Research Article

Traditional Processing, Physicochemical Property, Phytochemical Content, and Microbiological and Sensory Quality of the Yellow “Téa Lémi” Wine Made in the Far-North of Cameroon

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Received 19 November 2020; Revised 23 February 2021; Accepted 2 March 2021; Published 18 March 2021

Academic Editor: Walid Elfalleh

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“Téa Lémi” is a traditional wine made from pummelos by the Kapsiki in the Far-North of Cameroon. Despite its importance as a source of income for the country people, the know-how supporting production of this beverage and its quality attributes still remain unknown. Hence, this study was aimed at describing the processing and quality of “Téa Lémi” produced and marketed in northern Cameroon. The field investigation and the ethnographical technique were used to describe the production process. Physicochemical, phytochemical, and microbiological properties of the beverage were examined using referenced techniques. Quantitative descriptive analysis was used for describing the sensory profile of the wine. Surveys showed that processing of the grapefruit wine is typically artisanal. This can be seen by the uncontrolled addition of some ingredients such as sugar, extract of banana, and honey and a significant fermentation step started by wild, unselected yeasts. The physicochemical analyses revealed that the wine had an acid pH of around 3.84, with a total acidity between 7.72 g/L and 8.79 g/L. The alcohol and soluble solids contents were 14% (v/v) and 12 °Brix, respectively. Total sugar and conductivity values ranged from 57.8 to 96.8 g/L and 573 to 686 $\mu\text{S/cm}$. Mean contents of polyphenols and flavonoids of 616.4 mg PE/L and 322.5 mg QE/L and an antioxidant capacity of 261.03 mg TE/L have been revealed in the indigenous wine, respectively. The assessment of hygienic quality showed alarming sign of microbiological contamination revealed by total aerobic bacteria and spore-forming bacteria counts beyond the critical level. The good sensory quality (13 out of 20) of the grapefruit wine seemed to be linked to the sweetness ($r = 0.999$; $p < 0.001$) and odor/flavor ($r = 0.997$; $p < 0.001$). The beverage has been described by the panel as pale yellow colored, slightly tart, and bitter accompanied by some fruity esters and sweet notes of citrus and caramelized sugar.

1. Introduction

Almost all over the world, fruit production and consumption remain important income-generating activities and play an important role in the diet of populations. The importance given to fruits originates from the key role they play in human nutrition as they constitute one of the main sources of micronutrients such as vitamins and minerals [1]. However, their high water content makes them sensitive to the action of the biological and physicochemical altering

agents. Consequently, fruits are very perishable foodstuffs; hence, they need transformation into various drinkable products [1]. Among these fruits, there are citrus fruits which are considered as one of the world's most important crops [2].

Global production of citrus fruits, including oranges, mandarins, limes, lemons, grapefruits, and pummelos, was estimated at 105 million metric tons every year, with a strong increase in the last decades [3]. Pummelo (*Citrus maxima*), belonging to the Rutaceae family, is widely grown in the

warm climates of sub-Saharan Africa and Southeast Asia [4]. Pummelo, sometimes called grapefruit because of their similarities, is characterized by greenish-yellow or pale yellow colored peel with pale pulp that contains many seeds [2, 5]. The pummelo tree bears large pear-shaped and tart-flavored fruits, which can reach 8 kg. It is appreciated as food both for its taste and for its moderate energy supply (42 cal/100g). Pummelos are recognized as being a healthful source of bioactive compounds such as vitamin C, carotenoids, fibre, minerals, and phenolic compounds [6, 7]. Currently, there is much evidence that pummelos have strong antioxidant, antimicrobial, and anti-inflammatory properties [5, 8]. Therefore, pummelo is becoming an increasingly popular health-promoting fruit. Much consumed as food, pummelo fruits are also used for producing fresh juice and citrus-based drinks [3]. “Téa Lémi,” also known as the yellow wine in “Kapsiki” tribe, is one these citrus-based drinks, made from spontaneous fermentation of pummelo juice. Kapsiki is one of the several tribes of the Far-North region who peopled plains of the Mandara Mountains that delimit the Sudano-Sahelian zone of Cameroon with the Benue valley.

The Far-North is the most extreme part of the Cameroonian Sudano-Sahelian zone, bordered by Chad and Northeast of Nigeria. This region, located within the coordinates of latitude 10°34'55" North and longitude 14°19'39" East [9], is characterized by a warm and dry climate with temperature reaching 45°C during the hottest months (January to May) and rainfall ranging from 800 to 900 mm between July and October [9]. In this dry area, the production of indigenous beverages is culturally embedded and constitutes a complex and rudimentary activity based on the know-how transmitted from ascendants to descendants. The “Téa Lémi” wine, like many other beverages produced in the Far-North region such as “foléré” drink [10], sorghum red “Kapsiki” beer [11], and white “Kapsiki” beer [12], is highly valued by people because of its low cost compared to the manufactured drinks, the social values with which it is associated, and certain therapeutic attributes conferred to this yellow wine in the “Kapsiki” tribe. However, low hygienic care during the processing associated with the hot climate of the region may result in the production of poor quality homemade beverages. Considered as ready-to-eat foods, homemade drinks have contributed to various food-borne diseases in various parts of the world [13, 14]. This increased concern is worrying because of lack of interest of the consumers in safe or unsafe status of this kind of drinks.

