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# The Rheological Analysis of Ancestral Beverages, Neutrosophic C-Means (NCM) Clustering Algorithm of Data

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**Abstract.** This study focuses on the rheological analysis of cassava and chonta chichas (Manihot esculenta Crantz and Bactris gasipaes) produced in the Province of Pastaza, aiming to preserve and disseminate the cultural and nutritional heritage of these traditional beverages. The research emphasizes the integration of ancestral knowledge into modern production practices, exploring sensory characteristics that could influence consumer preferences and production standardization. In Pastaza, it has been observed that traditional production methods, such as chewing cassava and chonta to initiate fermentation, expose the product to microbial risks, making it potentially unpalatable and unsafe for consumption. To address these issues, this work incorporates neutrosophic theory to manage the uncertainties in sensory evaluation and applies Neutrosophic C-means clustering to analyze the data obtained from both expert assessments and instrumental measurements. This approach aims to enhance our understanding of how variations in the production process affect the beverage's properties and to develop a standardized production protocol that ensures both the safety and quality of the chichas. Through empirical data and rheological studies, this research seeks to contribute significantly to the sustainable preservation and enhancement of traditional beverage production.

**Keywords:** Rheological Analysis, Traditional Beverages, Neutrosophic Theory, Neutrosophic C-means clustering

## 1. Introduction

A rheological study is an investigation that focuses on the behavior of matter in response to applied forces, specifically in relation to its flow, elasticity, and viscosity [1, 2]. Rheology is the branch of physics that studies the deformation and flow of matter, and a rheological study concentrates on measuring and analyzing how materials respond to mechanical forces, such as tension, compression, or shear. The purpose of a rheological study [3, 4] includes:

- Material Characterization: Allows understanding of the mechanical properties of materials, such as viscosity, elasticity, and plasticity, among others.
- Process Design: Assists in the design and control of industrial processes where the fluidity and behavior of materials are critical.
- Product Development: Fundamental in the formulation and improvement of products such as food, cosmetics, paints, and polymers, among others, to ensure their quality and performance.

The functional foods market is one of the fastest-growing segments in the food product development category, as an increasing number of consumers are concerned about health-related issues [5].

In Ecuador, there is limited research on this topic, making the integration of this analysis into the food industry novel, especially when applied to ancestral beverages such as chichas, which have significant historical recognition. Chicha is a traditional drink in various countries of Latin America, and its consistency and texture can vary depending on the region and recipe. The main problem at the beginning of the research is the cultural importance of chicha, as well as its nutritional and sensory value. Therefore, it can be said that the lack of information and valuation of the cultural importance of chicha de jora in the Sierra Norte is the motivation for this study, along with its various recipes and ways of preparation [6].

It can be said that studies conducted in this area of rheology do not provide regulations that set rheological parameters for fermented beverages that can be valued and referenced in research or production of yuca and chonta chichas. This is why entrepreneurs cannot validate the quality of the product endorsed by these types of studies. This lack of guidance or regulations is counterproductive because it does not provide a standardization that "guides" the producer to make yuca and chonta chichas in a way consistent with ancestral customs and allows the product to be endorsed for marketing.

For this reason, in this work, it was decided to emphasize the search for parameters based on sensory characteristics in order to rescue the ancestral knowledge of the drink, promote its preservation, and disseminate its cultural and nutritional wealth. It is intended to determine the rheological study of yuca (Manihot esculenta crantz) and chonta (Bactris gasipaes) chichas with enzymatic preparations made in the province of Pastaza. This work aims to better understand how variations in the production process affect the final properties of the product and to expand knowledge about the standardization of the production process of yuca and chonta chichas.

The study will be carried out in the Province of Pastaza where it was detected that the producers do not have raw materials nor a harmless process, making the process susceptible to microbial agents that can cause health damage, since it is traditionally done with the chewing of yuca and chonta masato which makes it unpalatable to the consumer. The study will be conducted involving neutrosophic theory in the processing of the magnitudes of the variables in the sensory evaluation for the rheological study before the experts. Given such inherent uncertainty in the use of experts, it was decided to apply neutrosophic sets for clustering using Neutrosophic C-means in the case of these evaluations and compare them with those obtained by the instruments and the proven properties, to issue criteria based on the contribution of the empirical data of the tests to be carried out in the rheological study. To illustrate the technological process, Table 1 shows a summary of the steps and significant details of this.

**Table 1:** Yuca and Chonta Masato Preparation Processes. Source: own elaboration based on direct observation.

| Process | Description | Technical details |
|---|---|---|
| White Yuca Masato | Raw Material Preparation: Selection, washing, and cooking of cassava and sweet potato. | Weight: 5.4 kg of cassava, 333.3 g of sweet potato.<br>Cooking: 80ºC for 40 min.<br>Grinding: Homogeneous mass in a clean container. |
| Burnt Yuca Masato | Burning and Fermentation Process: Washing, burning, and controlled fermentation. | Burning: Directly at 89°C until soft.<br>Fermentation: 4-5 days at room temperature, covered with bijao leaves and aluminum foil. |
| Wiwis Yuca Masato | Scraping and Cooking: Removal of the peel and cooking of cassava and sweet potato. | Cooking: 85°C for 40 min.<br>Fermentation: 5 days at room temperature, covered with achira leaves. |
| Masato of Chonta | Cooking and Homogenization: Cooking of peach palm and sweet potato, followed by crushing. | Cooking: 90-94°C for 2.5 hours.<br>Additions: 5% cooked sweet potato, 250 g of distilled water. |
| Enzymatic Hydrolysis | Preparation and Enzymation: Mixing masato with water and enzymes, temperature control. | Enzymes: α-amylase, β-amylase, amyloglucosidase (0.05%, 0.10%, 0.15%).<br>Temperature: 55ºC initial, up to 95ºC for inactivation. |
| Rheological Analysis | Rheological Tests: Use of a rheometer to measure flow properties of the beverages. | Equipment: Anton Paar MCR 302 Rheometer.<br>Conditions: 17.9 °C and 59.6% HR. |
| Physicochemical Analysis | Quality Evaluation: Measurement of acidity, Brix degrees, pH, alcoholic degrees, taste, color, and odor. | Comparison: Differences between chichas with and without enzymes. |

## 2 Neutrosophic C-Means (NCM) to be applied to evaluations carried out by experts

A neutrosophic set is an extension of classical and fuzzy set theory that allows modeling uncertainty and indeterminacy. An element of a neutrosophic set has three associated parameters: the degree of truth T, the degree of indeterminacy I, and the degree of falsehood F of x in A, respectively, and their images form standard or non-standard subsets within the range from 0 to 1. For this study, the following functions are defined:

- T= for the membership functions to true, where T ∈[0,1].
- I= for the membership functions to indeterminate, where I ∈[0,1].
- F= for the membership functions to false, where F ∈[0,1] [7].

A neutrosophic number is of the form (T, I, F) as shown in Table 2.

**Table 2:** Definition of linguistic terms according to the method and single-valued neutrosophic numbers. Source: Developed based on [7].

| Single-Valued Neutrosophic Number | Interpretation for the studio |
|---|---|
| (1,0,0) | Excellent Variable Behavior |
| (0.9, 0.1, 0.1) | Very Good Variable Behavior |
| (0.8,0,15,0.20) | Good Variable Behavior |
| (0.70,0.25,0.30) | Acceptable Variable Behavior |

| Single-Valued Neutrosophic Number | Interpretation for the studio |
|---|---|
| (0.60,0.35,0.40) | Moderately Good Variable Behavior |
| (0.50,0.50,0.50) | Uncertain |
| (0.40,0.65,0.60) | Moderately Poor Variable Behavior |
| (0.30,0.75,0.70) | Poor Variable Behavior |
| (0.20,0.85,0.80) | Very Poor Variable Behavior |
| (0.10,0.90,0.90) | Extremely Poor Variable Behavior |
| (0,1,1) | Terrible Variable Behavior |

Fuzzy C-means, also known as fuzzy C-means clustering, is a clustering technique used in machine learning. Unlike traditional K-means clustering, which assigns each data point to a single cluster, Fuzzy C-means allows data points to belong to multiple clusters with varying degrees of membership [7-13]. In this method, each data point is assigned a value between 0 and 1 for each cluster, indicating the degree to which it belongs to that cluster. A value of 0 means it does not belong, and 1 indicates complete membership. The process is iterative. Initially, random membership values are assigned to the data points. Then, the algorithm refines these values until they no longer change significantly [14].

The Neutrosophic C-means (NCM) algorithm is based on neutrosophic theory, extending the Fuzzy C-Means (FCM) by incorporating three types of memberships for each data point in relation to each cluster: truth T, indeterminacy I, and falsehood F. Below is an explanation of how these memberships are defined and the objective function of NCM [15,16].

The objective function of NCM is a generalization of that of FCM, incorporating the neutrosophic degrees. The aim is to minimize:

$$J(T,I,F,C)=\sum_{i=1}^{N}\sum_{j=1}^{C}\left(\omega_1 T_{ij}^{m}\parallel x_i-c_j\parallel^2+\omega_2 I_{ij}^{m} d_{max}+\omega_3 F_{ij}^{m}\parallel x_i-c_j\parallel^2\right) \quad (1)$$

Where:

- *tij* is the degree of truth that point *i* belongs to cluster *j*.
- *Iij* is the degree of indeterminacy for point *i* in cluster *j*.
- *Fij* is the degree of falsehood that point *i* belongs to cluster *j*.
- $\omega_1,\omega_2,\omega_3$ are weights associated with truth, indeterminacy, and falsehood, respectively.
- *m* is a parameter that controls the diffusivity of the membership, similar to the "fuzziness" parameter in FCM.
- $d_{max}$ is the maximum distance between any point and the centers of the clusters, used to normalize the influence of indeterminacy.
- $x_i$ is the feature vector of point i.
- $c_j$ is the centroid of cluster j.
- *N* is the total number of data points.
- *C* is the number of clusters

Update of Cluster Centers ($c_j$):

$$c_j=\frac{\sum_{i=1}^{N}(T_{ij}^{m}+F_{ij}^{m})\,x_i}{\sum_{i=1}^{N}(T_{ij}^{m}+F_{ij}^{m})} \quad (2)$$

Updating Membership Degrees:

Truth ($T_{ij}$): $$T_{ij}=\frac{1}{\sum_{k=1}^{C}\left(\frac{\|x_i-c_i\|}{\|x_i-c_k\|}\right)^{\frac{2}{m-1}}} \quad (3)$$

Indeterminacy ($I_{ij}$): $$I_{ij}=1-T_{ij}-F_{ij} \quad (4)$$

Falsehood ($F_{ij}$): $$F_{ij}=\frac{\|x_i-c_j\|^2/d_{max}}{\sum_{k=1}^{C}\left(\frac{\|x_i-c_k\|^2}{d_{max}}\right)} \quad (5)$$

### 2.1 Methodology to follow

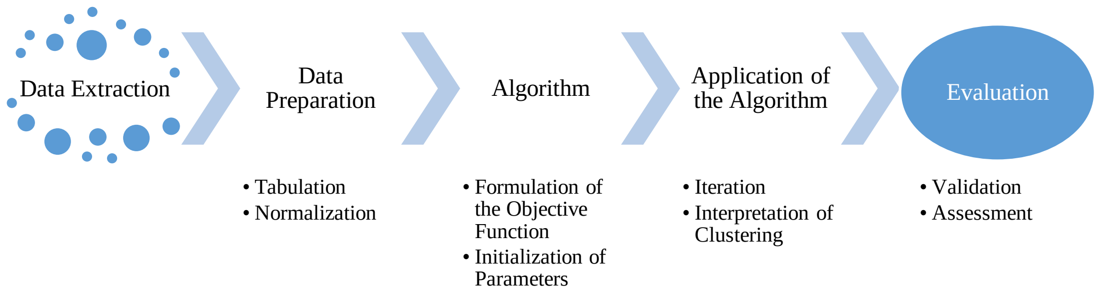


**Figure 1:** Data processing. Source: own elaboration.

## 3 Results

### 3.1 Extraction of relevant data

For this purpose, Brix degrees, pH, acidity, and alcoholic degrees during the fermentation of yuca and chonta chichas are established as relevant, measured every 72 hours, as well as specific values for different types of chichas, such as burned, white, wiwis, and chonta with and without enzymatic preparations, as explained below:

- ❖ Brix Degrees: Brix degree values throughout the fermentation process for yuca and chonta chichas, measured at various points over 72 hours.
- ❖ pH: pH measurements conducted at similar intervals during the fermentation process.
- ❖ Acidity: Acidity levels expressed in Dornic degrees, also taken during the fermentation process.
- ❖ Alcoholic Degrees: Volumetric alcohol percentages obtained from the chichas at different measurement points.

**Organized Data for Rheological Analysis:** These data include both rheological parameters (density ρ, viscosity μ, consistency index k, flow behavior n, shear stress τ, deformation rate γ) and physicochemical parameters (Brix degrees °Bx, pH, acidity, and alcoholic degrees % vol.) for each type of chicha and treatments with and without enzymatic preparations (CPE and SPE). Table 3 provides a comprehensive view of the parameters that influence the rheological behavior of the chichas, obtained using measurement instruments.

**Table 3:** Data Frame for Analysis with Instruments: Source: Developed from measurements taken from chicha samples during the production process.

| Beverage | Treatment | ρ (g/cm³) | μ (cP) | k (Pa.s) | n | τ (Pa) | γ (1/s) | °Bx | pH | Acidity (°D) | Alc. % vol. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Burnt Chicha | SPE | 1.0107 | 111 | 0.0852 | 0.0009 | 0.0855 | 77 | 49 | 4.02 | 0.55 | 3.2 |
| Burnt Chicha | CPE | 1.0319 | 18 | 0.0138 | 0.0004 | 0.0138 | 77 | 18 | 3.50 | 0.68 | 5.2 |
| White Chicha | SPE | 0.9935 | 113 | 0.0780 | 0.0142 | 0.0823 | fifty | 25 | 5.70 | 0.58 | 2.2 |
| White Chicha | CPE | 1.0124 | 113 | 0.1072 | 0.0305 | 0.1203 | fifty | 13 | 5.25 | 0.68 | 4.1 |
| Chicha Wiwis | SPE | 1.0112 | 38 | 0.0294 | 0.0004 | 0.0294 | 77 | 43 | 4.50 | 0.59 | 2.9 |
| Chicha Wiwis | CPE | 1.0280 | 292 | 0.2203 | 0.0021 | 0.2223 | 76 | 122 | 3.72 | 0.71 | 4.1 |
| Chicha de Chonta | SPE | 1,011 | 113 | 0.0097 | 0.0002 | 0.0097 | fifty | 35 | 3.96 | 0.30 | 2.5 |
| Chicha de Chonta | CPE | 1.0207 | 113 | 0.0122 | 0.0020 | 0.0123 | fifty | 8 | 4.25 | 0.44 | 4.9 |

For sample collection, in the case of experts, 17 individuals working in the production workshops and enterprises in the Pastaza area, who belong to the agricultural producers' association where the chichas are made and marketed, are chosen. Their sensory evaluation will be provided in this case through a questionnaire using neutrosophic linguistic terms aligned with the parameters to be measured by instruments, as outlined in the following survey:

- ❖ Density (ρ) [g/cm³]: Very Low | Mostly Low | Uncertain | Mostly High | Very High
- ❖ Viscosity (μ) [cP]: Very Fluid | Mostly Fluid | Uncertain | Mostly Viscous | Very Viscous
- ❖ Consistency (k) [Pa.s]: Very Weak | Mostly Weak | Uncertain | Mostly Consistent | Very Consistent
- ❖ Flow Index (n): Very Fluid | Mostly Fluid | Uncertain | Mostly Thick | Very Thick
- ❖ Shear Stress (τ) [Pa]: Very Low | Mostly Low | Uncertain | Mostly High | Very High

- Shear Rate (γ) [1/s]: Very Slow | Mostly Slow | Uncertain | Mostly Fast | Very Fast
- Brix Degrees (°Bx): Very Diluted | Mostly Diluted | Uncertain | Mostly Concentrated | Very Concentrated
- pH: Very Acidic | Mostly Acidic | Uncertain | Mostly Basic | Very Basic
- Acidity (°D): Very Low | Mostly Low | Uncertain | Mostly High | Very High
- Alcohol (% vol): Very Low | Mostly Low | Uncertain | Mostly High | Very High

From the application of the questionnaire, a database with an entry of 136 data points was obtained, which were tabulated for preparation. As an example, Table 4 is presented showing the sensory evaluation of a type of chicha with and without enzymes:

**Table 4:** Extraction of sensory evaluation data using neutrosophic linguistic terms for rheological study. Source: Developed from questionnaires provided by 17 experts.

| Beverage | Treatment | ρ (g/cm³) | μ (cP) | k (Pa.s) | n | τ (Pa) | γ (1/s) | °Bx | pH | Acid (°D) | Alc. %vol |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Burnt Chicha | SPE | Very low | Very viscous | Very consistent | Mostly fluid | very high | Mostly slow | Mostly concentrated | Very acidic | very high | Mostly high |
| Burnt Chicha | SPE | Very high | Very fluid | Very weak | Very thick | Mostly high | Mostly slow | Very diluted | Very basic | very high | Mostly low |
| Burnt Chicha | SPE | Mostly high | Uncertain | Mostly consistent | Very thick | Mostly high | Uncertain | Mostly diluted | Mostly acidic | Very low | Uncertain |
| Burnt Chicha | SPE | Mostly high | Very fluid | Uncertain | Very fluid | Mostly low | Mostly slow | Very diluted | Very acidic | Uncertain | Mostly high |
| Burnt Chicha | SPE | Mostly high | Very fluid | Very weak | Very thick | very high | Uncertain | Very concentrated | Very basic | Mostly high | Very low |
| Burnt Chicha | SPE | Very high | Very fluid | Very weak | Very fluid | Uncertain | very slow | Very diluted | Mostly acidic | Very low | Very low |
| Burnt Chicha | SPE | Mostly high | Mostly viscous | Very weak | Mostly thick | Very low | Uncertain | Mostly diluted | Mostly basic | Uncertain | Mostly high |
| Burnt Chicha | SPE | Very high | Very fluid | Very consistent | Mostly fluid | Mostly low | Uncertain | Mostly concentrated | Mostly acidic | Uncertain | Mostly high |
| Burnt Chicha | SPE | Mostly high | Very viscous | Mostly consistent | Mostly fluid | Mostly high | Mostly fast | Very concentrated | Uncertain | Very low | Mostly high |
| Burnt Chicha | SPE | Uncertain | Uncertain | Very consistent | Very fluid | Uncertain | Uncertain | Mostly diluted | Mostly acidic | very high | Very low |
| Burnt Chicha | SPE | Mostly high | Uncertain | Mostly consistent | Mostly fluid | Uncertain | Uncertain | Very concentrated | Mostly acidic | Uncertain | Very low |
| Burnt Chicha | SPE | Very high | Very fluid | Very consistent | Very thick | Very low | very slow | Uncertain | Uncertain | very high | Mostly high |
| Burnt Chicha | SPE | Mostly low | Mostly viscous | Very consistent | Uncertain | Mostly high | Mostly fast | Very diluted | Very basic | Very low | very high |
| Burnt Chicha | SPE | Mostly high | Mostly viscous | Uncertain | Very fluid | very high | Very fast | Uncertain | Very basic | very high | very high |
| Burnt Chicha | SPE | Mostly low | Very viscous | Very consistent | Mostly fluid | Uncertain | very slow | Mostly diluted | Mostly acidic | Mostly low | Mostly low |
| Burnt Chicha | SPE | Uncertain | Very fluid | Mostly weak | Very fluid | Very low | very slow | Mostly concentrated | Uncertain | Mostly high | Uncertain |
| Burnt Chicha | SPE | Very low | Uncertain | Uncertain | Very fluid | very high | Very fast | Very concentrated | Uncertain | Uncertain | very high |
| Burnt Chicha | CPE | Uncertain | Mostly viscous | Very consistent | Uncertain | Mostly high | Uncertain | Very diluted | Mostly basic | Mostly high | Very low |
| Burnt Chicha | CPE | Mostly high | Very fluid | Very weak | Very thick | Uncertain | Mostly slow | Very concentrated | Very basic | very high | very high |
| Burnt Chicha | CPE | Mostly low | Mostly viscous | Mostly weak | Very fluid | very high | Mostly fast | Mostly diluted | Very acidic | Uncertain | Mostly low |
| Burnt Chicha | CPE | Mostly low | Mostly viscous | Mostly weak | Mostly fluid | very high | Mostly slow | Very concentrated | Very basic | very high | Mostly low |
| Burnt Chicha | CPE | Very high | Uncertain | Mostly weak | Mostly thick | very high | Very fast | Very diluted | Very basic | Mostly low | Uncertain |
| Burnt Chicha | CPE | Mostly low | Mostly fluid | Uncertain | Very fluid | Uncertain | very slow | Mostly diluted | Mostly basic | Very low | very high |
| Burnt Chicha | CPE | Very high | Very viscous | Very consistent | Very fluid | Uncertain | very slow | Very concentrated | Very acidic | Uncertain | Very low |
| Burnt Chicha | CPE | Very low | Very viscous | Very consistent | Uncertain | Mostly low | Mostly fast | Mostly concentrated | Mostly basic | Mostly low | Very low |
| Burnt Chicha | CPE | Mostly high | Uncertain | Very weak | Very thick | Mostly high | very slow | Mostly diluted | Very acidic | Mostly low | Mostly high |
| Burnt Chicha | CPE | Very high | Mostly viscous | Very weak | Mostly thick | Very low | very slow | Mostly diluted | Mostly acidic | Uncertain | Very low |
| Burnt Chicha | CPE | Very low | Very fluid | Mostly weak | Mostly fluid | very high | Mostly fast | Mostly concentrated | Very acidic | very high | Uncertain |
| Burnt Chicha | CPE | Mostly low | Mostly viscous | Very weak | Mostly thick | Mostly low | Mostly fast | Uncertain | Mostly basic | Mostly low | Uncertain |
| Burnt Chicha | CPE | Mostly low | Uncertain | Uncertain | Mostly fluid | Very low | Very fast | Very diluted | Very basic | Mostly high | Very low |
| Burnt Chicha | CPE | Very low | Very viscous | Very consistent | Very thick | Mostly low | very slow | Uncertain | Very acidic | Mostly low | Very low |
| Burnt Chicha | CPE | Mostly low | Mostly viscous | Mostly weak | Mostly fluid | Uncertain | very slow | Very concentrated | Very acidic | very high | Mostly high |

| Beverage | Treatment | ρ (g/cm³) | μ (cP) | k (Pa.s) | n | τ (Pa) | γ (1/s) | °Bx | pH | Acid (°D) | Alc. %vol |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Burnt Chicha | CPE | Very low | Very viscous | Very weak | Uncertain | very high | Very fast | Mostly concentrated | Uncertain | very high | Very low |
| Burnt Chicha | CPE | Very high | Very fluid | Uncertain | Uncertain | Very low | Uncertain | Uncertain | Very basic | Mostly high | Mostly high |

### 3.2 Data preparation

To effectively apply the Neutrosophic C-means method, data entries in neutrosophic linguistic terms were converted into qualitative data according to the following transformation rules:

**Table 5:** Transformation rules. Source: own elaboration.

| Variable | Burnt Chicha without enzymatic treatment | Burnt Chicha with enzymatic treatment | White Chicha without enzymatic treatment | White Chicha with enzymatic treatment | Wiwis Chicha without enzymatic treatment | Wiwis Chicha with enzymatic treatment | Chonta chicha without enzymatic treatment | Chonta chicha with enzymatic treatment |
|---|---|---|---|---|---|---|---|---|
| ρ (g/cm³) | Mostly low to Uncertain (about 1 g/cm³) | Mostly low to Uncertain (about 1 g/cm³) | Mostly low to Uncertain (about 1 g/cm³) | Mostly low to Uncertain (about 1 g/cm³) | Mostly low to Uncertain (about 1 g/cm³) | Mostly low to Uncertain (about 1 g/cm³) | Mostly low to Uncertain (about 1 g/cm³) | Mostly low to Uncertain (about 1 g/cm³) |
| μ (cP) | Mostly fluid to Uncertain (about 1 cP) | Lower viscosity than untreated (about 0.5 cP) | Mostly fluid to Uncertain (about 1 cP) | Lower viscosity than untreated (about 0.5 cP) | Mostly fluid to Uncertain (about 1 cP) | Lower viscosity than untreated (about 0.5 cP) | Mostly fluid to Uncertain (about 1 cP) | Lower viscosity than untreated (about 0.5 cP) |
| k (Pa.s) | Mostly weak to Uncertain (about 0.001 Pa.s) | Lower consistency than without treatment (around 0.0005 Pa.s) | Mostly weak to Uncertain (about 0.001 Pa.s) | Lower consistency than without treatment (around 0.0005 Pa.s) | Mostly weak to Uncertain (about 0.001 Pa.s) | Lower consistency than without treatment (around 0.0005 Pa.s) | Mostly weak to Uncertain (about 0.001 Pa.s) | Lower consistency than without treatment (around 0.0005 Pa.s) |
| n | Mostly Fluent to Uncertain (about 1) | Mostly Fluent to Uncertain (about 1) | Mostly Fluent to Uncertain (about 1) | Mostly Fluent to Uncertain (about 1) | Mostly Fluent to Uncertain (about 1) | Mostly Fluent to Uncertain (about 1) | Mostly Fluent to Uncertain (about 1) | Mostly Fluent to Uncertain (about 1) |
| τ (Pa) | Mostly low to Uncertain (about 0.1 Pa) | Lower shear stress than untreated (about 0.05 Pa) | Mostly low to Uncertain (about 0.1 Pa) | Lower shear stress than untreated (about 0.05 Pa) | Mostly low to Uncertain (about 0.1 Pa) | Lower shear stress than untreated (about 0.05 Pa) | Mostly low to Uncertain (about 0.1 Pa) | Lower shear stress than untreated (about 0.05 Pa) |
| γ (1/s) | Mostly slow to Uncertain (about 0.1 $s^{-1}$) | Mostly slow to Uncertain (about 0.1 $s^{-1}$) | Mostly slow to Uncertain (about 0.1 $s^{-1}$) | Mostly slow to Uncertain (about 0.1 $s^{-1}$) | Mostly slow to Uncertain (about 0.1 $s^{-1}$) | Mostly slow to Uncertain (about 0.1 $s^{-1}$) | Mostly slow to Uncertain (about 0.1 $s^{-1}$) | Mostly slow to Uncertain (about 0.1 $s^{-1}$) |
| °Bx | Mostly concentrated to Very concentrated (between 12 °Bx and 18 °Bx) | Mostly concentrated to Very concentrated (between 12 °Bx and 18 °Bx) | Mostly diluted to Mostly concentrated (between 5 °Bx and 12 °Bx) | Mostly diluted to Mostly concentrated (between 5 °Bx and 12 °Bx) | Mostly diluted to Mostly concentrated (between 5 °Bx and 12 °Bx) | Mostly diluted to Mostly concentrated (between 5 °Bx and 12 °Bx) | Mostly diluted to Mostly concentrated (between 5 °Bx and 12 °Bx) | Mostly diluted to Mostly concentrated (between 5 °Bx and 12 °Bx) |
| pH | Mostly Acid to Uncertain (between 3.0 and 4.0) | Mostly Acid to Uncertain (between 3.0 and 4.0) | Mostly acidic to Uncertain (between 3.5 and 4.5) | Mostly acidic to Uncertain (between 3.5 and 4.5) | Mostly acidic to Uncertain (between 3.5 and 4.5) | Mostly acidic to Uncertain (between 3.5 and 4.5) | Mostly acidic to Uncertain (between 3.5 and 4.5) | Mostly acidic to Uncertain (between 3.5 and 4.5) |
| Acidity (°D) | Mostly high to Very high (between 0.6°D and 1.2°D) | Mostly high to Very high (between 0.6°D and 1.2°D) | Mostly low to Mostly high (between 0.2°D and 0.6°D) | Mostly low to Mostly high (between 0.2°D and 0.6°D) | Mostly low to Mostly high (between 0.2°D and 0.6°D) | Mostly low to Mostly high (between 0.2°D and 0.6°D) | Mostly low to Mostly high (between 0.2°D and 0.6°D) | Mostly low to Mostly high (between 0.2°D and 0.6°D) |
| Alc. % vol. | Mostly low to Uncertain (between 1% vol and 2% vol) | Mostly low to Uncertain (between 1% vol and 2% vol) | Mostly low to Uncertain (between 1% vol and 2% vol) | Mostly low to Uncertain (between 1% vol and 2% vol) | Mostly low to Uncertain (between 1% vol and 2% vol) | Mostly low to Uncertain (between 1% vol and 2% vol) | Mostly low to Uncertain (between 1% vol and 2% vol) | Mostly low to Uncertain (between 1% vol and 2% vol) |

- ρ (g/cm³) - Density: "Very low" to "Mostly low" could be considered as "Uncertain", so (0.50,0.50,0.50).
- μ (cP) - Viscosity: "Very fluid" to "Mostly fluid" could range from "Moderately good" to "Good", so (0.60,0.35,0.40) to (0.80,0.15,0.20).
- k (Pa.s) - Consistency Index: "Very weak" to "Mostly weak" can be assigned as "Moderately poor", so (0.40,0.65,0.60).

- n - Flow Index: "Mostly fluid" aligns with "Moderately good", so (0.60,0.35,0.40).
- τ (Pa) - Shear Stress: "Very high" to "Mostly high" could translate to "Very Good" or "Excellent", so (0.90, 0.1, 0.1) to (1.0,0,0).
- γ (1/s) - Rate of Deformation: "Mostly slow" would map to "Moderately poor", so (0.40,0.65,0.60).
- °Bx - Brix Degrees: "Very concentrated" could be considered "Excellent", so (1.0,0,0).
- pH: "Very acidic" to "Mostly acidic" could be "Poor", so (0.30,0.75,0.70).
- Acidity (°D): "Very high" to "Mostly high" can be viewed as "Very Good", so (0.90, 0.1, 0.1).
- Alc. % vol.: "Mostly high" could be assigned as "Good", so (0.80,0.15,0.20).

**Table 6**: Sample of data preparation. Source: own elaboration.

| Beverage | Treatment | ρ (g/cm³) | μ (cP) | k (Pa.s) | n | τ (Pa) | γ (1/s) | °Bx | pH | Acidity (°D) | Alc. % vol |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Burnt Chicha | SPE | (0.5, 0.5, 0.5) | (0.5, 0.5, 0.5) | (0.5, 0.5, 0.5) | (0.6, 0.35, 0.4) | (0.9, 0.1, 0.1) | (0.4, 0.65, 0.6) | (0.5, 0.5, 0.5) | (0.3, 0.75, 0.7) | (0.9, 0.1, 0.1) | (0.8, 0.15, 0.2) |
| Burnt Chicha | SPE | (0.5, 0.5, 0.5) | (0.5, 0.5, 0.5) | (0.5, 0.5, 0.5) | (0.5, 0.5, 0.5) | (0.9, 0.1, 0.1) | (0.4, 0.65, 0.6) | (0.5, 0.5, 0.5) | (0.5, 0.5, 0.5) | (0.9, 0.1, 0.1) | (0.5, 0.5, 0.5) |
| Burnt Chicha | SPE | (0.5, 0.5, 0.5) | (0.5, 0.5, 0.5) | (0.5, 0.5, 0.5) | (0.5, 0.5, 0.5) | (0.9, 0.1, 0.1) | (0.5, 0.5, 0.5) | (0.5, 0.5, 0.5) | (0.3, 0.75, 0.7) | (0.5, 0.5, 0.5) | (0.5, 0.5, 0.5) |
| Burnt Chicha | SPE | (0.5, 0.5, 0.5) | (0.5, 0.5, 0.5) | (0.5, 0.5, 0.5) | (0.5, 0.5, 0.5) | (0.5, 0.5, 0.5) | (0.4, 0.65, 0.6) | (0.5, 0.5, 0.5) | (0.3, 0.75, 0.7) | (0.5, 0.5, 0.5) | (0.8, 0.15, 0.2) |

## 3.3 Algorithm

- Selection of the number of clusters: Based on the variety of treatments and types of beverages present in the data, start with a moderate number, such as 4 clusters, and adjust if necessary in future iterations.
- Initialization of membership degrees: Initialize the membership degrees of each data point for each cluster randomly, ensuring that the sum of the degrees of truth, indeterminacy, and falsehood for each point and cluster equals 1.
- Fuzzification Constant (m): 2
- Initialization of Cluster Centers: k-means++ algorithm with Euclidean distance
- Termination Criteria: Improvement in the objective function less than 0.001, maximum of 100 iterations
- Additional Parameters: m: 2 and δ: 0.1

## 4 Application of the algorithm and interpretation

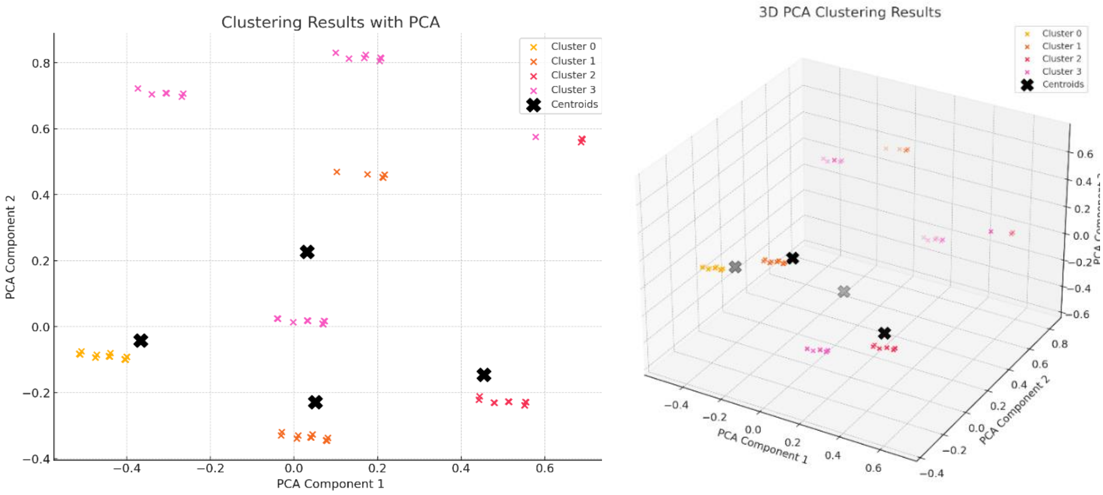


**Figure 2**: Clusters plotting using Principal Component Analysis to reduce dimensionality and plot the data points in a 2D and 3D space, colored according to their cluster. Source: Developed by the author.

In the graphs, each point represents a data point and is colored according to the cluster it belongs to. The black 'X'-shaped markers represent the centroids. Here is the cluster analysis by their distribution: Cluster 0: 39 points, Cluster 1: 31 points, