihydroxyindane-1,3-dione), sodium acetate (CH_3COONa), 2,6-dichlorophenolindophenol (2,6-DCPIP), ascorbic acid ($C_6H_8O_6$), glycine ($C_2H_5NO_2$), ammonium sulfate ((NH4)2SO4), pure glucose ($C_6H_{12}O_6$), acetic acid 90% (CH_3COOH), pure starch ((C6H10O5) n), formalin (CH_2O), acetylacetone ($C_5H_8O_2$), ethanol (C_2H_5OH), 1-butanol 80% ($C_4H_{10}O$) were purchased from Sigma-Aldrich (Darmstadt, Germany).

Sampling

The study was carried out using three popular commercial samples of dry red wines in the same price range (1300 FCFA/per 1-litre unit) and with the same packaging. The three popular brands of wine were produced in August 2022 from concentrated *Vitis vinifera L.* grape must of the *Garnacha Tintorera Valencia variety*, as shown in the technological diagram below (Figure 1). Three units (bricks) of 1L each of the same production batch of each sample were taken from three cellars in the city of Yaoundé on 27/08/22. All samples were transported to the Food Science and Metabolism Laboratory of the University of Yaoundé 1 on 28/08/22. Composite samples of each brand were then prepared by homogeneously mixing the same volumes of wine for sensory and physicochemical analysis. The bottles containing the samples were coded (wine 587; wine 886 and wine 654= reference) and stored in a refrigerator at 10-12ºC throughout the test period with oxygen vacuum corks to preserve the wine in good condition. The glasses were coded with the same 3-digit numbers. Sensory analyses were carried out from

Hedonic sensory analysis of the three wines

This analysis combines the general appreciation of each wine, the acceptability index of each wine and the influence of the hedonic descriptors on the overall appreciation of the wines. It was carried out using the AFNOR method.

General conditions and ethical statement: The panellists were recruited voluntarily and they were asked to sign an informed consent form in which they were informed about the presence of sulfite and ethanol in the sample wines to avoid any related issues. The maximum quantity of wine per glass per sample was 30 mL per glass per sample [15] and the wines contained approximately 13% v/v ethanol (3.9 g of ethanol per 30 mL sample). The study was conducted following the Declaration of Helsinki [16]**.** There was no cost to participate; refusal to participate did not imply any penalties or loss of benefits, and participants were permitted to withdraw at any time without giving any reason. Based on this statement and since the participants were instructed to spit the wine after the analysis and the sample were commercial products available on the market, approval from an ethics committee was not required [15]. In all three assessments of sample water and unsalted crackers were provided for palate cleansing. The panel was formed of 108 naïve assessors (91% male, 9% female; mean age 38.5 ± 11.9 years). All assessors were educated adults working in the trade sector, with a good level of comprehension. As the panel was composed of naïve assessors, formal training sessions were not required. The panel leader ensured that each descriptor was well understood by the assessors by using familiar vocabulary to explain them. To avoid misunderstandings and to reflect consumers' perception of the products, explanations of each descriptor evaluated, using simple and understandable vocabulary, were given to consumers. The monitor ensured that consumers would understand the explanation before proceeding with the evaluation questionnaires [15]**.** For example, the dryness of the mouth on contact with the wine was used to explain the descriptor "astringency" to the tasters, the wine as heavy as boiling or as light/ fluid in the mouth as water was used to explain the descriptor "volume in the mouth", the warmth in the mouth was used for the descriptor "richness in alcohol".

Overall assessment: A panel of 108 naive judges with experience of consuming wine was recruited from the Nkolen-Eton and Elig-Edjoua markets in Yaounde. The age of the panelists ranged from

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21 to 64 years. The following scale legend was used for the overall assessment and evaluation of the hedonic descriptors: (1=Don't like at all, 2= Don't like too much, 3= Indifferent, 4= Like a little, 5= Like too much). Each panelist gave an overall assessment based on 5 points. The acceptability index was then evaluated by dividing the average overall rating by 5.

Evaluation of the hedonic descriptors on the hedonic appreciation of the different wines: Hedonic descriptors such as volume in the mouth, dryness in the mouth, warmth in the mouth, odour, colour, bitterness, sweetness and acidity were evaluated and scored on a 5-point ordinal scale. The tasting conditions were carried out according to the method described by Duley *et al.* [12] and Casamayor *et al.* [17].

Samples of 30 mL of each wine were presented simultaneously to the tasters in three transparent glasses, each coded with a three-digit random number. All wines were served at room temperature (approximately 25°C) and evaluated individually. The tasters were given the following instructions: successively bring the small quantity of wine contained in the glass into the mouth and suck in a trickle of air; then stir the wine in the mouth and wait for about twelve seconds, swallow or spit it out; rinse the mouth with water before moving on to the next sample. At the end, record the hedonic descriptors for each product tasted successively, on the 5-point ordinal scale on the tasting sheet, according to the level of hedonic appreciation. Then give your your overall appreciation of each wine by marking the hedonic evaluation on a 5-point scale. For each judge, questions relating to age, sex and whether or not they drank dry red wine were asked. The results were expressed by calculating the average points for each descriptor out of five.

Physicochemical characteristics of wines

Current oenological parameters: The analytical methods proposed by the International Organisation of Vine and Wine [18] were used to determine the following wine physicochemical parameters: pH, titratable acidity, volatile acidity, free and total sulphite content (SO_2L and SO_2T), dry extract, density and alcoholic content. Volatile acidity and titratable acidity were expressed as g sulphuric acid per litre and tartaric acid, respectively, at 20 °C. Alcoholic content was expressed as the percentage of ethanol (v/v) at 20 °C. free and total sulphite content was expressed in mg/L. Reducing sugars were determined by measuring the absorbances at wavelengths 530 nm, using the DNS (3,5-dinitrosalicylic acid) colorimetric method described by Fischer and Stein [19].