In the literature, there is some information about the processing and the quality of the indigenous beverages made in the Far-North region [10–12], but much remains to be done in the light of the great potential which is still unexplored. To date, to the best of our knowledge, the information on the production process of “Téa Lémi” remains unknown, and no study on the quality of this yellow wine marketed in the Far-North region has yet been done. In order to upgrade the quality of the commercial “Téa Lémi,” it seems suitable to record data on the production process based on referenced methods and provide an overview of some quality attributes of that beverage. Hence, this study

was aimed at describing the processing of “Téa Lémi” wine and evaluating sensory, physicochemical, and microbial characteristics of the samples sold in the Far-North region. We went further to explore the phytochemical contents and the antioxidant activity of the samples collected.

2. Materials and Methods

2.1. Field Investigation and Sampling Zone. The Far-North region represents the second most populated region of Cameroon, with 3,480,414 inhabitants, after the Centre Region [15]. The “Téa Lémi” wine, which is the main biological material, was collected from its original production area, more precisely on the rural sites of Zimi-Mogodé (10°37'46.7"N; 013°35'42.2"E), Vitté (10°38'52.1"N; 013°38'25.5"E), and Sir (10°34'10.7"N; 013°39'51.5"E). They are located on the valleys of the Mandara Mountains, Mayo-Tsanaga Division, in the Far-North of Cameroon (Figure 1). The choice of the sites is due to the fact that this geographical area is populated by the “Kapsiki” ethnic group whose population appears to be the only one to have developed the expertise in the production of this original pummelo-based wine. The triangulation approach was chosen to better cover the study zone, and the proximity to the city of Maroua, the chief town of the Far-North region, has also been an important factor underlying our choice.

2.2. Data Collection on the Processing of the “Téa Lémi” Wine. To collect information about the production process of the “Kapsiki” wine, cluster sampling associated with the ethnographic techniques has been used and three study sites were selected, Zimi-Mogodé, Sir, and Vitté, because the beverage was commonly consumed and largely marketed in these areas. Cluster had two degrees of units, with production sites and markets as primary unit. The secondary level consisted of individual and groups of individual respondents. Survey on the basis of a questionnaire, supplemented by direct discussions with randomly chosen producers and retailers located in the study sites, was carried out. The survey questionnaires were focused on the socio-cultural aspects of production, the raw material and factors determining their choice, the nature and description of production stages, the production parameters, and the mixing and fermentation time. A total of 6 production sites and 10 markets were visited, 15 producers-retailers, 35 retailers, and 50 consumers were interviewed. The factors that influence the processing of the indigenous pummelos wine are summarized in Table 1.

2.3. Sampling. The sampling of the “Téa Lémi” wine was done during the raining season between June and July 2019 at the supplier level. In each site, an oriented and triplicated sampling was carried out from the main producers-retailers present on the site. For the first harvesting, five samples had been taken in each locality (samples type 1). After two weeks, another set of five samples were collected in the same localities (samples type 2). The same operation was repeated for the third time two weeks later (samples type 3). Each

FIGURE 1: Map of the survey and sampling sites.

TABLE 1: Factors influencing the processing of the indigenous “Téa Lémi” wine.

Factors	Explanation
Harvesting period	From January and February, because the maturity of the fruits used as raw material is got in that period of the year.
Type of the raw material	Yellow skin pummelos are more suitable than green skin pummelos for the wine production.
Use or not of a starter	Introduction of the yeasts accelerates fermentation process and reduces time needed to get ready-to-serve beverage.
Fermentation time	Globally, time ranges between 1.5 and 3 months at least depending on use of an exogenous starter.
Weather	Cold temperatures occurring during the raining season or winter decelerate fermentation process.

sampling was daily performed, and only the beverages produced by natural spontaneous fermentation without adding yeasts were considered in that study. At the end, fifteen samples had been collected in each site, and forty-five commercial traditional pummelo wines were sampled over the study zone. After each sampling, the harvested beverages were aseptically introduced into 1000 mL sterile glass bottles,

sealed, labelled, put in icebox containers mid-filled with lump ice, and transported under cold regime in the laboratory for evaluation of the quality control parameters.

2.4. Samples Preparation. Prior to the analyses, the commercial ready-to-serve samples were centrifuged for 10 min

at $1000 \times g$ and the supernatants were successively filtered through filter paper (Whatman #1) and a membrane filter ($0.62 \mu\text{m}$ diameter). The filtrates collected were used for physicochemical, phytochemical, and antioxidant analyses of the samples. For microbiological and sensory analyses, the collected samples were immediately used without any prior preparation.

2.5. Physicochemical Analysis of “Téa Lémi” Wine Samples. Parameters such as conductivity, pH, and total soluble solids (TSS) were determined according to the AOAC methods [16]. Total titratable acidity (TTA) was obtained by titration of the wine with 0.1 N sodium hydroxide solution [17], the alcohol content was evaluated by the boiling method which consisted in heating 50 mL of wine sample at 78.4°C until a constant weight [18] was reached, and total sugar was measured using the phenol-sulfuric acid improved method as described previously [19]. The content of dry matter was determined according to the standard ISO 11465:1993 method [20] by drying the sample at 105°C until a constant weight was obtained.

2.6. Content of Total Polyphenols. Phenolic content of the wine samples was determined employing the Folin–Ciocalteu method as described by Mahmoudi and others [21]. Twenty-five (25) microliters of wine filtrate (10% v/v) was mixed with 0.225 mL of distilled water, 0.75 mL of Folin–Ciocalteu (1 : 10 diluted) reagent, and 1 mL of Na_2CO_3 (7.5% m/v). After mixing and incubation for 90 minutes at room temperature, the absorbance values were read at 725 nm using a UV-Vis spectrophotometer (Jenway 7305, Bibby Scientific, Group HQ, UK). The measurement was carried out in triplicate, and the total phenolic content was expressed as mg of pyrogallol equivalent (PE) per liter (mg of PE/L) using the calibration curve ($y = 0.271x$, $R^2 = 0.994$) obtained from a series of pyrogallol ($100 \mu\text{g/mL}$) dilutions as described previously.

2.7. Content of Total Flavonoids. Total flavonoids content was determined using previously described protocol with slight modification [22]. Fifty microliters of filtered wine aliquots (10%, v/v) was mixed with 1.95 mL of distilled water, added to 0.15 mL of 5% NaNO_2 . After 5 minutes of incubation, 0.15 mL of 10% AlCl_3 was added and the mixture allowed to stand for a further 6 minutes. Finally, 0.5 mL of NaOH (1 mM) solution and 1 mL of distilled water were added, and the absorbance at 510 nm was read against a blank where wine was replaced by distilled water, using a UV-Vis spectrophotometer (Jenway 7305, Bibby Scientific, Group HQ, UK). Total flavonoids content was calculated from a calibration curve ($y = 0.0241x$; $R^2 = 0.9963$) using quercetin ($100 \mu\text{g/mL}$) as standard and expressed as mg quercetin equivalent (QE) per liter (mg of QE/L).

2.8. Antioxidant Activity. The antioxidant activity was monitored using the 2,2-diphenyl-1-picrylhydrazyl radical

(DPPH) method following the protocol previously described by Brand-Williams and others [23]. The wine aliquots (0.4 mL) were mixed with 2 mL of DPPH/ethanol (1:10 v/v) solution. After a stand for 15 min in the dark, the absorbance was read at wavelength of 517 nm. Each test was run in triplicate, and the free radical scavenging activity was calculated as the inhibition percentage. The absorbance values obtained were also used to estimate the total antioxidant capacity from the calibration curve ($y = 0.0037x$, $R^2 = 0.9632$) obtained from a series of trolox (0.125 mg/mL) dilutions by following the previous procedure. The total antioxidant capacity was expressed as mg of trolox equivalent (TE) per liter (mg of TE/L).

2.9. Microbiological Evaluation. The microbial loads of the wine samples were evaluated using standard methods. Series of decimal dilutions were done using 0.85% sterile saline solution, followed by spreading in specific solid medium plate dishes [24]. The different analytical methods and standards used for microbial counting contained in the samples are indicated in Table 2.

2.10. Sensory Evaluation of “Téa Lémi” Wine. The sensory evaluation of the “Téa Lémi” wine samples was assessed using an adapted 5-point hedonic scale (1 = dislike extremely, 5 = like very much) [30] with a panel of sixteen (16) judges of regular “Téa Lémi” wine consumers recruited among students and academic and staff members of the University of Maroua, Cameroon. The panel was made up of 13 males and 3 females aged 21–35 years and trained for an hour prior testing. The panel members were selected for their interest and their ability to identify well-rated sensory attributes such as alcoholic taste, bitterness, sweetness, sourness, odor/flavor, color/appearance, and overall acceptability of wine samples. The overall sensory quality score of the wine was determined using another hedonic scale based on a modified version of the 20-point rating system previously described by Mounigan and Badrie [31]. The multirating system was based on taste and aroma (0–8 scores), odor and flavor (0–5 scores), appearance and color (0–3 scores), and overall acceptability (0–4 scores). The sum of the scores of the four descriptors was used to calculate the sensory quality score (hedonic score), and the wine was judged as unacceptable (0–8), insufficient (9–12), good (13–16), and superior (17–20) out of 20-point sensory quality score [32].

2.11. Statistical Analysis. Data obtained were recorded in a designed Excel database, and the results were expressed as mean $\pm$ SD. Statgraphics Centurion 16.1 software (Technologies Inc., Virginia, USA) was used for the statistical analysis. One-way analysis of variance (ANOVA) was performed to compare means. Differences between means were determined by Tukey’s honestly significant difference (HSD) multiple comparison test, and significance was accepted at $p < 0.05$. Correlations between different physicochemical, microbiological, and sensory parameters were achieved by Pearson’s correlation coefficient (r) at a

TABLE 2: Flora, norms, culture media, and incubation conditions used for microbiological assays.

Flora	Standards	Culture media	Temperature and time of incubation	References
Total mesophilic aerobic bacteria	ISO 4833:2003	Plate count agar	30°C for 24 to 48 h	[25]
Yeasts and moulds	ISO 21527-2:2008	Sabouraud agar	25°C for 5 days	[26]
Total coliforms	ISO 4832:2006	Eosine methylene blue agar	35°C for 24 h	[27]
Fecal coliforms	ISO 9308-1:2000	Eosine methylene blue agar	44°C for 24 h	[28]
Total mesophilic spore-forming bacteria	SP-VG M008 (3):1998	Bromocresol purple glucose agar	35°C for 48 h	[29]

significance level of 95% ($p < 0.05$). Principal component analysis (PCA) was performed using XLSTAT Version 2007.8.04 software (Addinsoft, New York, NY, USA). PCA has been carried out to allow the measured variables such as physicochemical, phytochemical, microbiological, and sensory characteristics to be grouped into new variables named “factors.” This analysis was run to design the loadings between variables and factors.

3. Results

3.1. Artisanal Scale Production of the “Téa Lémi” Wine. The results of the field investigation made it possible to describe the artisanal production process of the “Téa Lémi” wine (Figure 2). It has been noticed that the pummelos harvested at maturity are first kept in a cool place for two weeks to eliminate some unpleasant odor of the fruits peel. After sorting and washing, the pummelos are subjected to a manual pressing or to a special mechanical press used by some producers. The integuments (peelings), seeds, and other residues are removed and separated from the crude extract using a cotton tissue with extremely tiny pores. The filtrate is transferred into clean plastic containers, and sugar is added with or without wild unselected yeast. Sugar is added proportionally to the volume of the filtrate collected from the pummelo juice. Typically, producers use a 30 L plastic canister-type container, and they introduce 7.5 L of pummelo filtrate, 7.5 kg of sugar, and 10 L of tap water, corresponding to 3:3:4 ratio (filtrate/sugar/water). The resulting mixture is lightly homogenized, and then water is added. After 5 min of mixing, the cap is left semiopen for 3 days for allowing the release of dissolved carbon dioxide. After a second mixing, the container is tightly closed up until consumption. The presence or absence of the yeast inoculum dictates the length of fermentation. When yeasts are introduced, the fermentation lasts for a month and half, whereas three months up to even a year is sometimes needed when no exogenous starter has been added. Fermentation of the “Téa Lémi” wine, like most traditionally fermented alcoholic drinks, relies on the microorganisms present in the substrates, the processing environment, and the fermentation equipment. As a result, fermentation is natural, uncontrolled, and long-term. Among the microorganisms involved, species from *Lactobacillus* and *Saccharomyces* genera are the most predominant. Some variants of the indigenous yellow wine intended for home consumption are blended with certain optional ingredients such as ripe banana extracts, pineapple juice, honey, and egg white to enhance the organoleptic properties.

3.2. Physicochemical Characterization. The physicochemical parameters of the “Kapsiki” wine samples are presented in Table 3. In terms of pH, no significant difference was observed between the different samples. The pH values of the “Kapsiki” wine varied between 3.79 ± 0.59 and 3.87 ± 0.56 for samples of Vitté and Sir, respectively. There was not a significant variation ($p > 0.05$) in total acidity of samples from Sir (8.79 ± 1.61 g/L), Zimi-Mogodé (7.72 ± 1.27 g/L), and Vitté (7.79 ± 1.61 g/L). A significant difference ($p < 0.05$) in the alcohol content of wine samples has been revealed, and the highest value was recorded with samples from Sir ($15 \pm 0.25\%$). The highest total soluble solids have been displayed by the wine samples from Zimi-Mogodé (13.91 ± 0.54 °Brix) compared to the values of samples from Sir (11.52 ± 0.97 °Brix) and Vitté (10.61 ± 0.43 °Brix) sites that were significantly low. The lowest total sugar content was recorded in the samples from Vitté (114.1 ± 30.2 g/L) and the highest in those from Zimi-Mogodé (181.44 ± 11.05 g/L). The mean values that have been recorded for the dry matter and electrical conductivity of the “Téa Lémi” wine samples from the different sites were significantly different ($p < 0.05$) and varied within $7.74 \pm 0.98\%$ - $11.71 \pm 0.98\%$ and 572.77 ± 35.61 $\mu\text{S}/\text{cm}$ - 686.11 ± 35.66 $\mu\text{S}/\text{cm}$, respectively.

3.3. Phytochemicals and Antioxidant Activity of the Cameroonian Pummelo-Based Wine. The phytochemical parameters, including the contents of polyphenols and flavonoids of the “Téa Lémi” wine, are shown in Table 4. The variation in phytochemicals values with samples of the different sites was significant ($p < 0.05$). Polyphenols and flavonoids contents of 74.5 mg PE/100 mL and 35.61 mg QE/100 mL were revealed in the “Téa Lémi” yellow wine, respectively. The highest polyphenols content was recorded with the samples produced in Zimi-Mogodé (74.5 ± 5.5 mg PE/100 mL), and the lowest content was seen in samples of Vitté (50.3 ± 1.03 mg PE/100 mL). The content of flavonoids was significantly ($p < 0.05$) high in the wine samples of Zimi-Mogodé (35.61 ± 1.3 mg QE/100 mL). Antioxidant activity, expressed as both scavenging activity and total antioxidant capacity, is summarized in the same table. As expected, the highest antioxidant activity has been exhibited by the samples with the most relevant phytochemical compounds. The highest scavenging ability with DPPH radical and the best antioxidant capacity have been displayed by the “Téa Lémi” wine produced at the Zimi-Mogodé site, with values of $67.8 \pm 2.18\%$ and 90.54 ± 1.72 mg TE/100 mL, respectively. The lowest values of both antioxidant parameters were recorded in the “Téa Lémi” wine sampled in Vitté ($53.9 \pm 4.18\%$ and 61.34 ± 1.91 mg TE/100 mL).

FIGURE 2: Flowchart of artisanal processing of yellow “Téa Lémi” wine. *Ratio applicable for 25 L of beverage. **Optional. ***Natural fermentation.

3.4. Microbiological Parameters of the Yellow Wine Made in the Far-North of Cameroon. Microbial parameters of the yellow wine marketed in northern Cameroon are listed in Table 5. The total mesophilic bacteria load of wine samples ranged from $(3.6 \pm 1) \times 10^7$ cfu/mL to $(4.1 \pm 1) \times 10^7$ cfu/mL with the highest count recorded for the yellow “Téa Lémi” wine made in Vitté. The results showed that the wine samples did not conform to the French standard (AFNOR) which recommends 10^6 cfu/mL as the maximum allowed for the mesophilic bacteria flora. Massive presence of spore-forming bacteria has been revealed in all the analyzed wine samples, with the values higher than standard recommended, which are 10^4 cfu/mL. The spore-forming bacteria count varied between $(3.55 \pm 0.35) \times 10^7$ cfu/mL and $(1.44 \pm 0.63) \times 10^8$ cfu/mL for samples made in Vitté and Sir, respectively. Total coliforms loads recorded have conformed to the French standard agency known as AFNOR ($<10^3$ cfu/mL). The lowest values were recorded for the yellow wine produced at Zimi-Mogodé $((6.75 \pm 0.49) \times 10^2$ cfu/mL) and the highest loads were observed for wine samples from Sir $((10 \pm 0.56) \times 10^2$ cfu/mL). However, there were no fecal coliforms, yeasts, and moulds in all analyzed samples. The

French standard (AFNOR) recommends 10^5 cfu/mL and 10^2 cfu/mL as the maximum allowed for yeasts/moulds and fecal coliforms, respectively.

3.5. Sensory Evaluation. The sensory quality and overall hedonic score of the “Téa Lémi” wine are summarized in Tables 6 and 7, respectively. No significant difference ($p > 0.05$) has been shown in the sensory quality of the yellow wine from one site to another. The best sweet taste was exhibited by the yellow “Kapsiki” wine made in Sir (3.06 ± 1.06) and Zimi-Mogodé (3.18 ± 1.04) sites. The same samples were the most appreciated for their appearance and color (3.3 ± 0.94) and (3.5 ± 0.96) . Globally, the yellow “Téa Lémi” wine has been well appreciated by the panel, and the samples from Zimi-Mogodé were the most accepted with an overall acceptability of 4.25 ± 1 . As expected, the best overall hedonic score was got by the yellow wine marketed at Zimi-Mogodé (13.58 ± 4.47) . Table 7 shows that the “Téa Lémi” wine was globally judged by the panel members as a good wine (13.00 ± 4.41) according to Jackson’s scale [32].

3.6. Correlation and Multivariate Analysis. Pearson correlation coefficients (r) are shown in Table 8. A significant positive correlation was found between total count and pH ($r = 0.920$; $p < 0.001$), dry matter and sugar ($r = 0.949$; $p < 0.001$), and dry matter and total soluble solids ($r = 0.973$; $p < 0.001$), but also between sugar and polyphenols ($r = 0.869$; $p < 0.01$) from one side, and flavonoids ($r = 0.810$; $p < 0.01$) from the other side. A strong positive correlation was noticed between polyphenols and DPPH scavenging activity ($r = 0.919$; $p < 0.001$) as well as polyphenols and total antioxidant capacity ($r = 0.978$; $p < 0.001$). The overall acceptability and hedonic (sensory quality) score were very significantly correlated to the sweet taste ($r = 0.995$ and $r = 0.999$; $p < 0.001$), odor/flavor ($r = 0.999$ and $r = 0.997$; $p < 0.001$), pH ($r = 0.990$ and $r = 0.994$; $p < 0.001$), total acidity ($r = 0.84$ and $r = 0.846$; $p < 0.01$), and total bacteria count ($r = 0.892$ and $r = 0.884$; $p < 0.01$) of the wine samples. The same analysis has shown a significant negative correlation between total coliforms and antioxidant capacity ($r = -0.801$; $p < 0.01$). The principal component analysis (PCA) was applied to show correlation between the measured parameters (variables) and factors (principal components) on the one hand, and the structuration of the studied samples on the other hand. As shown in the PCA biplot displayed in Figure 3, the twenty-two variables were reduced into two principal components PC1 and PC2 which accounted for 52.1% and 35.1%, respectively. Both components explained 87.2% of the total variance after the rotation. The PCA (Figure 3) has shown that the microbial parameters (such as total bacteria count, spore-forming bacteria load), certain physicochemical variables (pH, total acidity, alcohol content, electrical conductivity), and all the sensory parameters (taste, odor/flavor, acceptability, overall hedonic score) were loaded and positively contributed to PC1, thus explaining why the great part of the given data is aggregated in the principal component PC1. The remaining physicochemical parameters (like total sugar, dry matter,

TABLE 3: Physicochemical profile of the “Téa Lémi” wine from the Far-North of Cameroon.

Parameters	Sampling sites		
	Zimi-Mogodé	Vitté	Sir
pH	3.86 ± 0.65 ^a	3.79 ± 0.59 ^a	3.87 ± 0.56 ^a
Total titratable acidity (g/L)	7.72 ± 1.27 ^a	7.97 ± 0.68 ^a	8.79 ± 1.61 ^a
Alcohol content (% v/v)	12.66 ± 0.52 ^a	13.66 ± 0.57 ^a	15 ± 0.25 ^b
Total soluble solids (°Brix)	13.91 ± 0.54 ^a	10.61 ± 0.43 ^b	11.52 ± 0.97 ^c
Total sugar (g/L)	181.4 ± 11.05 ^a	114.1 ± 30.2 ^b	119.33 ± 10.3 ^b
Dry matter (%)	11.71 ± 0.98 ^a	7.74 ± 0.98 ^b	9.14 ± 0.56 ^c
Conductivity (μS/cm)	572.77 ± 35.61 ^a	578.88 ± 25.17 ^a	686.11 ± 35.66 ^b

Mean values ($n = 15$ samples) with the same letter (a, b, c) were not significantly different ($p < 0.05$) for the same line according to Tukey's test.

TABLE 4: Phenols and flavonoids contents, scavenging activity, and antioxidant capacity of the pummelo-based wine made in northern Cameroon.

Parameters	Sampling sites			
	Zimi-Mogodé	Vitté	Sir	Mean
Total polyphenols (mg PE/100 mL)	74.54 ± 5.6 ^a	50.3 ± 1.03 ^b	60.12 ± 0.9 ^c	61.64 ± 1.2
Total flavonoids (mg QE/100 mL)	35.61 ± 1.3 ^a	31.9 ± 0.14 ^b	29.2 ± 0.7 ^c	32.25 ± 3.03
DPPH scavenging activity (%)	67.8 ± 2.18 ^a	53.9 ± 4.18 ^b	60.7 ± 4.12 ^{a,b}	60.3 ± 3.95
Antioxidant capacity (mg TE/100 mL)	90.54 ± 1.72 ^a	61.34 ± 1.91 ^b	75.43 ± 1.05 ^c	75.43 ± 1.8

Mean values ($n = 15$ samples) in the same line followed by the same letter (a, b, c) were significantly different ($p < 0.05$) according to Tukey's multiple test.

TABLE 5: Microbial counts of the “Téa Lémi” wine.

Parameters (cfu/mL)	Sampling sites			
	Zimi-Mogodé	Vitté	Sir	Norms (AFNOR)
Total count	(3.6 ± 1)10 ^{7a}	(4.1 ± 1)10 ^{7b}	(3.93 ± 0.52)10 ^{7b}	<10 ⁶
Yeasts and moulds	nd	nd	nd	<10 ⁵
Total coliforms	(6.75 ± 0.49)10 ^{2a}	(10 ± 0.56)10 ^{2b}	(9.9 ± 0.84)10 ^{2b}	<10 ³
Fecal coliforms	nd	nd	nd	<10 ²
Total mesophilic spore-forming bacteria	(9.3 ± 0.56)10 ^{7a}	(3.55 ± 0.35)10 ^{7b}	(1.44 ± 0.63)10 ^{8c}	<10 ⁴

The mean values ($n = 15$ samples) followed by the same letter (a, b, c) were not significantly different ($p < 0.05$) for the same line according to Tukey's test. nd: not detected.

TABLE 6: Sensory quality of the “Téa Lémi” wine from northern Cameroon.

Sensory attributes		Sampling sites		
		Zimi-Mogodé	Vitté	Sir
Taste	Alcoholic	3.4 ± 1.2 ^a	3.56 ± 0.9 ^a	3.5 ± 1.03 ^a
	Acidic	3.43 ± 1.2 ^a	3.5 ± 1.03 ^a	4.0 ± 0.81 ^a
	Bitter	3.06 ± 1.06 ^a	3.0 ± 1.15 ^a	2.43 ± 1.09 ^a
	Sweet	3.18 ± 1.04 ^a	3 ± 1.09 ^a	3.06 ± 1.06 ^a
Odor/flavor		2.68 ± 1.3 ^a	2.43 ± 1.15 ^a	2.37 ± 1.3 ^a
Appearance/color		3.5 ± 0.96 ^a	2.3 ± 1.3 ^b	3.3 ± 0.94 ^a
Overall acceptability		4.25 ± 1 ^a	4.12 ± 0.88 ^a	4.06 ± 0.99 ^a

The means ($n = 15$ samples) followed by the same letter (a, b, c) are not significantly different ($p < 0.05$) for the same line according to Tukey's test.

TABLE 7: Hedonic quality score of the yellow wine.

Descriptors	Sampling sites			
	Zimi-Mogodé	Vitté	Sir	Overall score/20
Taste/aroma	5.4 ± 1.8	5.42 ± 1.7	5.26 ± 1.8	13.00 ± 4.41
Odor/flavor	2.68 ± 1.3	2.43 ± 1.2	2.4 ± 1.3	
Appearance/color	2.1 ± 0.6	1.4 ± 0.8	2.0 ± 0.6	
Overall acceptability	3.4 ± 0.8	3.29 ± 0.7	3.24 ± 0.8	
Overall score/20	13.58 ± 4.47	12.54 ± 4.32	12.9 ± 4.46	

TABLE 8: Pearson's correlation coefficients (r) among the analyzed physicochemical, microbiological, and sensory parameters.

Variables	pH	TTA	Alcohol	TSS	Sugar	DM	Cond	Phe	Flav	DPPH	AC	Bact	TC	spore	Alcoh	Sour	Bitter	Sweet	Odor	Color	OA	OHS
pH	1																					
TTA	0.873**	1																				
Alcohol	0.658	0.887**	1																			
TSS	0.388	0.162	0.203	1																		
Sugar	0.432	0.067	-0.287	0.931**	1																	
DM	0.432	0.169	-0.137	0.973***	0.949***	1																
Cond	0.484	0.767**	0.902***	-0.081	-0.212	-0.007	1															
Phe	0.255	0.045	-0.206	0.947**	0.869**	0.969***	-0.041	1														
Flav	0.205	-0.166	-0.534	0.761*	0.810**	0.705*	0.678*	0.919***	1													
DPPH	0.488	0.296	-0.023	0.960**	0.905***	0.971***	0.149	0.978***	0.580	1												
AC	0.163	-0.013	-0.255	0.931**	0.847**	0.947***	-0.014	0.978***	0.592	0.929***	1											
Bact	0.920***	0.795*	0.716*	0.036	0.166	0.120	0.465	-0.068	-0.008	0.153	-0.171	1										
TC	0.288	0.549	0.756*	-0.727*	-0.711*	-0.704*	0.582	-0.790*	-0.756*	-0.591	-0.801**	0.532	1									
Spore	0.402	0.654	0.560	0.413	0.175	0.392	0.787	0.384	-0.234	0.569	0.451	0.150	0.102	1								
Alcoh	0.967***	0.889**	0.693*	0.279	0.318	0.310	0.464	0.136	0.166	0.361	0.029	0.941***	0.385	0.336	1							
Sour	0.961***	0.921***	0.823**	0.221	0.250	0.301	0.682*	0.144	-0.047	0.375	0.065	0.933***	0.450	0.480	0.950***	1						
Bitter	0.936***	0.698*	0.396	0.427	0.532	0.436	0.158	0.237	0.441	0.453	0.133	0.862**	0.151	0.147	0.935***	0.812**	1					
Sweet	0.995***	0.847**	0.596	0.429	0.483	0.461	0.428	0.274	0.259	0.520	0.190	0.900***	0.244	0.390	0.978***	0.933***	0.957***	1				
Odor	0.988**	0.831**	0.558	0.462	0.502	0.480	0.369	0.301	0.330	0.526	0.204	0.879**	0.200	0.360	0.977***	0.908**	0.970***	0.995***	1			
Color	0.880**	0.732*	0.491	0.673*	0.683*	0.736*	0.515	0.595	0.278	0.808**	0.563	0.682*	-0.044	0.619	0.794*	0.842**	0.770*	0.885**	0.865**	1		
OA	0.990***	0.840**	0.577	0.432	0.475	0.451	0.381	0.271	0.306	0.499	0.173	0.892**	0.231	0.353	0.983***	0.915**	0.969***	0.995***	0.999***	0.854**	1	
OHS	0.994***	0.847**	0.589	0.464	0.504	0.493	0.425	0.313	0.285	0.549	0.226	0.884**	0.211	0.408	0.975***	0.929**	0.954***	0.999***	0.895**	0.996***	0.996***	1

*Correlation between the analyzed variables was statistically significant ($p < 0.05$). **Correlation between analyzed variables was statistically significant ($p < 0.01$). ***Correlation between analyzed variables was statistically significant ($p < 0.001$). AC: antioxidant capacity; Alcoh: alcoholic taste; Bact: total plate count; Cond: conductivity; DM: dry matter; Flav: flavonoids; OA: overall acceptability; OHS: overall hedonic score; Phe: polyphenols; DPPH: scavenging activity; spore: spore-forming bacteria count; TC: total coliforms count; TSS: total soluble solids; TTA: total titratable acidity.

FIGURE 3: Loadings and scores biplot derived from principal component analysis (PCA) after varimax rotation and Kaiser normalization ($p < 0.001$) using most of the measured parameters. AC antioxidant capacity; Alcoh: alcoholic taste; Bacteria: total count; Cond conductivity; DM dry matter; Flav: flavonoids; OA overall acceptability; OHS overall hedonic score; Phe polyphenols; DPPH scavenging activity; spore: spore-forming bacteria; TSS: total soluble solids; TTA: total titratable acidity.

total soluble solids and all the phytochemicals (polyphenols and flavonoids) and antioxidant parameters (DPPH scavenging activity and antioxidant capacity) were strongly loaded on the positive side of the principal component PC2, whereas “total coliforms” was the only microbiological variable strongly loaded on the negative side of the same principal component. According to the PCA, the samples from Zimi-Mogodé have been essentially related to the positive side of PC2 indicating high amount of bioactive compounds in those samples. On the other hand, grape samples from Vitté (Vitté 1 and Vitté 2) which were linked to the negative side of the same component were found more contaminated with coliforms. Other grape samples from Vitté 3 and Sir 3 were located on the positive side of component PC1. Those samples presented high bacteria load, total acidity, electrical conductivity, and alcohol content.

4. Discussion

Traditional processing of the “Téa Lémi” wine includes two main stages, brewing and fermentation. As most African beverages, manufacturing of the yellow wine is entirely based on the empirical know-how. The fermentation stage of the indigenous pummelo-based wine known as “Téa Lémi” is similar to that of “matango”, a traditional palm wine made in southern Cameroon [33]. Both beverages undergo natural fermentation without addition of starter. However, the fermentation time needed for achievement of the ready-to-serve product is a day for the “matango” wine compared to three months at least required for the “Téa Lémi” wine [33]. The empirical manufacturing of the “Téa Lémi” wine has shown a lack of various technological treatments including

pasteurization and chemical preservatives which are much requisite for production of the industrial grape-based wine and were implied for production of modified wine like cocoa/roselle-based wine in the northern Cameroon [34]. Absence of a significant variation of some physicochemical parameters such as pH and total acidity of the “Téa Lémi” wine sampled from the different sites could be explained by the fact that, with the manufacturing being empirical, the producers kept the same reflexes and habits. It has also been reported by producers that, beyond three months of fermentation, the quality of the “Téa Lémi” wine does not change, or changes just a little bit. It has been shown that the indigenous “Téa Lémi” wine was an acidic beverage. A pH value of about 3.84 has been found. This value, being lower than 4.5, is satisfactory according to CODEX STAN 243-2003. Similar pH was reported by Kouassi and others [35] who revealed a pH of 3.83 for “gnamakoudji”, a ginger-based beverage made in Ivory Coast.

However, “Téa Lémi” was found less acidic than most of the indigenous beverages produced in northern Cameroon like “foléré” beverage and “Kapsiki” beers [10–12]. The total acidity of the “Téa Lémi” wine (7.72–8.79 g/L) was found similar to that of the cocoa-roselle wine [34], and was greater than those of “tej,” an indigenous Ethiopian honey wine [36], and “bandji,” a wine made from palm sap in Ivory Coast [37]. Increase of the total acid content in the “Téa Lémi” wine, above the recommended level of 4 g/L [38], is due to additional production of organic acids during fermentation of sugars. The alcohol content of the wine samples of about 14% (v/v) corroborates what was reported by Mounigan and Badrie [31] and Djoulde and others [39] regarding sorrel wine and alcoholic honey-based beverage “kuri,” respectively. The high alcohol content of the “Kapsiki” wine is dependent on the amount of sugar added and that present in the pummelo extract. That is why a very high sugar content has been noticed in the final product commercialized in the Far-North market. This value of about 138 g/L seems worrying because consumption of a half liter automatically puts consumer above the level recommended by legislation, which is less than 50 grams of sugar per day. Consequently, an overconsumption of the “Téa Lémi” wine might have harmful health effect by leading to some chronic diseases such as diabetes and cardiovascular affections. However, good correlation between sugars, polyphenols, and flavonoids contents of the “Téa Lémi” wine as shown from PCA could suggest that both bioactive phytochemicals (flavonoids and polyphenols) contained in the beverage, by their antioxidant property, can efficiently counter the side effects of sugar on the consumer’s health [40]. The antioxidant capacity and total polyphenol content were highly correlated ($R^2 = 0.96$, $p < 0.001$) in the “Téa Lémi” wine. Such correlation has been confirmed in the report of Mitić and others [41], where the authors showed a similar correlation between antioxidant activity and total phenolic content ($R^2 = 0.968$) in different kinds of Serbian white wines. The contents of polyphenols and flavonoids in the “Téa Lémi” wine (61.64 mg PE/L and 32.25 mg QE/L) were higher than those in grapefruit juices [2] and in various Italian red wines from different geographical origins [42], but they were found

to be less than those in the red “Kapsiki” beer made in the Far-North of Cameroon [11]. This is explained by the kind and composition of the raw material (fruits or cereals) and the type of fermentation used for the production of each beverage. Microbiological analysis showed the presence of mesophilic aerobic bacteria, total coliforms, and spore-forming bacteria in the traditional yellow wine. Their presence indicates unhygienic practices during the production, in particular the poor pretreatment of the raw material, the insalubrity of equipment requisite for squeezing of the fruits, and the questionable quality of water. Indeed, the poor quality of the water used for the production of indigenous drinks in the Far-North region was previously identified as limiting factor [10, 15]. No fungi have been observed in the samples of “Téa Lémi”. This could be explained by the high alcohol content of the wine samples (about of 14%). According to Ould El Hadj and others [43], excessive alcohol content can inhibit yeast growth. It was reported that 2% of alcohol weakens the growth of yeasts and 6% stops the multiplication of cells, during the first days of fermentation [44]. Absence of fecal coliforms in the yellow wine might be an indication of a good sanitary quality of the beverage. This could be related to the acidic pH, high alcohol content, and temperature of the samples which were not compatible with the growth of the thermotolerant coliforms. Such conditions cannot be favorable for the microbial growth, and this has been proved by previous work [45]. Evaluation of sensory characteristics revealed that there was no significant difference between samples from the different sites. The stability observed in the overall sensory quality scores would be a sign of homogeneity and perfect mastery of the indigenous wine preparation by the producers. It has been revealed from the correlation analysis that sensory acceptance (overall acceptability and hedonic score) of the yellow wine was strongly and positively correlated to the bitterness ($r = 0.969$ and $r = 0.954$; $p < 0.001$) and odor/flavor ($r = 0.999$ and $r = 0.997$; $p < 0.001$) of the beverage. The mild bitterness and the fresh flavor of the samples could be due to esters and sulfurous compounds present in the beverage. It was reported that the typical aroma of hand-squeezed grapefruit juice is caused by two major sulfurous compounds, 1-p-menthene-8-thiol and 4-mercapto-4-methylpentan-2-one mixed with fruity esters and fruity sweet wine lactone notes [46]. It has been clearly shown by the PCA that component PC1 mostly referred to the sensory quality of the beverage, where some samples were grouped from Sir, Vitté, and its surroundings. On the other hand, component PC2, where both phytochemicals and sugar were found, mostly indicated the health and nutritional attributes of this factor and also of all the wine samples (those of Zimi-Mogodé and its surroundings) that were associated with the positive side of the factor PC2. Samples with the best sensory property were also the most acidic and contaminated by bacteria. This suggests that some organic acids produced by bacteria may contribute to reinforcing of sensory acceptance of the “Téa Lémi” wine. This remark is in line with the study of Adjou and others [47] which revealed that the accentuation of the aroma in a beverage is correlated with its content of organic acids. However, the organic acid content of the beverage

should be moderated because of the positive correlation between sensory acceptance and pH of the indigenous wine samples.

5. Conclusion

Technological and quality characterization of the indigenous pummelos-based yellow wine made from northern Cameroon were investigated for the first time. It has been observed that the production of the “Téa Lémi” wine requires deep improvements for some processing steps. The “Téa Lémi” wine has interesting antioxidant potential, as indicated by its important polyphenols and flavonoids contents. Even if “Téa Lémi” can be considered a good dietary source of nutrients and bioactive compounds, its consumption should be moderated because of its high content of alcohol and sugar. The presence of both mesophilic aerobic bacteria and spore-forming bacteria beyond the recommended levels showed a worrying microbiological quality of the “Téa Lémi” wine. Therefore, improvement of this microbiological quality could upgrade the merchandizing of that indigenous wine, source of natural antioxidants, and may help reduce the import of the grape-based industrial wines which represent a huge market in Cameroon (~\$ 350 million per year).

Data Availability

The dataset used to support the study is available upon request to the corresponding author.

Disclosure

The beverages used for this research are commonly and predominantly used products in the authors’ area of research. The authors do not intend to use these products as an avenue for any litigation, but for the advancement of knowledge.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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