Research Article

Assessment of Physicochemical Properties of Tequila Brands: Authentication and Quality

Alejandra Carreon-Alvarez,¹ Amaury Suárez-Gómez,¹ Florentina Zurita,² Sergio Gómez-Salazar,³ J. Felix Armando Soltero,³ Maximiliano Barcena-Soto,⁴ Norberto Casillas,⁴ Porfirio-Gutierrez,⁵ and Edgar David Moreno-Medrano⁶

¹Departamento de Ciencias Exactas y Naturales, Centro Universitario de los Valles (CUVALLES), Universidad de Guadalajara, Carretera Guadalajara-Ameca Km. 45.5, 46600 Ameca, JAL, Mexico

²Departamento de Ciencias Tecnológicas, Centro Universitario de la Cienega (CUCIENEGA), Universidad de Guadalajara, Avenida Universidad 1115, Colonia Lindavista, 47820 Ocotlan, JAL, Mexico

³Departamento de Ingeniería Química, Centro Universitario de Ciencias Exactas e Ingeniería, Universidad de Guadalajara, Boulevard Marcelino García Barragán 1451, 44430 Guadalajara, JAL, Mexico

⁴Departamento de Química, Centro Universitario de Ciencias Exactas e Ingeniería, Universidad de Guadalajara, Boulevard Marcelino García Barragán 1451, 44430 Guadalajara, JAL, Mexico

⁵Departamento de Matemáticas, Centro Universitario de Ciencias Exactas e Ingeniería, Universidad de Guadalajara, Boulevard Marcelino García Barragán 1451, 44430 Guadalajara, JAL, Mexico

⁶Centro Universitario UTEG, 44430 Guadalajara, JAL, Mexico

Correspondence should be addressed to Alejandra Carreon-Alvarez; ale-carreon_a@yahoo.com.mx

Received 23 February 2016; Accepted 10 May 2016

Academic Editor: Jose M. Jurado

Copyright © 2016 Alejandra Carreon-Alvarez et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Several physicochemical properties were measured in commercial tequila brands: conductivity, density, pH, sound velocity, viscosity, and refractive index. Physicochemical data were analyzed by Principal Component Analysis (PCA), cluster analysis, and the one-way analysis of variance to identify the quality and authenticity of tequila brands. According to the Principal Component Analysis, the existence of 3 main components was identified, explaining the 87.76% of the total variability of physicochemical measurements. In general, all tequila brands appeared together in the plane of the first two principal components. In the cluster analysis, four groups showing similar characteristics were identified. In particular, one of the clusters contains some tequila brands that are not identified by the Regulatory Council of Tequila and do not meet the quality requirements established in the Mexican Official Standard 006. These tequila brands are characterized by having higher conductivity and density and lower viscosity and refractive index, determined by one-way analysis of variance. Therefore, these economical measurements, PCA, and cluster analysis can be used to determinate the authenticity of a tequila brand.

1. Introduction

Comprehensive knowledge of the physicochemical properties of spirituous beverages is required in order to design and operate processing plants properly [1]. In addition, this information might be used in quality control to authenticate a product or as an alternative to improve its production. These physicochemical properties may also be used in the development of new products and preservation methods

and as parameters to determine compatibility and suitable uses for prepared drinks [2–5]. Although it has not been explicitly stated in the literature, it is possible to identify a set of physicochemical properties that could be used as a fingerprint for spirituous beverages. These properties include pH, density, viscosity, conductivity, alcohol content, total solids, and antioxidant capacity [2, 6–8]. Two of the spirituous beverages that have received a great deal of attention are white and red wines. A large amount of information exists

in the literature with regard to their chemical and physicochemical properties, surely driven by historic issues and their widespread consumption worldwide [8–11]. For these spirituous beverages, it has been identified that the presence of polyphenols, tannins, phthalocyanines (as well as pH values), specific gravity, and alcohol content all contributes to their final character and organoleptic properties [8]. In this vein, wines have pH values ranging from 3.0 to 4.0 and a total soluble solids content varying from 14 to 240°Brix [9, 12–14]. Further investigations have demonstrated that pH, in conjunction with other storage or aged conditions, plays a key role in determining the organoleptic properties of spirituous beverages [5, 9]. An example of the modifications of such physicochemical properties is observed in red wines at pH 3–4 in the presence of oxygen at concentrations of 0.2 mg/L. A proton is released during the oxidation of ethanol to ethanal, modifying ethyl bridges between flavonoids and anthocyanins [12].

Cynthiana wine, produced in the US states of Illinois, Arkansas, Texas, West Virginia, Oklahoma, Kansas, Indiana, and New Jersey, illustrates the important role of pH in the quality of spirituous beverages. This particular spirituous beverage has a pH ranging from 3.5 to 4.1, which is adjusted with an ion exchange system in order to stabilize and keep the color [13]. By putting aside both scarce knowledge and limited consumption of certain native, traditional spirits from countries not recognized as global spirituous beverage producers, it is possible to identify spirituous beverages whose physicochemical properties are of great interest. Within this group we can identify spirits from Ethiopia, Africa, Serbia, and Mexico [6, 14–16]. Distinctive, native, and spirituous beverages coming from different regions within the same country usually present rather different physicochemical properties, due to differences in raw materials, preparation methods, fermentation procedures, and microorganisms employed. In addition, differences can also be attributed to other variables inherent to the brewing process, such as temperature, aeration, and alcohol content [15]. This is valid, for example, in the case of three traditional spirituous beverages produced in Ethiopia: Tella, Tej, and Areki [15]. An investigation of 10 different production regions showed an average pH of 4.6, a specific gravity of 1.0050 g/mL, and an average alcohol content of 5.17% V/V [15]. There are also reports in the literature related to physicochemical properties of native spirituous beverages from Africa, including Burukutu, Kunnuzaki, Whistle, Palm wine, Adoyo, Ogogoro, Nunu, Fura da Nunu, Zobo, and Omi wara. The pH values of these beverages range from 4.2 to 6.3 with an average of 5.2 and a specific gravity ranging from 0.9897 to 1.318 with an average of 1.1015 [6]. On the other hand, alcohol content for almost all of these spirituous beverages is rather low except for Ogogoro (distilled Palm wine, 37.6% v/v), Burukutu (sorghum beer, 4.6% v/v), and Palm wine (3.1% v/v). In other spirits, it is less than 0.3% [6]. Physicochemical properties of peach wines (*Prunus persica*) have also been reported in terms of several parameters, such as pH, alcohol content, and total phenolic and antioxidant activity, and have been compared to the properties of white wines [14].

In Mexico, there are several native, traditional, spirituous beverages, such as raicilla, sotol, pulque, and bacanora, which do not have appellation names. Only few information is known about their chemical and physicochemical properties. This information is needed to tag their identity and draft regulations [17–20]. Unlike previously mentioned beverages, tequila is a Mexican spirituous beverage, well known around the world and recognized with an appellation name [21]. Tequila is made of agave *Tequilana* Weber (blue variety), which is extensively grown in specific regions of Mexico for a period of 5 to 7 years. A large and abundant description concerning fabrication methods for Tequila is readily available elsewhere in the literature [17, 22].

Tequila is commonly classified as one of two main types: 100% agave and mixed. Enforced regulations by the Regulatory Council of Tequila (CRT) [21] establish that only sugars coming from agave can be used for the 100% agave preparation, whereas for the mixed agave beverage it is allowed to use up to 51% of agave sugar with the remainder coming from other sources, such as sugar cane [17, 23]. Another classification takes into account aged time in a wooden barrel before the product is named; in this case, tequila is classified as silver, gold, aged, and extra aged [17]. Silver tequila is bottled directly after a second distillation and a dilution process until it has reached its required alcoholic grade of 38–40°GL according to regulations. Gold tequila is silver tequila with added caramel, which gives its distinctive brown color, making it look like aged tequila. Tequilas with an aged process are further classified into three different types: aged tequila, which is aged in oak wooden barrels for at least two months and up to one year; extra aged tequila, which is aged in 600-liter oak wooden barrels for at least one year; and ultra aged tequila, which is aged for more than three years [24]. For a tequila brand to be marketed and recognized as this drink, it is mandatory to be registered in the CRT and to meet all the quality requirements established in the Mexican Official Standard 006 [24]. There are other agave distillates, commonly known as “guachicol” that are marketed as tequila but are not officially recognized by the CRT.

Multivariate analysis has been widely used for the characterization of various food products such as cachaça, grape, and tequila. It is a statistical tool whose goal is to correlate the analytical results between samples (objects) through chemical analysis (chemometrics). Among the used methods, Principal Component Analysis (PCA) transforms a set of original correlated variables into a new set of uncorrelated variables, called principal components [25].

As was mentioned above, physicochemical properties of tequila are required for the design and construction of tequila production facilities and serve as a reliable information source to compare legal and adulterated products. Although there are several reports in the literature dealing with different topics concerning tequila production [26, 27], raw materials [11, 28], equipment [29, 30], tequila constituents [31], metal content [18, 32, 33], and maturation [34], sufficient information still lacks concerning physicochemical properties, not only for tequila, but also for other Mexican spirituous beverages [34–36]. To fulfill these requirements, an investigation was performed to evaluate physicochemical properties of

tequila, which are not established in the Mexican Official Standard 006, in different brands of tequila registered and not registered in the CRT. This evaluation was performed by applying PCA method and cluster, allowing elucidating similar characteristics with the parameters analyzed, correlating and joining them with respect to different brands. This study allows proposing different economic alternatives that can authenticate the tequila, could be employed by small tequila industry, and finally contribute with more knowledge of this traditional alcoholic beverage from Mexico.

2. Materials and Methods

A total of 53 commercial tequila brands were chosen from different categories: silver, gold, aged and extra aged. Some tequila were purchased at 3 liquor stores in Guadalajara, Mexico, which are registered in CRT, and other beverages sold as tequila were purchased in other places; these are known as guachicol; they are not registered in CRT and were labeled with the numbers 2, 11, and 17. The analyzed samples include 11 silver tequilas, 5 gold tequilas, 29 aged tequilas, and 8 extra aged tequilas.

3. pH Measurements

pH measurements were carried out using a conventional pH glass electrode with analytical sensors and a pH meter Orion model SA 72. Before using it, a calibration routine was performed with pH 4, 7, and 10 buffers. Subsequently, the sensor was immersed in the tequila and the pH was measured in triplicate. The pH electrode was rinsed with abundant distilled water before and after each pH measurement. All experiments were performed at room temperature.

4. Conductivity Measurements

Conductivity measurements were carried out with an Orion 4 Stars conductometer. The procedure consisted in calibrating the instrument with 1413 μS and 12.9 mS/cm standards, and, subsequently, the sensor was immersed in tequila and the conductivity was measured in triplicate. The electrode was rinsed with abundant water before and after each immersion. All experiments were performed at room temperature.

5. Density and Sound Velocity Measurements

Density and ultrasound velocity measurements were carried out with an Anton Paar DSA5000 densimeter and sound velocity analyzer equipped with a new-generation stainless-steel cell. Temperature control was maintained with a Peltier element with a resolution of 0.001°C, giving rise to uncertainties in density of ca. $1 \times 10^{-6} \text{ g/cm}^3$. Errors in ultrasound velocity measurements arise mainly from temperature variations, and in this study the resolution was 10^{-2} m/s . The densimeter was cleaned following the routine, consisting of injecting Alconox at a concentration of 40% for several times. Later, ultrapure water was injected in order to calibrate at 20°C until density reached a value of $0.998203 \text{ g cm}^{-3}$.

Once this measurement was achieved, density and viscosity of tequila samples were measured. The determination of the density and sound velocity in the tequilas was carried out at 25°C in triplicate. Both density and sound velocity measurements were performed at the same time.

6. Refractive Index Measurements

Measurements of the refractive index in the tequila were carried out with a refractometer of the company Abbe, model 2WA. The analysis consisted in initially cleaning the prism with ethylic alcohol, followed by calibration with a drop of pure ethylic alcohol. The visual field of the equipment was adjusted to illuminate half of the field while the other half remained dark. Once the equipment was working properly, a measurement of 1.36 was obtained. Later, a drop of tequila was put on the sample holder in order to obtain its refractive index. All measurements were performed in triplicate at 25°C.

7. Viscosity

Viscosity measurements of different tequilas were performed with an ARES rheometer TA-22 G2 using a Couette geometry double-wall type. The inner and outer diameters of the hollow cylinder are 29.51 and 32 mm, respectively, while the inner and outer diameters of the cup are 27.94 and 34 mm, respectively. All measurements were performed at 25°C. An amount of 8 mL of tequila was placed in the sample holder and maintained at a shear velocity of 10 s^{-1} .

8. Data Statistical Treatment

The 53 commercial tequila brands were sampled in a sequential series starting from 1 to 53. The analysis of the results was performed using the commercial software Statgraphics Centurion XVI [42]. Principal Component Analysis (PCA) and cluster analysis were applied to evaluate the relation among the physicochemical properties. PCA was used to investigate the most representative physicochemical properties of tequila, which can be determined from those measurements that contribute the most to the variance.

A table known as the variance contribution of principal components is obtained as a result, containing the same amount of main components than physicochemical properties analyzed. The Eigenvalues and the variance explained through each principal component are found in this table. One of the main objectives of the PCA is to reduce the dimensionality of the problem, which means explaining the overall physicochemical properties with few principal components. For this, it is necessary to select all major components whose Eigenvalue is greater than one. Under this criterion, only 3 main components are considered in this study, from which it is possible to explain the 87.76% of the total variance of the physicochemical measurements of tequila. Moreover, cluster analysis is also performed. The goal of cluster analysis is to group the 53 brands of tequila based on their physicochemical properties. In order to determine the presence of significant differences ($p \leq 0.05$) and to identify

the difference between the groups, the one-way analysis of variance (ANOVA) was performed from the cluster analysis, taking the physicochemical properties as the dependent variable.

9. Results and Discussion

Measurements of pH, conductivity, density, sound velocity, and viscosity of 53 tequila registered and not registered in the CRT are summarized in Table 1 with their respective categories. The first column corresponds to the tequila number considered, for its statistical analysis by means of the commercial software Statgraphics and the second one corresponds to the category (i.e., silver, gold, aged, and extra aged). Further columns summarize the average of physicochemical values obtained from at least three replicates, except for viscosity measurements that correspond to an average of at least 10 measurements.

The pH of silver tequilas (4.3 ± 0.4) was slightly higher than that of aged tequilas (4.1 ± 0.3) and extra aged tequilas (4.1 ± 0.3). In general terms, tequila pH varied from 3.5 to 4.9 for all tequila types, except for two brands whose pH was 3.44, lower than the average pH. Conversely, numbers 17 and 33 displayed a higher-than-average pH of approximately 5.3. An acidic pH is related to the presence of organic acids in the tequila [31]. In addition, pH can also be dependent on oxidation reactions of some tequila constituents in contact with metals [27]. When comparing the pH of tequila with other Mexican spirituous beverages, it is observed that tequila (distilled spirit) presents a lower pH than Agave sap type 1 (6.6–7.5) [39], presumably because some of the volatile components that predominate in the former are carboxylic acids that evidently contribute to the acidity of the beverage. Other components added along the production process might be responsible for the acidity [28, 38], particularly the addition and use of *Saccharomyces cerevisiae* during the fermentation process [38]. Mouro, a Greek spirit distilled from fermented fruits of the mulberry tree, has a pH equal to 4.46, similar to tequila's pH [43]. On the other hand, these results show that aged tequilas have a pH lower than silver tequilas, likely due to water loss in tequila during the aged stage, which induces an increase in the concentration of organic acids [44]. The pH can also have side effects in some alcoholic beverages affecting other organic compounds and color for wines [9, 13].

Another relevant property of tequila that deals with its ion content is conductivity, varying from 10 to 60 $\mu\text{S}/\text{cm}$ for almost every brand and tequila type investigated. Only three brands appeared outside of this conductivity range, more specifically brands numbers 2, 11, and 17, whose conductivities varied between 100 and 230 $\mu\text{S}/\text{cm}$. Conductivity variations can be traced back to differences between ionic species, mobility, and concentration in solution, as well as the chemical equilibrium, that is, dictated by speciation as a function of pH [45, 46]. Some tequilas with higher conductivity also had pH values which were too far away from the average value. Once again, brands numbers 2 and 11 displayed a pH of 3.4 and 3.6 and conductivities of 162.87 and 103.47 $\mu\text{S}/\text{cm}$, respectively, whereas brand number 17 had a pH of 5.3 and a conductivity of 222.03 $\mu\text{S}/\text{cm}$. Such behavior is at least

congruent in terms of the concentration of H^+ and OH^- in the media. With regard to the type of tequila, it was found that the conductivity of silver tequilas ($23.30 \pm 12.98 \mu\text{S}/\text{cm}$) was lower than the conductivity of aged tequilas ($31.97 \pm 11.07 \mu\text{S}/\text{cm}$) and extra aged tequilas ($32.44 \pm 7.12 \mu\text{S}/\text{cm}$). Likely, these differences can be attributed to the loss of water during the aged stage and thus an increase in salt concentration. Another plausible explanation is that other types of ions from the wood of the barrels may diffuse into the beverage during the aged process [28].

Most of tequila's densities varied closely to each other in the range of 0.94 to 0.96 g cm^{-3} . Tequilas numbers 2, 4, 11, and 17 had a higher density than the average value, just as it happened with respect to pH and conductivity. These deviations suggest that they fall outside of regulations. Their differences can be attributed to different factors such as the presence of caramels, colorants, salts, or other unknown additives [44]. The average density of silver tequilas ($0.94860 \pm 0.00290 \text{ g cm}^{-3}$) was slightly lower than that of aged tequilas ($0.95122 \pm 0.00392 \text{ g cm}^{-3}$) without significant difference. On the other hand, tequila's density for every tequila type was lower than that of pure distilled water at room temperature (around 0.99 g cm^{-3}) and higher than ethanol density (0.79 g cm^{-3}), similar to values reported by Flood and Puagsa, 2000 [47]. This intermediate value is in reasonable agreement with the colligative properties of alcohol-water mixtures, considering that ethanol is one of the largest constituents of tequila [31, 48].

Sound velocity in tequila was also measured since it can be used as a parameter to determine authenticity. This physicochemical property varies according to the medium and organic molecule content [1]. The sound velocity ranged from 1580 to 1620 m/s for most of the tequilas. It was found that tequila number 2 had a sound velocity smaller than the average, while tequila number 17 displayed the highest sound velocity. This could be due to the presence of large molecules that come from additives, such as caramel or colorants.

Viscosity is a highly relevant parameter; it determines the acceptability, processing, and handling of foods [3]. The average viscosity of silver tequilas ($2.48 \pm 0.076 \text{ mPa}\cdot\text{s}$) was similar to aged tequilas ($2.44 \pm 0.076 \text{ mPa}\cdot\text{s}$). Since viscosity is closely related to the concentration of sugars and ethanol content, it is also relevant for spirituous beverages. A high viscosity in tequila is usually an indication that a higher sugar concentration (i.e., caramel) and alcohol content are present. In addition, viscosity depends on molecules with large molecular weights, molecular structure, and hydrogen bridges between OH^- and water [49]. In this case, the viscosity for most of the tequilas ranged from 2.3 to 2.6 $\text{mPa}\cdot\text{s}$. Tequilas numbers 2, 11, and 14 had the lowest viscosity of the whole group (2.3 $\text{mPa}\cdot\text{s}$), while tequila number 17 had the highest viscosity of 2.6 $\text{mPa}\cdot\text{s}$. As above mentioned, these differences are likely due to its higher sugar content and colorants or other additives usually added to make tequila appear aged. Looking at viscosity measurements in terms of different tequila categories, there is no significant difference. Thus, values remain almost constant across tequila categories. In comparison, the viscosity of the distilled water is about

TABLE 1: Mean value and standard deviations for measurements of pH, conductivity, viscosity, density, sound velocity, and refractive index of 53 commercial tequila brands.

(a)

Number	Category	pH	Conductivity ($\mu\text{S/cm}$)	Viscosity mPa·s
1	Aged	3.72 ± 0.01	48.90 ± 0.50	$2.496 \pm 3 - 05$
2	Aged	3.44 ± 0.05	162.87 ± 0.47	$2.209 \pm 8E - 05$
3	Aged	4.11 ± 0.01	41.60 ± 0.26	$2.382 \pm 2E - 05$
4	Aged	3.82 ± 0.03	29.28 ± 0.34	$2.306 \pm 2E - 05$
5	Aged	3.98 ± 0.01	25.68 ± 0.15	$2.522 \pm 10E - 06$
6	Aged	4.22 ± 0.11	34.10 ± 0.26	$2.473 \pm 6E - 05$
7	Silver	4.05 ± 0.01	18.42 ± 0.31	$2.484 \pm 4E - 05$
8	Gold	4.87 ± 0.07	41.60 ± 0.00	$2.343 \pm 2E - 05$
9	Aged	3.99 ± 0.05	30.30 ± 0.26	$2.4888 \pm 2E - 05$
10	Aged	4.07 ± 0.05	39.80 ± 0.00	$2.489 \pm 2E - 05$
11	Silver	3.62 ± 0.03	103.47 ± 0.38	$1.945 \pm 4E - 05$
12	Silver	3.95 ± 0.02	50.03 ± 0.57	$2.501 \pm 4E - 05$
13	Aged	4.14 ± 0.32	35.17 ± 0.35	$2.184 \pm 4E - 05$
14	Silver	4.76 ± 0.05	13.09 ± 0.10	$2.499 \pm 2E - 05$
15	Gold	3.90 ± 0.26	44.50 ± 1.57	$2.429 \pm 3E - 05$
16	Gold	3.97 ± 0.21	55.80 ± 0.20	$2.457 \pm 2E - 05$
17	Gold	5.25 ± 0.10	222.03 ± 1.30	$2.672 \pm 5E - 05$
18	Aged	4.23 ± 0.26	19.43 ± 0.18	$2.428 \pm 4E - 05$
19	Aged	4.05 ± 0.06	28.18 ± 0.11	$2.466 \pm 2E - 05$
20	Silver	4.06 ± 0.04	25.55 ± 0.16	$2.448 \pm 2E - 05$
21	Aged	4.72 ± 0.01	56.77 ± 0.32	$2.391 \pm 2E - 05$
22	Aged	3.73 ± 0.01	38.13 ± 0.25	$2.369 \pm 3E - 05$
23	Aged	3.80 ± 0.09	31.67 ± 0.35	$2.408 \pm 8E - 05$
24	Aged	3.63 ± 0.03	40.67 ± 0.25	$2.481 \pm 2E - 05$
25	Aged	3.64 ± 0.02	48.43 ± 0.40	$2.473 \pm 4E - 05$
26	Aged	4.07 ± 0.02	35.00 ± 0.30	$2.479 \pm 2E - 05$
27	Aged	4.20 ± 0.01	37.73 ± 0.21	$2.428 \pm 2E - 05$
28	Aged	4.61 ± 0.03	20.04 ± 0.19	$2.361 \pm 2E - 05$
29	Aged	3.98 ± 0.03	36.47 ± 0.15	$2.449 \pm 1E - 05$
30	Aged	4.55 ± 0.03	29.13 ± 0.05	$2.513 \pm 2E - 05$
31	Extra aged	3.95 ± 0.02	31.33 ± 0.15	$2.512 \pm 2E - 05$
32	Extra aged	3.97 ± 0.02	24.59 ± 0.56	$2.472 \pm 2E - 05$
33	Silver	5.27 ± 0.02	13.46 ± 0.34	$2.472 \pm 2E - 05$
34	Extra aged	4.06 ± 0.01	34.43 ± 0.21	$2.493 \pm 5E - 05$
35	Aged	4.08 ± 0.04	17.67 ± 0.13	$2.477 \pm 3E - 05$
36	Silver	4.56 ± 0.02	38.87 ± 0.42	$2.493 \pm 1E - 05$
37	Gold	4.52 ± 0.01	40.83 ± 0.06	$2.440 \pm 3E - 05$
38	Aged	4.56 ± 0.01	49.50 ± 0.10	$2.459 \pm 2E - 05$
39	Aged	4.86 ± 0.01	20.19 ± 0.07	$2.466 \pm 6E - 05$
40	Extra aged	4.70 ± 0.01	28.52 ± 0.12	$2.441 \pm 2E - 05$
41	Aged	4.02 ± 0.02	20.12 ± 0.24	$2.465 \pm 3E - 05$
42	Silver	4.28 ± 0.01	19.99 ± 0.13	$2.492 \pm 1E - 05$
43	Aged	4.58 ± 0.00	27.26 ± 0.05	$2.350 \pm 2E - 05$
44	Extra aged	4.42 ± 0.01	40.30 ± 0.00	$2.532 \pm 1E - 05$
45	Silver	3.97 ± 0.01	18.13 ± 0.09	$2.318 \pm 4E - 05$
46	Aged	4.15 ± 0.01	27.50 ± 0.20	$2.394 \pm 2E - 05$
47	Extra aged	4.12 ± 0.01	43.67 ± 0.15	$2.480 \pm 1E - 05$
48	Aged	4.30 ± 0.02	11.72 ± 0.01	$2.475 \pm 2E - 05$

(a) Continued.

Number	Category	pH	Conductivity ($\mu\text{S}/\text{cm}$)	Viscosity $\text{mPa}\cdot\text{s}$
49	Aged	3.61 ± 0.02	32.10 ± 0.10	$2.478 \pm 2E-05$
50	Extra aged	3.75 ± 0.03	33.40 ± 0.10	$2.520 \pm 2E-05$
51	Silver	4.19 ± 0.05	12.18 ± 0.11	$2.602 \pm 4E-05$
52	Aged	4.14 ± 0.02	14.72 ± 0.23	$2.584 \pm 5E-05$
53	Extra aged	3.97 ± 0.01	23.26 ± 0.21	$2.543 \pm 1E-05$

(b)

Number	Category	Density (g cm^{-3})	Sound velocity (m/s)	RI*
1	Aged	$0.94786 \pm 7E-05$	1596.50 ± 0.12	$1.35297 \pm 6E-05$
2	Aged	$0.98448 \pm 1E-06$	1550.21 ± 0.04	$1.33760 \pm 2E-08$
3	Aged	$0.95481 \pm 2E-04$	1612.52 ± 0.46	$1.35156 \pm 1E-04$
4	Aged	$0.96410 \pm 1E-04$	1620.17 ± 0.45	$1.35063 \pm 3E-04$
5	Aged	$0.94738 \pm 7E-05$	1595.07 ± 0.20	$1.35327 \pm 3E-04$
6	Aged	$0.95261 \pm 6E-04$	1608.45 ± 1.34	1.35160 ± 0
7	Silver	$0.94851 \pm 2E-04$	1597.98 ± 0.60	$1.35303 \pm 1E-04$
8	Gold	$0.95409 \pm 1E-04$	1611.64 ± 0.34	$1.35150 \pm 2E-04$
9	Aged	$0.94831 \pm 1E-04$	1596.51 ± 0.40	$1.35340 \pm 2E-04$
10	Aged	$0.94552 \pm 2E-04$	1589.53 ± 0.40	$1.35350 \pm 3E-08$
11	Silver	$0.96814 \pm 5E-04$	1613.03 ± 0.16	$1.34490 \pm 2E-04$
12	Silver	$0.94802 \pm 9E-05$	1596.70 ± 0.12	1.35300 ± 0
13	Aged	$0.95232 \pm 1E-03$	1606.35 ± 0.78	$1.34600 \pm 1E-04$
14	Silver	$0.94612 \pm 3E-04$	1591.84 ± 1.13	$1.35353 \pm 2E-04$
15	Gold	$0.95196 \pm 4E-05$	1606.42 ± 0.01	$1.35220 \pm 1E-04$
16	Gold	$0.94927 \pm 6E-05$	1599.58 ± 0.04	$1.35267 \pm 2E-04$
17	Gold	$1.01763 \pm 5E-05$	1631.45 ± 0.04	$1.36170 \pm 1E-04$
18	Aged	$0.95353 \pm 3E-05$	1607.88 ± 0.05	$1.35213 \pm 1E-04$
19	Aged	$0.95050 \pm 2E-04$	1603.46 ± 0.41	$1.35243 \pm 5E-04$
20	Silver	$0.94787 \pm 1E-04$	1596.21 ± 0.40	$1.35290 \pm 3E-04$
21	Aged	$0.95392 \pm 5E-05$	1611.18 ± 0.01	$1.35130 \pm 3E-04$
22	Aged	$0.95315 \pm 4E-05$	1609.13 ± 0.03	$1.35126 \pm 1E-04$
23	Aged	$0.95350 \pm 9E-05$	1607.76 ± 0.09	$1.35150 \pm 1E-04$
24	Aged	$0.94810 \pm 8E-05$	1596.28 ± 0.13	$1.35143 \pm 4E-04$
25	Aged	$0.94774 \pm 1E-04$	1595.07 ± 0.08	$1.35313 \pm 3E-04$
26	Aged	$0.94790 \pm 5E-05$	1595.59 ± 0.15	$1.35303 \pm 6E-05$
27	Aged	$0.95142 \pm 5E-05$	1604.65 ± 0.01	1.35160 ± 0
28	Aged	$0.95572 \pm 1E-03$	1611.06 ± 0.18	$1.35126 \pm 2E-04$
29	Aged	$0.95489 \pm 7E-04$	1609.68 ± 0.28	$1.35230 \pm 1E-04$
30	Aged	$0.95106 \pm 1E-04$	1601.03 ± 0.10	$1.35250 \pm 1E-04$
31	Extra aged	$0.95167 \pm 6E-04$	1600.14 ± 0.18	$1.35350 \pm 1E-04$
32	Extra aged	$0.94933 \pm 1E-06$	1596.28 ± 2.87	$1.35293 \pm 2E-04$
33	Silver	$0.95005 \pm 3E-06$	1602.26 ± 0.05	$1.35233 \pm 6E-05$
34	Extra aged	$0.94970 \pm 4E-06$	1599.00 ± 0.03	$1.35363 \pm 2E-04$
35	Aged	$0.94911 \pm 5E-04$	1597.41 ± 0.09	$1.35303 \pm 1E-04$
36	Silver	$0.94890 \pm 4E-05$	1598.81 ± 0.03	$1.35297 \pm 2E-04$
37	Gold	$0.94922 \pm 2E-04$	1599.07 ± 0.09	$1.35320 \pm 1E-04$
38	Aged	$0.95025 \pm 5E-05$	1602.03 ± 0.01	$1.35263 \pm 3E-04$
39	Aged	$0.95143 \pm 5E-04$	1602.65 ± 0.06	$1.35306 \pm 6E-05$
40	Extra aged	$0.94870 \pm 7E-05$	1598.43 ± 0.03	$1.35310 \pm 2E-04$
41	Aged	$0.95046 \pm 5E-04$	1598.69 ± 0.01	$1.35316 \pm 2E-04$
42	Silver	$0.94872 \pm 1E-03$	1597.97 ± 3.12	$1.35313 \pm 3E-04$
43	Aged	$0.95348 \pm 7E-05$	1608.99 ± 0.35	$1.35087 \pm 3E-04$

(b) Continued.

Number	Category	Density (g cm^{-3})	Sound velocity (m/s)	RI*
44	Extra aged	$0.94612 \pm 9E-04$	1590.15 ± 1.89	$1.35410 \pm 1E-04$
45	Silver	$0.95471 \pm 4E-04$	1610.59 ± 0.22	$1.35090 \pm 2E-04$
46	Aged	$0.95343 \pm 1E-04$	1607.91 ± 0.46	$1.35076 \pm 6E-05$
47	Extra aged	$0.95042 \pm 8E-05$	1601.57 ± 0.18	$1.35166 \pm 3E-04$
48	Aged	$0.95272 \pm 1E-04$	1607.36 ± 0.27	1.35200 ± 0
49	Aged	$0.94476 \pm 2E-04$	1586.20 ± 0.85	$1.35406 \pm 6E-05$
50	Extra aged	$0.94637 \pm 3E-03$	1585.99 ± 0.90	$1.35430 \pm 2E-04$
51	Silver	$0.94476 \pm 2E-04$	1586.95 ± 0.65	$1.35350 \pm 1E-04$
52	Aged	$0.94550 \pm 1E-03$	1587.57 ± 1.02	$1.35410 \pm 1E-04$
53	Extra aged	$0.94484 \pm 4E-04$	1586.91 ± 1.40	$1.35417 \pm 2E-04$

*RI: refractive index.

TABLE 2: Table of variance contribution for the principal components.

Component number	Eigenvalue	Percentage of variance	Accumulated percentage
1	2.1704	36.174	36.174
2	2.0095	33.492	69.666
3	1.0855	18.092	87.758
4	0.5934	9.891	97.648
5	0.0953	1.588	99.237
6	0.0458	0.763	100.000

0.9918 mPa·s and 1.24 mPa·s for ethylic alcohol, similar to values reported in the literature: 0.815 mPa·s and 0.964 mPa·s, respectively [47]. Generally, liquids with low molecular weight tend to behave as Newtonian fluids, whereas polymers with high molecular weight are usually non-Newtonian. According to the obtained results, tequila usually behaves as Newtonian-like fluid [3].

Refractive index is usually employed to determine sugar and alcohol content. In the case of tequila, this parameter varied from 1.3500 to 1.3525. The refractive index of silver tequila (1.35279 ± 0.00085) was similar to the refractive index for aged tequilas (1.35209 ± 0.00153) ($p > 0.05$). On the other hand, the refractive indexes for pure alcohol and distilled water were 1.3599 and 1.333, respectively. In the literature, values of 1.3600 and 1.3330 have been reported for these compounds at a temperature of 25°C [47, 50]. Tequilas numbers 2, 11, and 13 had refractive indexes below the average value, very likely due to their greater water content than normal tequilas. Also, tequila number 17 had a refractive index higher than the average, suggesting a higher alcoholic or sugar content from some additives such as caramel.

For PCA, Tables 2 and 3 were obtained. Table 2 corresponds to the variance contribution of the principal components, in which the existence of 3 main components is identified, explaining the 87.76% of the total variability of physicochemical measurements that is found in the tequila. Component 1 explains the 36.17%, component 2 explains the 33.49%, and component 3 explains the 18.09%. Table 3 shows the weights of the main components, allowing identifying

TABLE 3: Table of weights of the main components.

	Component 1	Component 2	Component 3
Conductivity	0.429585	0.437078	0.40954
Density	0.396038	0.538949	0.18673
pH	-0.238999	0.446694	-0.275948
RI	-0.550304	0.331601	0.145879
Sound velocity	-0.055658	0.42743	-0.669443
Viscosity	-0.543652	0.162192	0.501823

FIGURE 1: Distribution of physicochemical properties of tequila brands in the plane of the first two PCs.

the variables (physicochemical properties) that contribute the most to each component. For this, the weights with higher value in each component must be selected. In this way, the principal component 1, which corresponds to the most relevant physicochemical properties, states that there are some brands of tequila that present an opposite relation between the conductivity, the density, and the RI and the viscosity, which means that some brands of tequila present high values of RI and viscosity (or the contrary). The main component 2 shows that the second most relevant physicochemical properties are the density, the pH, the conductivity, the sound velocity, and the RI. The main component 3 states that there are some brands of tequila that present an opposite relation between viscosity, conductivity, and sound velocity; that is, some brands of tequila present high values for sound velocity or the contrary. Figure 1 shows the distribution of

FIGURE 2: Dendrogram plot of tequila brands.

(a)

(b)

(c)

(d)

(e)

(f)

FIGURE 3: Means graphs obtained by the method of Fisher's LSD from cluster analysis: (a) pH, (b) conductivity, (c) viscosity, (d) density, (e) sound velocity, and (f) RI.

TABLE 4: Summary of the physicochemical properties of different traditional, spirituous beverages worldwide. (a) pH and ethanol content, (b) specific gravity, viscosity, total soluble solid, total sugar, total solids, reducing sugar, and ascorbic acid, (c) refractive index, titratable acidity, density, conductivity, and alcohol content.

(a)									
Alcoholic beverage/measure				pH	Ethanol content		Reference		
Country liquor of India				7.1			[37]		
Sotol (first distillation)				4.4			[20]		
Millet				5.0					
Maize				4.69			[38]		
Guinea corn				4.66					
Agave sap type 1				6–7.5					
Agave sap type 2				4.5					
Pulque type 1				3–4.2			[39]		
Pulque type 2				3.5–4.0					
Comercial local in Osun state of Nigeria	Palm wine			4.3	3.1%				
	Ogogoro			6.3	37.6%				
	Fura da nono			5.2	0.3		[6]		
	Burukutu			4.8	4.6%				
Coconut toddy	Fresh toddy			5.5 ± 0.03	0.2				
	Stored toddy				4.5		[7]		
Wine	White wine			2.72–3.9	8.5–14		[40]		
	Red wine “Blauer Zweigelt Klassik”			3.6 ± 0.1	11.8 ± 0.4				
	White wine “Grüner Veltliner”			3.5 ± 0.1	11.1 ± 0.1		[10]		
	Ethanol			6.5 ± 0.7	12				
Ethiopian traditional beverages	Tella			4.00–4.99	3.84–6.48				
	Tej			3.56–3.95	8.94–13.16		[15]		
	Areki			4.30–4.51	33.95–39.90				
Cabernet Sauvignon wine	Before bottling			3.58	13.1		[5]		
Nonalcoholic beverage from Nigeria	Kunu Zaki			5.79			[41]		
	Soy milk			6.90					
	Peach wine			3.90 ± 0.01	8.12 ± 0.03		[14]		
Cynthiana wine	Storage at 28°C			4.11			[13]		
(b)									
Alcoholic beverage/measure		Specific gravity	Viscosity	Total soluble solid	Total sugar	Total solids	Reducing sugar	Ascorbic acid	Reference
Commercial local in Osun state of Nigeria	Palm wine	1.0387			1.9	3.4%	1.3	8.4 mg/100 g	
	Ogogoro	0.9897		3–10.7%	0.0	1.2%	0.0	0.0 mg/100 g	
	Fura da nono	1.3180			7.5	21.8%	1.1	17.5 mg/100 g	[6]
	Burukutu	1.0812		0.8	0.2	7.9%	0.2	5.6 mg/100 g	
Coconut toddy	Fresh toddy			14.1 ± 1.4				3.5 mg/100 mL	
	Stored toddy			11.4 ± 0.9				5.8 mg/100 mL	[7]
Ethiopian traditional beverages	Tella	1.0038– 1.0097							[15]

(b) Continued.

Alcoholic beverage/measure		Specific gravity	Viscosity	Total soluble solid	Total sugar	Total solids	Reducing sugar	Ascorbic acid	Reference
Nonalcoholic beverage from Nigeria	Kunu Zaki	1.0426	7.247 cts						[41]
	Soy milk	1.0249	2.093 cts						
	Agave sap type 1					13–17 g 100 mL ⁻¹			[39]
	Agave sap type 2					7 g 100 mL ⁻¹			

Alcoholic beverage/measure		Refractive index		Titrateable acidity	Density (g/dm ³)	Conductivity (μS/cm)	Alcohol content °GL	Reference
	Agave sap type 1	59–100						[39]
	Agave sap type 2	27						
	Pulque type 1	1.3390–1.3406						
	Pulque type 2	1.3365–1.3380						
Sotol	First distillation						35	[20]
	Second distillation						46–50	
Ethiopian traditional beverages	Tella	1.3353–1.3405						[15]
Nonalcoholic beverage from Nigeria	Kunu Zaki	131.33 g/L		2.30%				[41]
	Soy milk	68.54 g/L		1.45%				
Coconut toddy	Fresh toddy			0.75 ± 0.02				[7]
	Stored toddy			1.78 ± 0.02				
	Peach wine			4.47 ± 0.09				[14]
Cynthiana wine	Storage at 25°C			6		3937		[13]
	White wine				0.9881–1.0103			[40]

physicochemical properties of tequila brands in the plane of the first two PCs. As can be seen PC1 is positively correlated to conductivity and density and negatively correlated to RI and viscosity. In this graph, three points are separated from the majority of the points, corresponding to the tequila brands numbers 2, 11, and 17, which are not recognized by CRT.

Figure 2 shows the dendrogram analysis, performed in order to identify the groups of tequila that have similar physicochemical properties. From this analysis it was mainly found the presence of four clusters, which are identified as I, II, III, and IV. Cluster I includes the 1, 12, 16, 24, 25, 5, 20, 32, 9, 26, 34, 31, 7, 35, 41, 42, 10, 44, 14, 51, 52, 53, 49, and 50 tequila brands. In this cluster the category of tequila is silver, gold, aged, and extra aged. Cluster II includes the 30, 38, 36, 37, 40, 33, and 39 tequila brands. The category of tequila of this cluster is the same compared to cluster I. Cluster III includes the 3, 46, 45, 15, 29, 22, 23, 4, 13, 6, 27, 19, 47, 18, 48, 8, 21, 28, and 43 tequila brands. The category of tequila of this cluster only does not contain the silver tequila. Cluster IV includes the 2, 11, and 17 tequila brands, in which the category of tequila is aged, silver, and gold, which are characterized by having the higher conductivity and density and by having the lower viscosity and RI. It is worth mentioning that the last cluster represents the agave distilled beverages sold as tequila, commonly known as guachicol. It is interesting to

note that the same brands appear isolated in Figure 1. These beverages are not registered in the CRT and they do not follow the International Standard 006. Moreover, their results generally differed from the average values obtained in most physicochemical measurements, allowing proposing that the combination between these measurements and the statistical analysis could be used to know the authenticity and quality of tequila.

From the cluster analysis, the ANOVA was conducted in every group (I, II, III, and IV) for all physicochemical properties. It was found that the clusters obtained were statistically significant with respect to the physicochemical properties taken as the variable (p value < 0.05). Figure 3 corresponds to the mean graph obtained by the method of Fisher's LSD. It shows that group II contains the highest pH. Group III contains the highest sound velocity, which could be due to the presence of large molecules coming from additives, such as caramel or colorants. Recalling that in group IV there are the 2, 11, and 17 tequila brands. It is notable that group IV contains a higher conductivity and density and lower viscosity and RI, such as mentioned in the cluster analysis (Figure 2). These variations can be attributed to the loss of water, an increase in salt concentration, and the presence of caramels, colorants, salts, or other unknown additives [44].

Finally, a comparison of the properties of some traditional beverages with those of tequila is summarized in Tables 4(a)–4(c). This includes the physicochemical properties of 29 different spirituous beverages, such as country liquor of India [37], Sotol [20], Millet, maize guinea corn [38], agave sap type 1, agave sap type 2, Pulque type 1, Pulque type 2 [39], local beverages of Nigeria [6], coconut toddy [7], wine of different colors [10, 40], Ethiopian traditional beverages [15], Cabernet Sauvignon wine [5], nonalcoholic beverages from Nigeria [41], and peach and Cynthiana wines [13, 14]. The physicochemical properties measured for all cases are pH, refractive index, total solids, alcohol content, specific gravity, viscosity, total soluble solids, total sugar, reductive sugar, ascorbic acid, titratable acidity, density, and conductivity. Two Mexican traditional beverages, Sotol and Pulque types 1 and 2, have similar pH (4.4, 3.7–4.2 and 3.5–4.0, resp.) to the tequila pH obtained in this study. This is probably due to the fact that all these spirits share similar raw materials from the agave family and production procedures [39]. The pH of tequila is similar to that of Palm wine and Tella and Cynthiana wines with pH of 4.3 and 4 and 4.11, respectively; these beverages are from Nigeria, Ethiopia, and Cynthiana. In the case of the refractive index of tequila, the average value is close to the two types of Pulque (1.339–1.3406 and 1.3365–1.3380). The viscosity, density, and conductivity were measured in the alcoholic beverage from Nigeria, in the white wine and in the Cynthiana wine. These values were found to be different from the corresponding values in tequila. Some other physicochemical properties for spirituous beverages that appear in Tables 4(a)–4(c) were not investigated in this work for tequila.

10. Conclusions

PCA and cluster analysis were used to evaluate physicochemical properties in tequila brands, which are not established in the Mexican Official Standard 006. By using the PCA, it was found that there are some brands of tequila that present an opposite relation between the conductivity, the density, and the RI and the viscosity, with a total variance of 36.17%. With regard to the cluster analysis, it was revealed that those tequila brands (2, 11, and 17), which are not registered in the CRT (namely “guachicol”) and do not meet the quality requirements established in the Mexican Official Standard 006, have similar physicochemical characteristics. According to these findings, the physicochemical properties measured in this investigation and the cluster analysis can be used to determine the authenticity and the quality of a tequila brand.

Competing Interests

The authors declare that they have no competing interests.

Acknowledgments

The authors are thankful to the Consejo Nacional de Ciencia y Tecnología (CONACyT) for their support to Alejandra Carreon-Alvarez.

References

- [1] A. García-Abuín, D. Gómez-Díaz, M. D. La Rubia, J. M. Navaza, and R. Pacheco, “Density, speed of sound, and isentropic compressibility of triethanolamine (or *N*-methyldiethanolamine) + water + ethanol solutions from $t = (15 \text{ to } 50)^\circ\text{C}$,” *Journal of Chemical & Engineering Data*, vol. 54, no. 11, pp. 3114–3117, 2009.
- [2] V. Lavigne, A. Pons, P. Darriet, and D. Dubourdieu, “Changes in the sotolon content of dry white wines during barrel and bottle aging,” *Journal of Agricultural and Food Chemistry*, vol. 56, no. 8, pp. 2688–2693, 2008.
- [3] I. Öztürk, S. Karaman, F. Törnük, and O. Sagdic, “Physicochemical and rheological characteristics of alcohol-free probiotic boza produced using *Lactobacillus casei* Shirota: estimation of the apparent viscosity of boza using nonlinear modeling techniques,” *Turkish Journal of Agriculture and Forestry*, vol. 37, no. 4, pp. 475–487, 2013.
- [4] E. Hosseini, M. Kadivar, and M. Shahedi, “Physicochemical properties and storability of Non-alcoholic malt drinks prepared from oat and barley malts,” *Journal of Agricultural Science and Technology*, vol. 14, no. 1, pp. 173–182, 2012.
- [5] H. Hopfer, P. A. Buffon, S. E. Ebeler, and H. Heymann, “The combined effects of storage temperature and packaging on the sensory, chemical, and physical properties of a cabernet sauvignon wine,” *Journal of Agricultural and Food Chemistry*, vol. 61, no. 13, pp. 3320–3334, 2013.
- [6] R. O. Adeleke and O. A. Abiodun, “Physico-chemical properties of commercial local beverages in Osun state, Nigeria,” *Pakistan Journal of Nutrition*, vol. 9, no. 9, pp. 853–855, 2010.
- [7] K. Singaravadjvel, K. Alagusundaram, and B. Hariharan, “Physicochemical properties of fresh and stored coconut palm toddy,” *Open Access Scientific*, vol. 1, article 8, 2012.
- [8] M. Serafini, G. Maiani, and A. Ferro-Luzzi, “Effect of ethanol on red wine tannin—protein (BSA) interactions,” *Journal of Agricultural and Food Chemistry*, vol. 45, no. 8, pp. 3148–3151, 1997.
- [9] J. M. McRae, S. Kassara, J. A. Kennedy, E. J. Waters, and P. A. Smith, “Effect of wine pH and bottle closure on tannins,” *Journal of Agricultural and Food Chemistry*, vol. 61, no. 47, pp. 11618–11627, 2013.
- [10] K. I. Liszt, J. Walker, and V. Somoza, “Identification of organic acids in wine that stimulate mechanisms of gastric acid secretion,” *Journal of Agricultural and Food Chemistry*, vol. 60, no. 28, pp. 7022–7030, 2012.
- [11] B. Burlingame, “Wine: food of poets and scientists,” *Journal of Food Composition and Analysis*, vol. 21, no. 8, pp. 587–588, 2008.
- [12] N. Kontoudakis, E. González, M. Gil et al., “Influence of wine pH on changes in color and polyphenol composition induced by micro-oxygenation,” *Journal of Agricultural and Food Chemistry*, vol. 59, no. 5, pp. 1974–1984, 2011.
- [13] T. Walker, J. Morris, R. Threlfall, and G. Main, “pH modification of cynthiana wine using cationic exchange,” *Journal of Agricultural and Food Chemistry*, vol. 50, no. 22, pp. 6346–6352, 2002.
- [14] S. M. Davidovic, M. S. Veljovic, M. M. Pantelic et al., “Physicochemical, antioxidant and sensory properties of peach wine made from Redhaven cultivar,” *Journal of Agricultural and Food Chemistry*, vol. 61, no. 6, pp. 1357–1363, 2013.
- [15] T. Yohannes, K. Melak, and F. Siraj, “Preparation and physicochemical analysis of some Ethiopian traditional alcoholic beverages,” *African Journal of Food Science*, vol. 7, no. 11, pp. 399–403, 2013.

- [16] E. J. Kwak, J. Y. Lee, and I. S. Choi, "Physicochemical properties and antioxidant activities of Korean traditional alcoholic beverage, yakju, enriched with mulberry," *Journal of Food Science*, vol. 77, no. 7, pp. C752–C758, 2012.
- [17] M. C. Cedeño, "Tequila production," *Critical Reviews in Biotechnology*, vol. 15, no. 1, pp. 1–11, 1995.
- [18] A. Carreon-Alvarez, N. Casillas, J. G. Ibanez et al., "Determination of Cu in tequila by anodic stripping voltammetry," *Analytical Letters*, vol. 41, no. 3, pp. 469–477, 2008.
- [19] A. Trujillo-Orozco, S. Gómez-Salazar, M. Barcena-Soto et al., "Detection of Cu, Pb, Cd and Zn in Mexican spirituous beverages by Differential Pulse Polarography (DPP)," *ECS Transactions*, vol. 36, no. 1, pp. 363–372, 2011.
- [20] H. De La Garza-Toledo, M. Martínez, L. Lara, R. Rodríguez-Herrera, J. Rodríguez-Martínez, and C. N. Aguilar, "Production of a Mexican alcoholic beverage: sotol," *Research Journal of Biological Sciences*, vol. 3, no. 6, pp. 566–571, 2008.
- [21] CRT (Tequila Regulatory Council), "Agreement between the European Community and México on the mutual recognition and protection of designations for spirit drinks," Official Journal L 152, 11/06/1997, 1997, <http://www.crt.org.mx/>.
- [22] R. Lamas-Robles, G. C. Sandoval-Fabián, A. A. Osuna-Tenes, R. Prado-Ramírez, and A. C. Gschaedler-Mathis, "Cocimiento y molienda," in *En Ciencia y Tecnología del Tequila Avances y Perspectivas*, pp. 41–60, CIATEJ, Guadalajara, Mexico, 1st edition, 2004.
- [23] A. Valenzuela-Zapata and G. P. Nabhan, *Tequila*, The University of Arizona Press, 1st edition, 2003.
- [24] Norma Oficial Mexicana NOM-006-SCFI-2005, Diario Oficial de la Federación.
- [25] W. D. Santiago, M. das Graças Cardoso, L. M. Zaccaroni et al., "Multivariate analysis for the characterization of physicochemical profiles of cachaça produced in copper stills over a period of six years in Minas Gerais state," *Journal of the Institute of Brewing*, vol. 121, no. 2, pp. 244–250, 2015.
- [26] R. Prado-Ramírez, *Ciencia y Tecnología del Tequila Avances y Perspectivas*, CIATEJ, 2004.
- [27] R. Prado-Ramírez, V. González-Alvarez, C. Pelayo-Ortiz, N. Casillas, M. Estarrón, and H. E. Gómez-Hernández, "The role of distillation on the quality of tequila," *Journal of Food Science and Technology*, vol. 40, pp. 701–708, 2005.
- [28] J. G. Ibañez, A. Carreon-Alvarez, M. Barcena-Soto, and N. Casillas, "Metals in alcoholic beverages: a review of sources, effects, concentrations, removal, speciation, and analysis," *Journal of Food Composition and Analysis*, vol. 21, no. 8, pp. 672–683, 2008.
- [29] A. Carreón, N. Casillas, V. González-Álvarez, and R. Prado-Ramírez, "Corrosion of copper in tequila at different temperatures," *Materials Performance*, vol. 40, no. 12, pp. 50–52, 2001.
- [30] A. Carreon-Alvarez, R. C. Valderrama, J. A. Martínez et al., "Corrosion of aluminum, copper, brass and stainless steel 304 in tequila," *International Journal of Electrochemical Science*, vol. 7, no. 9, pp. 7877–7887, 2012.
- [31] S. M. Benn and T. L. Peppard, "Characterization of tequila flavor by instrumental and sensory analysis," *Journal of Agricultural and Food Chemistry*, vol. 44, no. 2, pp. 557–566, 1996.
- [32] S. G. Ceballos-Magaña, J. M. Jurado, M. J. Martín, and F. Pablos, "Quantitation of twelve metals in tequila and mezcal spirits as authenticity parameters," *Journal of Agricultural and Food Chemistry*, vol. 57, no. 4, pp. 1372–1376, 2009.
- [33] A. Carreon-Alvarez, A. Herrera-Gonzalez, N. Casillas et al., "Cu (II) removal from tequila using an ion-exchange resin," *Food Chemistry*, vol. 127, no. 4, pp. 1503–1509, 2011.
- [34] J. E. López-Ramírez, S. T. Martín-del-Campo, H. Escalona-Buendía, J. A. García-Fajardo, and M. Estarrón-Espinosa, "Physicochemical quality of tequila during barrel maturation. A preliminary study," *CyTA—Journal of Food*, vol. 11, no. 3, pp. 223–233, 2013.
- [35] A. M. Green, A. C. Clark, and G. R. Scollary, "Determination of free and total copper and lead in wine by stripping potentiometry," *Fresenius' Journal of Analytical Chemistry*, vol. 358, no. 6, pp. 711–717, 1997.
- [36] R. Kokkinofa, P. V. Petrakis, T. Mavromoustakos, and C. R. Theocharis, "Authenticity of the traditional Cypriot spirit 'zivania' on the basis of metal content using a combination of coupled plasma spectroscopy and statistical analysis," *Journal of Agricultural and Food Chemistry*, vol. 51, no. 21, pp. 6233–6239, 2003.
- [37] C. Behera, S. K. Gupta, D. N. Bharadwaj, O. P. Murty, R. K. Sharma, and T. D. Dorga, "Physical properties and alcohol content of country made liquors," *Indian Internet Journal of Forensic Medicine Toxicology*, vol. 4, no. 4, 2006.
- [38] G. B. Adebayo, G. A. Otunola, and T. A. Ajao, "Physicochemical, microbiological and sensory characteristics of Kunu prepared from millet, maize and Guinea corn and stored at selected temperatures," *Advance Journal of Food Science and Technology*, vol. 2, no. 1, pp. 41–46, 2010.
- [39] P. Lappe-Oliveras, R. Moreno-Terrazas, J. Arrizón-Gaviño, T. Herrera-Suárez, A. García-Mendoza, and A. Gschaedler-Mathis, "Yeasts associated with the production of Mexican alcoholic nondistilled and distilled Agave beverages," *FEMS Yeast Research*, vol. 8, no. 7, pp. 1037–1052, 2008.
- [40] M. Horák, "Prediction of wine quality from physicochemical properties," Semestral Work, Course 336VD: Data Mining, Czech Technical University in Prague, Prague, Czech Republic, 2009–2010.
- [41] B. Osuntogun and O. O. Aboaba, "Microbiological and physicochemical evaluation of some non-alcoholic beverages," *Pakistan Journal of Nutrition*, vol. 3, no. 3, pp. 188–192, 2004.
- [42] Statgraphics Centurion XVI, <http://www.statgraphics.net/>.
- [43] E. H. Soufleros, A. S. Mygdalia, and P. Natskouliis, "Characterization and safety evaluation of the traditional Greek fruit distillate 'Mouro' by flavor compounds and mineral analysis," *Food Chemistry*, vol. 86, no. 4, pp. 625–636, 2004.
- [44] J. M. F. Nogueira and A. M. D. Nascimento, "Analytical characterization of Madeira wine," *Journal of Agricultural and Food Chemistry*, vol. 47, no. 2, pp. 566–575, 1999.
- [45] D. R. Cardoso, L. G. Andrade-Sobrinho, A. F. Leite-Neto et al., "Comparison between cachaça and rum using pattern recognition methods," *Journal of Agricultural and Food Chemistry*, vol. 52, no. 11, pp. 3429–3433, 2004.
- [46] A. Moutsatsou, E. Chalarakis, and G. Zarangas, "Influence of raw materials and distillation equipment on the heavy metal content of waste from an alcoholic anis-type beverage," *Journal of Hazardous Materials*, vol. 96, no. 1, pp. 53–64, 2003.
- [47] A. E. Flood and S. Puagsa, "Refractive index, viscosity, and solubility at 30°C for the system fructose+glucose+ethanol+water," *Journal of Chemical & Engineering Data*, vol. 45, pp. 902–907, 2000.
- [48] W. G. Castellan, *Fisicoquímica*, Addison-Wesley Iberoamericana, 2nd edition, 1974.

- [49] A. Bouchard, G. W. Hofland, and G.-J. Witkamp, "Properties of sugar, polyol, and polysaccharide water-ethanol solutions," *Journal of Chemical and Engineering Data*, vol. 52, no. 5, pp. 1838–1842, 2007.
- [50] Skoog-leary, *Análisis Instrumental*, McGraw-Hill Education, New York, NY, USA, 1994.