Spectrophotometric parameters: The colorimetric analysis of wine samples was conducted by evaluating three characteristic wavelengths: absorbance at 420 nm (yellow), 520 nm (red), and 620 nm (mauve). Based on these measurements, three characteristic indices were calculated: color intensity (CI), hue (T), and the relative contribution (%) of each colour component.

Chromatic parameters of wines: The Colour intensity (CI) was determined by absorbance measurements using 1 mm path length cells, the values being converted to an optical path of 1 cm:

$$CI = (A_{420\ nm} + A_{520\ nm} + A_{620\ nm}) \quad (1)$$

The chromatic tone (T) value was calculated using the ratio of the absorbance at 420 to that at 520: $T = A_{420\ nm}/A_{520\ nm}$. The % Yellow, % Red and % Blue colorimetric indices were calculated by measuring the absorbances at wavelengths 420, 520 and 620 nm, respectively, using a RIGOL UV-vis spectrophotometer with a 0.5 cm quartz cuvette and using the following formula:

$$\%\ A_X = (A_X/CI) \times 100 \quad (2)$$

where A_X is the absorbance of each coloration [20].

Total Anthocyanins content: Total anthocyanins were determined using the method described by Ribéreau-Gayon and Stonestreet [21] To this end, a solution was prepared containing 0.5 mL of wine sample, 0.5 mL of 0.1% ethanol, and 10 mL of 2% HCl. Five millilitres of this solution were transferred into two test tubes: one was supplemented with 2 mL of distilled water (control tube), and the other with 2 mL of 15% (w/v) sodium bisulfite solution (bisulfite tube), in which anthocyanin discoloration was observed. Absorbance was measured after 20 minutes at 520 nm:

$$\text{Total Anthocyanins (mg/L)} = 875 \times (A_{520\ nm}\ \text{control} - A_{520\ nm}\ \text{bisulfite}) \quad (3)$$

where 875 is the conversion factor

Total tannins content

Total tannins were determined using the method described by Ribéreau-Gayon and Stonestreet. [22]. To this end, 2 mL of wine sample diluted 50-fold were placed in a hydrolysis tube along with 1 mL of distilled water and 3 mL of concentrated hydrochloric acid (12 N or 37%). The tube was sealed with a Teflon-lined cap and heated in a water bath at 100 °C for 30 minutes. Simultaneously, a control tube containing the same solution was kept on ice. After cooling of the hydrolyzed tube, 0.5 mL of ethanol was added to each tube, and the absorbance was measured at 550 nm:

$$\text{Total tannins (g/L)} = 19.33 \times (A_{550\ nm}\ \text{hydrolyzed} - A_{550\ nm}\ \text{control}) \quad (4)$$

where 19.33 is the conversion factor

Total phenolic compounds: Total phenolic compounds (TPC) were evaluated using two methods described by García [23]: Into a 100 mL volumetric flask were successively introduced: 1 mL of wine diluted 10-fold, 50 mL of distilled water, 5 mL of Folin–Ciocalteu reagent, and 20 mL of 20% (w/v) anhydrous sodium carbonate (Na_2CO_3) solution. The mixture was brought to volume with distilled water, homogenized, and left to stand for 30 minutes. Absorbance was measured at 760 nm:

$$\text{Folin–Ciocalteu index (FCI) (UA)} = A_{760\ nm} \times \text{dilution factor} \times 20 \quad (5)$$

where 20 is the conversion factor. Total Phenolic compounds index (TPI): The wine, diluted 100 times with distilled water, Absorbance was measured 30 min after adequate dilution of samples, using 1 cm path length cells

$$TPI = A_{280nm} \times 100 \quad (6)$$

The total phenol content was expressed as absorbance units (AU). where 100 is the dilution factor.

The carotenoids content: Total carotenoids were assessed using the method described by Maira et *al.* [24]. One milliliter of wine was introduced into one test tube and 1 mL of distilled water into another, followed by the addition of 5 mL of 70% (v/v) ethanol to each tube. The tubes were incubated in the dark for 15 minutes with shaking. Subsequently, the samples were centrifuged at 5000 rpm, and absorbance was measured at 665 nm, 649 nm, and 440 nm, respectively to the quantification of chlorophyll A, chlorophyll B, and carotenoids.

Nutritional parameters: The determination of total amino acid content was carried out using the ninhydrin method described by Kendall *et al.* [25] by measuring absorbances at 550nm. The total amino acid content was expressed in g/L. Crude protein (nitrogen x 6.25) was determined using a modified Kjeldahl procedure, which uses concentrated sulphuric acid and hydrogen peroxide to decompose the sample with the addition of metal catalysts [19]. Vitamin C content in the sample was determined using the method described by Iddah *et al.* [26], which uses sample, concentrated acetic acid and 2,6-dichlorophenol indophenol (2,6 DCPIP) solution for titration. The crude ash content and fibre were determined after calcination by the method described by A.O.A.C. [27]. They were expressed in g/L. All other analyses were performed using a RIGOL UV-vis spectrophotometer (Ultra-3400, China) with a 1-cm quartz cuvette.

Statistical analysis

The physico-chemical experiments were run in triplicate. The data of the sensorial and physico-chemical analysis were reported as mean ± standard deviation and treated using a one-way analysis of variance (ANOVA, Tukey test, $P < 0.05$) to identify significant differences between the wines. These statistical tests were performed using SPSS software, version 21.0 (IBM, Endicott, New York, USA). Linear regression with the overall hedonic appreciation (5-point scale) was used to highlight the hedonic determinants involved in wine appreciation. Principal Component Analysis (PCA) was used to study the correlations between the Physicochemical variables and the wines and overall liking, knowing the level of overall appreciation of the wines and to highlight the physicochemical determinants. These were performed using XLSTAT 2014 software (Addinsoft, Paris, France). The differences were considered significant at $P < 0.05$.

Results and Discussion

Sensory hedonic analysis of samples

A hedonic sensory analysis was conducted with 108 naive consumers selected to represent the target market. The participant cohort had a mean age of 38.5 ± 11.9 years and comprised 91% males and 9% females. This significant gender imbalance is a key feature of the study, as it deliberately mirrors the observed consumer base for affordable, locally produced red wines in the Cameroonian context. (Table 1) summarizes the overall liking scores and acceptability indices derived from this panel.

The hedonic evaluation revealed a statistically significant preference for wine 654, which obtained a mean appreciation score of 3.63 ± 0.94, outperforming both wine 587 (3.06 ± 0.97) and wine 886 (3.10 ± 1.04) ($P < 0.05$). This superior rating was corroborated by the Acceptability Index (AI): only wine 654 (AI = 0.72) surpassed the consumer acceptance benchmark of 0.7, whereas the other two samples did not (AI = 0.61 and 0.62). We analyzed the contribution of eight key sensory descriptors (Figure 2). These attributes spanned mouthfeel (volume, warmth, dryness), taste (bitterness, acidity, sweetness), aroma, and colour, allowing for a comprehensive breakdown of the drivers of overall liking.

A detailed analysis of the sensory descriptors (Figure 2) deconstructs the consumer preference for wine 654. This preferred sample consistently outperformed the others, showing significantly higher ratings ($P < 0.05$) across nearly all positive attributes when compared to wine 587. The distinction was narrower against wine 886, with mouthfeel and sweetness emerging as the key significant differentiators ($P < 0.05$). Crucially, the two less-preferred wines, 587 and 886, were sensorially indistinguishable; no significant differences ($P > 0.05$) were found for any descriptor, mirroring their similar overall hedonic scores. While this analysis identifies the attributes that were rated differently, linear regression was employed to determine which descriptors were most predictive of overall liking. (Table 2) presents the model outputs, quantifying the contribution of each sensory attribute to the final consumer rating.

To quantify the factors influencing overall liking, a linear regression analysis was performed (Table 2). The model revealed that in-mouth volume, odor, acidity, and in-mouth warmth were the sensory attributes that significantly and positively influence the overall liking of the wine ($P < 0.05$). Indeed, in-mouth volume often associated with perceptions of roundness, suppleness, and structure contributes to a sense of fullness during tasting. This sensation is generally appreciated by consumers, as it imparts a richer and more pleasant texture to the wine. Similarly, odor plays a crucial role in shaping hedonic expectations: intense and pleasant aromas (such as red fruits, floral, or spicy notes) enhance overall liking, as confirmed by several previous studies on the relationship between aroma intensity and acceptability**.** Indeed, according to the evaluators, wine

Table 1: Overall assessment ratings and acceptability indices for the different wines

Wine samples	587	654	886
Overall liking scores /5points	3.06 ± 0.97^b	3.63 ± 0.94^a	3.10 ± 1.04^b
Interpretation of ratings	Indifferent	Like a little	Indifferent
Acceptability index (AI)	0.61	0.72	0.62

^{a,b,c} The results associated with the same small letters on the same line mean the samples do not differ significantly with one another for the overall liking scores (P > 0.05). the sample was accepted if AI ≥ 0.7

Table 2: Linear regression of hedonic descriptors on overall hedonic appreciation of wines

Variables	Estimation	95% CI	SE	p-value
Volume in the mouth	0.11	0.00-0.23	0.058	0.038
Bitterness	0.09	-0.01-0.18	0.051	0.092
Odour	0.15	0.05-0.25	0.050	0.003
Colour	-0.01	-0.11-0.09	0.054	0.836
Acidity	0.18	0.07-0.28	0.051	0.001
Warmth in the mouth	0.27	0.16-0.38	0,055	0.001
Dryness in the mouth	0.01	-0.08-0.10	0.047	0.837
Sweetness	0.09	-0.00-0.18	0.047	0.062

The larger the estimation of regression coefficient (estimation) the stronger the association of the variable with overall hedonic appreciation and P < 0.05. CI=confidence interval, SE=standard error of estimation.

654 is considered sound due to its pleasant aroma, meaning it is free from off-odors or unusual unclean notes, as described by Yusen et *al.* [28]. Furthermore, when properly balanced, acidity brings freshness and promotes a sense of liveliness, thus contributing to the wine's organoleptic balance. Lastly, in-mouth warmth typically associated with alcohol content can be positively perceived when moderate, as it enhances the perception of body and roundness. These findings confirm that consumer preferences are closely linked to multisensory attributes that combine olfactory, gustatory, and tactile components. However, in contrast to the findings of Tamara *et al*. [29], other descriptors such as sweetness, color, and mouthfeel dryness did not exhibit a significant impact on hedonic appreciation in the present study. This lack of significant effect may be attributed to the panel's lower sensitivity to these specific characteristics or to their limited variation across the tested samples. These findings are consistent with those reported by Maria *et al.* [30], who observed no significant differences ($P > 0.05$) in sweetness preference among wines containing 2 g/L, 4 g/L, and up to 16 g/L of residual sugar except in individuals with high extraversion traits, for whom a preference shift was noted at 8 g/L. Despite the absence of significant differences in the perception of mouthfeel dryness and sweetness between samples, as evaluated by the panellists ($P > 0.05$), a wine with a "good" or "balanced" taste is one in which acidity, fruity aromas, sugar, and tannins are in harmony, with a pleasant and lingering aftertaste. The overall acceptability of wine sample 654 may be attributed to these sensory attributes [8]. In fruit wines, naturally occurring phenolic compounds may be responsible for the favorable aroma and taste of the wine products. According to Sun *et al.* [31], phenolic compounds in wine interact with salivary proteins in the mouth and are responsible for wine astringency and bitterness. These observations highlight the importance, for oenologists, of mastering the sensory dimensions that directly influence consumer satisfaction. Improving mouthfeel structure, aromatic expression, and acid–alcohol balance should be prioritized when developing wines aimed at Cameroonian dry red wine consumers from the middle-income market segment.

The physicochemical properties of the three wine samples were analyzed to identify the chemical basis for the observed sensory differences. The results are detailed in Table III and summarized below by category.

Table 3: Results of the analyses of the physicochemical parameters of current, spectrophotometric and nutritional of the three wines.

Physicochemical variables	Wine Samples		
	587	654	886
Current oenological analysis			
pH	3.21 ± 0.03ᵃ	2.97 ± 0.02ᵇ	3.15 ± 0.03ᵃ
Titratable acidity (g tartaric acid /L)	4.43 ± 0.14ᵃ	5.58 ± 0.01ᵇ	5.17 ± 0.51ᵃᵇ
Volatile acidity (g H_2SO_4/L)	0.92 ± 0.08ᵃ	0.79 ± 0.03ᵃ	1.04 ± 0.06ᵇ
Free sulphite (mg/L)	24.53 ± 1.85ᵃ	21.33 ± 1.85ᵃ	20.27 ± 1.85ᵃ
Total sulphite (mg/L)	122.33 ± 2.14ᵃ	87.47 ± 1.85ᵇ	149.33 ± 8.05ᶜ
Dry extract (g/L)	8.62 ± 0.01ᵃ	15.49 ± 0.01ᵇ	17.16 ± 0.01ᶜ
Density (g/mL)	0.99 ± 0.00ᵃ	0.99 ± 0.00ᵃ	0.99 ± 0.00ᵃ
Alcoholic% (V/V)	12.96 ± 0.06ᵃ	12.29 ± 0.09ᵇ	12.40 ± 0.10ᵇ
Reducing sugars (g/L)	8.04 ± 0.42ᵃ	5.08 ± 0.10ᵇ	5.15 ± 0.24ᵇ
Spectrophotometric analysis			
Tone	1.02 ± 0.00ᵃ	0.94 ± 0.00ᵇ	1.59 ± 0.01ᶜ
Colour intensity	5.22 ± 0.01ᵃ	6.89 ± 0.02ᵇ	6.26 ± 0.01ᶜ
%Yellow	46.23 ± 0.59ᵃ	44.98 ± 0.58ᵇ	57.20 ± 0.16ᶜ
%Red	45.31 ± 0.53ᵃ	47.88 ± 0.58ᵇ	35.87 ± 0.09ᶜ
% Mauve	8.45 ± 0.02ᵃ	7.14 ± 0.00ᵇ	6.93 ± 0.07ᶜ
Anthocyanins (mg/L)	24.57 ± 0.32ᵃ	40.40 ± 2.32ᵇ	40.10 ± 1.60ᵇ
Tanins (g/L)	0.61 ± 0.00ᵃ	0.97 ± 0.01ᵇ	1.04 ± 0.02ᶜ
FCI (UA)	3.60 ± 1.22ᵃ	10.60 ± 3.20ᵇ	7.60 ± 0.80ᶜ
TPI (UA)	22.24 ± 0.02ᵃ	30.20 ± 0.03ᵇ	26.85 ± 0.04ᶜ
Carotenoids (mg/L)	20.93 ± 1.29ᵃ	23.00 ± 0.89ᵃ	23.16 ± 2.52ᵃ
Nutritional analysis			
Total amino acids (g/L)	1.08 ± 0.02ᵃ	1.39 ± 0.03ᵇ	1.08 ± 0.03ᵃ
Total proteins (g/L)	1.84 ± 0.12ᵃ	1.21 ± 0.07ᵇ	2.32 ± 0.10ᶜ
Vitamin C (mg/L)	43.33 ± 15.28ᵃ	90.00 ± 10.00ᵇ	153.33 ± 15.28ᶜ
Ash (g/L)	0.63 ± 0.04ᵃ	1.56 ± 0.01ᵇ	1.82 ± 0.00ᶜ
Fibre (g/L)	0.13 ± 0.00ᵃ	0.59 ± 0.01ᵇ	0.69 ± 0.01ᶜ

a,b,c The same somall letters in the same line mean the samples do not differ significantly with one another for the of the same physicochemical parameter ($P > 0.05$). FCI = Folin Ciocalteu Index and TPI = Total Phenolic compounds Index.

Physicochemical analysis of samples

The physicochemical and nutritional characteristics of the three wine samples were analyzed, and the results are presented in (Table 3).

Current oenological analysis

pH, titratable acidity and volatile acidity content: The analysis of the physicochemical and sensory characteristics of the three red wine samples revealed notable differences, particularly in terms of their acidic profile, chromatic properties, and sensory acceptability. Sample 654, which was significantly better appreciated by consumers, was distinguished by a lower pH (2.97 ± 0.02) and a higher total acidity (5.58 ± 0.01 g/L), giving the wine an increased perception of freshness and greater microbiological stability. These values fell within the ranges reported by Ma *et al.* and Dhroso *et al.*, Delanoë *et al.* [8,14,7], who observed pH values between 2.8 and 3.8, and total acidity ranging from 3.9 to 6 g tartaric acid /L. Chemically, low pH promotes the predominance of the flavylium form of anthocyanins, the stable red pigment responsible for the intense color of young wines. As demonstrated by several authors [32], anthocyanins are mostly present in their colorless hemiketal form at pH 3–4, but as the pH decreases, they convert into the flavylium cation (A^+), thereby intensifying the red hue of the wine. This phenomenon would explain the better visual appreciation of sample 654, as well as the positive descriptive terms used by panelists to describe its color. Furthermore, this sample presented the lowest volatile acidity (0.79 ± 0.03 g H_2SO_4/L), below the threshold value of 0.98 g/L, beyond which wine develops a pungent odor typical of acetic acid. This moderate volatile acidity is an indicator of well-controlled fermentation, limiting the organoleptic deviations often caused by uncontrolled microbial development. The results thus confirmed the observations of Delanoë *et al.* [7] regarding the acceptable tolerance range for volatile acidity in red wines. On a biochemical level, the organic acid composition likely influenced the overall perception of the wine. Tartaric acid, the dominant acid in wine, although not metabolized, can be partially lost through precipitation or ionic neutralization with cations such as K^+, Ca^{2+} or Na^+, as mentioned by Rajković *et al.* [33]**.** The acid stability of the wine depends on this, thereby impacting its gustatory structure. Samples 587 and 886, which were less appreciated,

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displayed higher pH values (3.21 and 3.15) and lower total acidity, which may have reduced the perceived freshness and weakened the aromatic expression. This inverse relationship between pH and sensory intensity is corroborated by data from Scutarașu *et al.* [34], who demonstrated the importance of fermentation control on the final organic acid composition. Uncontrolled fermentations result in higher acid concentrations, but also in greater aromatic variability, which is sometimes negatively perceived.

Thus, the sensory superiority of sample 654 appears to result from the synergy between low pH, high total acidity, and moderate volatile acidity, combined with chemical reactions favorable to color stability and taste balance. These observations highlight the importance of precise management of acid–base parameters and fermentation conditions to optimize the quality of local red wines. Improving vinification processes in Cameroon could therefore rely on the rigorous control of these factors, while considering the complex chemical interactions that shape the sensory acceptability of the final products.

Free sulphite et total sulphite content

sulphur dioxide (SO_2) is an authorised antiseptic and antioxidant in wine production. A lack of sulphur dioxide can cause the wine to appear stale when tasted [7]. Wines containing sugars that combine with SO_2 require large quantities of total SO_2 in order to have a little free SO_2 to protect the wine against oxidation [35]. During wine ageing, free SO_2 values of 25 mg/L for red wine and 30 mg/L for white wine and a maximum of 40 mg/L for consumption are recommended. The concentrations of free sulfur dioxide did not show statistically significant differences among the wine samples analyzed. However, sample 654 was characterized by a significantly lower total SO_2 content ($P < 0.05$), which could indicate a more natural winemaking process or a more moderate use of sulfites. The measured concentrations of free SO_2 were 24.53 ± 1.85 mg/L (wine 587), 21.33 ± 1.85 mg/L (wine 654), and 20.27 ± 1.85 mg/L (wine 886), while the total SO_2 levels were 122.33 ± 2.14 mg/L, 87.47 ± 1.85 mg/L, and 149.33 ± 8.05 mg/L, respectively, for the same samples. These values complied with the French regulatory limits for red wines intended for consumption, set at 40 mg/L for free SO_2 and ≤180 mg/L for total SO_2 [35]. Moreover, they were consistent with those reported by Dhroso et al. [14] for red wines produced in various regions of Albania, where free SO_2 ranged from 12.8 to 28.6 mg/L and total SO_2 from 125 to 140 mg/L.

Dry extract, alcoholic, density, brix level and sugar content
The structural components associated with mouthfeel also showed significant variations. Sample 587 was the richest in alcohol (12.96 ± 0.06 % v/v) and sugar (8.04 ± 0.42 g/L; $P < 0.05$). In contrast, wine 886 had the highest dry extract content (17.16 ± 0.01 g/L). Sample 654, which was the most appreciated, exhibited a moderate alcohol level (12.29 ± 0.09 % v/v), lower sugar content (5.08± 0.10 g/L), and a moderate dry extract level (15.49 g/L).

Dry extract is determined by weighing the residue obtained after evaporation of the wine. It encompasses all non-volatile wine compounds, notably fixed acids, acid salts, sugars, glycerol, coloring matter, tannins, pectins, polysaccharides, proteins, and minerals [7]. Its quantification serves as a relevant indicator of wine authenticity. In the present study, dry extract contents differed significantly among samples ($P < 0.05$; Table III), with sample 587 showing the lowest value. The dry extract values of samples 587 and 886 were below the thresholds defined by European regulations, which recommend a range between 17 and 30 g/L for red wines. This non-compliance may be partially explained by their low density, measured at less than 0.99 ± 0.00 g/mL, likely due to a significant alcoholic enrichment during the winemaking process. These values were also lower than those reported by Dhroso *et al.* [14] for red wines produced in various regions of Albania, which ranged from 15.8 to 20 g/L. Accordingly, winemakers could improve product quality by limiting the degree of alcohol enrichment in their winemaking techniques.

The alcohol in a wine is the result of the total or partial transformation of the sugar contained in the grape or the must and/or of the alcoholisation in certain winemaking practices such as those that could generally be practised in Cameroon. The alcoholic strength of wine can vary according to the method of production and the country of origin. Alcohol content varies depending on the winemaking process and the geographic origin of the wine. In the present case, sample 587 had the highest alcohol concentration, while sample 654 had a more moderate level (12.29 ± 0.09). The latter was perceived as sweeter by naïve tasters, likely contributing to its overall gustatory balance. At low concentrations, ethanol provides a sweet sensation, whereas at higher levels, it generates a burning perception. Sample 587 was likely less appreciated due to a sensory imbalance related to its high alcohol content, combined with low acidity and low tannin concentration (Table 3). Notably, a high alcohol level is not necessary to balance a wine that is poor in acidity and tannins [17]. The values obtained in this study were similar to those reported for red wines produced in different regions of Albania, ranging from 12% to 14% [14].

The density values recorded in this study were higher than those reported for Kalecik Karası wines produced using cold maceration and thermovinification techniques by Tahmaz *et al.* [36] , which ranged between 0.9878 and 0.9883 g/cm³ (at 20°C). This was explained by the fact that those wines had lower residual sugar contents (1.1 to 1.3 g/L) and higher alcohol contents (14.80 to 16.38 % v/v). The density of a wine could influence the perception of the wine's volume on the palate.

The analysis of reducing sugars revealed a significant difference ($P < 0.05$) between sample 587 (8.04 ± 0.42 mg/L) and samples 654 (5.08 ± 0.10 mg/L) and 886 (5.15 ± 0.24 mg/L). The reducing sugar content of sample 587 was higher and significantly different ($P < 0.05$) from those of the other two samples, which were not significantly different from each other. This high concentration may indicate incomplete fermentation during the winemaking process. This residual sweetness in sample 587 could also have contributed to an unbalanced sensory perception. As pointed out by [17], excessive sugar is not necessarily beneficial for the sensory balance of a wine that is already high in alcohol. Thus, the interaction between alcohol content and residual sugars may affect the perceived taste quality, which could partly explain the lower appreciation of this sample during the sensory evaluation.

Spectrophotometric analysis

Determination of chromatic characteristics: These parameters showed significant differences among the three wines analysed ($P < 0.05$; Table III). The color intensities reported by Jordi *et al.* [2] in eight samples of young red Garnacha wines produced in Spain and France ranged from 5.09 to 9.7, while hue values ranged from 0.68 to 0.86. Additionally, Miao *et al.* [13] reported values ranging from 1 to 9.29 for colour intensity and from 0.6 to 1.5 for hue, respectively. The discrimination observed in the judges' selection of the best colour appears to be related to differences in anthocyanin concentrations as well as to the specific proportions of coloured pigments (yellow, red, mauve) in each sample. Sample 654, which was characterised by a higher anthocyanin content, was preferred for its colour.

Total anthocyanin contents

The analysis of anthocyanins confirmed that sample 587 exhibited the lowest anthocyanin concentration, with a significant difference ($P < 0.05$) compared to the two other samples. The highest concentration was observed in sample 654 (40.40 ± 2.32 mg/L), while the lowest was recorded in sample 587 (24.57 ± 0.32 mg/L) (Table 3). These concentrations remain well below those reported in the literature, particularly between 903 ± 81 and 1016 ± 50 mg/L according to Remy [37], and the value of 2.46 ± 0.09 mg cyanidin-3-glucoside/g reported by Güngör And Türker [10]. This deficit may be attributed to the high dilution of concentrated musts during their reconstitution in the local winemaking process. The low anthocyanin content observed in the samples could also be explained by the fermentation method applied in the production of these wines: the absence of lactic acid bacteria in the fermentation process on the one hand, and on the other hand, the lack of whole grape addition to the imported concentrated must for fermentation, followed by the absence of pre-fermentative freezing. Indeed, as demonstrated by Aakriti *et al.* [38], pre-fermentative freezing of grapes increases the extraction of total anthocyanins in the must, particularly the content of peonidin-3-glucoside and malvidin-3-glucoside, the latter of which is positively correlated with malolactic fermentation. Thus, the addition of grapes to the must and the use of lactic acid bacteria in the fermentation process in Cameroon could represent variables for optimizing the quality of popular wines intended for the Cameroonian population. As anthocyanins are the primary pigments responsible for the coloration of grapes and wines, their low concentration may explain the reduced visual intensity and the lower preference expressed by the panel for sample 587.

Total tannin content

Tannin analysis showed that wine sample 587 had the lowest tannin concentration (0.61 ± 0.00 g/L). Its concentration was significantly different ($P < 0.05$) from those of samples 654 (0.97 ± 0.01 g/L) and 886 (1.04 ± 0.02 g/L) (Table 3). This difference in tannin concentration between the samples could be explained by the addition or absence of commercial oenological tannins during correction (blending) in the winemaking process of each sample and/or by the use of different qualities (various origins) and quantities of concentrated grape must during the reconstitution by dilution of the raw material for fermentation. The tannin concentration in sample 886 was lower than the values ranging from 3421 ± 164 to 4233 ± 102 mg/L reported in wines analyzed using the same method as in this study [37]. Tannins contribute both positive and negative qualities to wine, such as structure and body, but also astringency, bitterness, and harshness when present in excess. These two types of perceptions must be balanced to obtain a high-quality wine. This balance will mainly depend on the quantity and quality of tannins solubilized in the wine. This could explain the preferential choice expressed by naïve judges regarding the dry mouthfeel (astringency) of sample 654, to the detriment of samples 587 and 886. Indeed, tannins interact with salivary proteins rich in proline (PRPs), leading to the perception of dryness, roughness, and mouth puckering [39]. Moreover, the tannin profile of wine 654 would likely be rich in procyanidins, which may have interacted with proteins (1.21 ± 0.07 g/L), contributing to its velvety body (as described by the "mouth-coating" terminology used by many judges during tastings). In fact, the rigidity, size, and stereochemistry of tannins strongly influence their affinity for proteins: highly polymerized procyanidins and C4–C8 linkages favor stronger interactions with proteins [40]. Similarly, Mekoue *et al.* [41] demonstrated the existence of interactions between tannins and yeast-derived products.

Total phenolic compounds

The Folin–Ciocalteu Index (FCI) and the Total Phenolic Index (TPI) were used to quantify the overall phenolic compound content. These two parameters showed significant variations among the three wines, with higher values in sample 654 also the most appreciated by consumers (Table1) and (Figure 1) and lower values in sample 587 (Table 3). This disparity could explain the lower overall acceptability of the latter, as illustrated in (Figure 2) and (Table 1). Indeed, enriching wine with phenolic compounds, particularly resveratrol (200 mg/L), contributes to the expression of volatile aromatic compounds, while catechins (200 mg/L) promote the expression of aromas and improve the sensory characteristics and antioxidant capacity of wine [42]. Thus, enriching wines with these compounds could be an exploratory alternative for improving the quality of wines produced in Cameroon. The measured values were lower than those reported by Jordi *et al.* [2], which ranged from 40.65 to 46.25 absorbance units (AU) in eight brands of dry red wines from the *Garnacha* grape variety. For

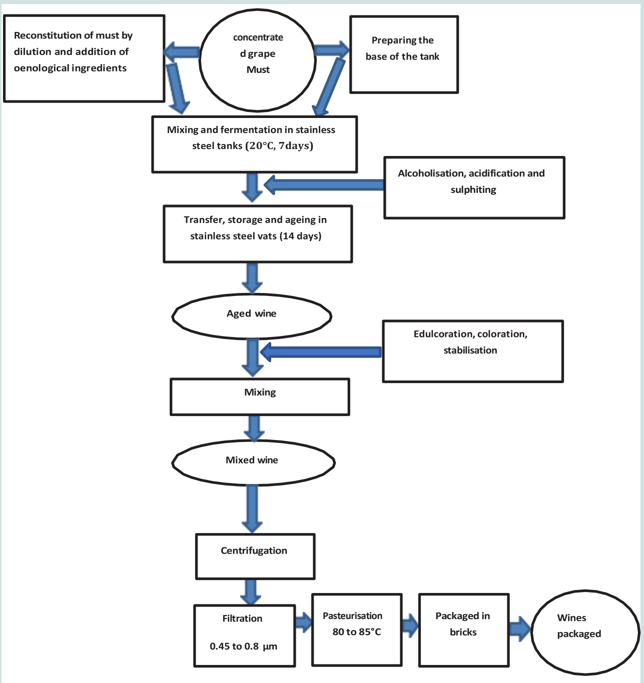

Figure 1: Technology diagram

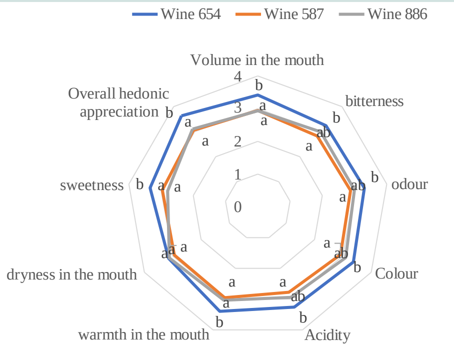

Figure 2: Influence of hedonic descriptors on the overall appreciation of the different wines.
[a, b, c]:The same small letters associated with a given hedonic descriptor indicate that the samples do not differ significantly from each other for that descriptor (P > 0.05).

comparison, Yıldırım *et al.* [43] reported total phenolic compound contents of 406.9 mg gallic acid equivalents per liter (mg GAE/L) in white wines and 1787 mg GAE/L in red wines. The phenolic content of grapes and wines varies depending on the region and may also fluctuate from year to year. It is also well established that these compounds are strongly influenced by terroir characteristics [44]. The low levels of anthocyanins and phenolic compounds observed in the Cameroonian samples may thus result from substantial dilution during the reconstitution of concentrated musts or be attributed to the very origin of the raw materials used [1].

Total carotenoid content

The carotenoid levels in the three wine samples were not significantly different. The high carotenoid content of wine sample 654 would have contributed to the appreciation of its odour. Carotenoids are precursors of odour molecules with very low perception thresholds, including ß-ionone [45].

Nutritional analysis

Total amino acid and protein content: The total amino acid (AA) content of wine sample 654 was significantly different ($P < 0.05$) and higher than those of wine samples 587 and 886. These differences in amino acid (AA) content among the three samples could be explained by various factors, such as the ripeness level of the grapes, the grape variety itself, or certain parameters related to the processing methods applied during the elaboration of each sample [46], as well as the enzymatic activity of bacteria during the production process of the different samples. The total free AA content of the must is significantly proportional to the ripeness level of the grapes and depends on the microclimate/terroir and the soil nutrition or vineyard management practices [47,48]. Furthermore, Alexandre *et al.* [48] demonstrated a progressive release of amino acids and peptides (ranging between 20–40 mg N/L) during the stationary phase of alcoholic fermentation, following the activity of protease A from Saccharomyces cerevisiae after autolysis. Moreover, the use of diammonium phosphate in winemaking processes in Cameroon could explain the high concentrations of total amino acids observed in this study due to their colorimetric interference with amino acids, which constitutes an analytical bias. Indeed, the high AA content of sample 654 may have contributed to its better appreciation by the naïve panelists. These results are consistent with the findings of Auriane *et al.*; Samantha *et al.* [46,49], who demonstrated the influence of amino acids on the sensory perception of wines; glutamic acid and proline interact with volatile and phenolic compounds, enhancing fruity aromatic intensity, perceived sweetness, and viscosity, while reducing astringency and bitterness. This further highlights the importance of selecting the origin of the must for effective quality management of wines produced in Cameroon.

Of course, the total protein contents of the three wine samples analysed were significantly different ($P < 0.05$) (Table 3). There were higher than 12.4 ± 1.3mg/L and 36.5 ± 6.1mg/L, respectively, for the protein fractions "chitinase and thaumatin-like", obtained by HPLC assay in a wine coded "Base wine CH08" by Bourse *et al.* [50]. This can be explained by the different composition of a wine's protein pool, mannoproteins of yeast, from the residues of protein glues used during the winemaking process and/or the extensive use of diammonium sulphate in the winemaking process practised in Cameroon, which causes a bias in the analysis of total proteins using the Kjeldahl method used in this study ($P < 0.05$) (Table 3). Similarly, mannoproteins were also shown to influence tannin aggregation by delaying tannin polymerization [51] and viscosity of wines [52] which influence the drying mouthfeel and body perception in wines.

Ascorbic acid content

is naturally present in grapes [53] but is rapidly consumed after the pressing stage. It is particularly added to wines that are less rich in ascorbic acid, depending on the wine production process. Ascorbic acid levels in wines generally vary from 50 to 150 mg/L [54], and it is mainly used for its antioxidant capacity. The European Union authorises it as an antioxidant additive at a maximum concentration of 250 mg/L. The ascorbic acid levels obtained for the three wines were significantly different. This difference in content could be explained by the variation in temperature applied during the pasteurization of each sample and/or by the use of different concentrations of ascorbic acid during the technological correction (blending) operation of each wine sample. Ascorbic acid was more concentrated in wine sample 886 and less concentrated in the least appreciated wine sample 587. This low content could explain the lower aroma rating of sample 587, as ascorbic acid contributes to the expression of fruity aromas in young wines without inducing undesirable reductive aromas. This is because the addition of ascorbic acid in combination with sulphite promotes the elimination of dissolved oxygen in wine and prevents the oxidation of the wine's aromatic compounds [55].

Ash and fibre content

Ash content represents the residual mineral matter in wine after combustion of organic constituents (water, sugars, acids, etc.). It consists of minerals (Ca, K, Mg, Fe, etc.). Ash is used in oenology as a quantitative indicator of minerality in wine. The results of this study showed that the content was significantly different in the three samples, with the highest average content in the most appreciated sample 654 and the lowest in the least appreciated sample. This difference could be explained either by the production technique used for each product, in particular the use or non-use of bentonite, or by the geographical origin of the raw material used for the production of each product [56].

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Fibre analysis showed that the total fibre content was significantly different in the samples ($P < 0.05$), with low, medium and high content respectively in wine samples 587 (0.13 ± 0.00 g/L), wine 654 (0.59 ± 0.01 g/L) and wine 886 (0.69 ± 0.01 g/L). These differences could be explained by the oenological techniques used in the production of each product (use or non-use of industrial yeast lysates) [57]. In red wine, the fibres are mainly composed of mannoproteins, polysaccharides and dietary fibres. These compounds have been shown to reduce the perception of astringency and bitterness in wine through their interaction with the wine's tannins and to improve the stability of red wines [58]. They also add body to wine [58]. However, the dose must be moderate in order to avoid altering the colour [59]. The moderate fibre content of wine sample 654 would have contributed to the appreciation of its volume in the mouth and, consequently, to its better overall appreciation.

Relationships between the physicochemical parameters and the three wines and overall liking

To visualize the relationships between the wines' physicochemical profiles and their consumer acceptance, a Principal Component Analysis (PCA) was performed (Figure 3).

The principal component analysis shows that the three wines occupy distinct positions on the plot. The most appreciated sample, wine 654, is positively associated with vectors for total acidity, total phenolic compounds, colour intensity, amino acids, anthocyanins, and the red coloured pigments. In contrast, the less-preferred wine 587 is primarily associated with alcohol content, reducing sugars, and the purple-coloured pigments. The third sample, wine 886, is distinguished by its strong association with vitamin C, higher colour tone, and the yellow-coloured pigments. The analyse revealed that wine sample 587 would be less appreciated because of its high content of mauve coloured chillies, alcohol and reducing sugars, which would be the cause of its sensory imbalance and its less appreciated colour. This analysis partially corroborates that of [17], who explained that "you don't need a lot of alcohol to balance a wine with low acidity and low tannin". We could also add that there is no need for too much sugar to balance a wine with low acidity and too much alcohol, according to the results of this study. On the other hand, the high levels of total amino acids, total phenolic compounds, total anthocyanins and the colour index in wine sample 654 would have contributed favourably to its overall assessment.

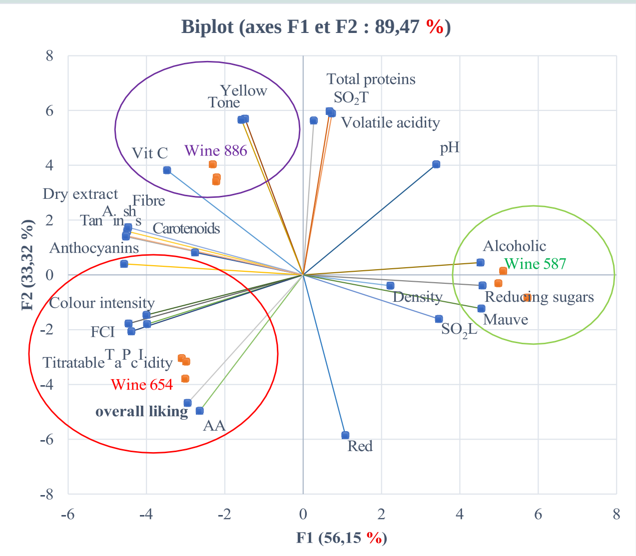

Figure 3: Principal component analysis of the three wines (wine 654; wine 886; wine 587) knowing the level of overall liking of each sample.
TPI = Total phenolic compounds index, FCI = Folin ciocalteu index, AA = Amino acids, Vit C = Vitamin C, SO2L= Free sulphur dioxide, SO2T = Total sulphur dioxide.

In summary, the PCA revealed that total acidity, pH, total phenolic content, amino acids, colour intensity, reducing sugars, alcohol, total proteins, volatile acidity, and total SO_2 constitute the principal physicochemical determinants influencing sensory quality. Owing to their strong relationship with overall consumer liking, these parameters may serve as key levers for optimizing wine quality.

Conclusion

This study successfully identified the key sensory and physicochemical drivers of consumer acceptance for popular, locally produced red wines in Cameroon. The findings unequivocally show that one wine (sample 654) was significantly preferred, achieving an acceptability index of 0.72. The preference for this wine was primarily driven by its mouthfeel, specifically the perception of in-mouth volume and warmth. Our analysis revealed that this superior sensory profile was rooted in a distinct chemical signature. The accepted wine was characterised by a balanced interplay of moderate alcohol (12.29 %), lower residual sugar (5.08 g/L), and a crisp acidic backbone (pH 2.97, TA 5.58 g/L). Furthermore, its robust phenolic structure evidenced by high colour intensity, anthocyanin content (40.40 mg/L), and total phenolic index (30.20 AU) distinguished it from the less-preferred samples. These results represent a foundational step in the scientific characterisation of Cameroon-produced wines. To build upon this work and provide local wineries with more precise production guidelines, future research should focus on a more granular analysis, including detailed phenolic compounds and organic acid profiling, as well as characterisation of the volatile aromatic compounds that contribute to the overall sensory experience. This will allow for the development of targeted oenological practices tailored to the specific palate of the Cameroonian consumer.

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Declarations

The author declares no competing interests.

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Authors' contributions

Kotue Taptue Charles and Kansci Germain conceptualized and supervised the study and were responsible for project administration, reviewed and edited the manuscript. Mbassi Manga Gilbert and Saha Feudjo Brice were responsible for the methodology and formal analysis. Teguem Tchoulegue Apollinaire authors validated the study and Mbassi Manga Gilbert visualized the study. All the authors have read and agreed to the published version of the manuscript.

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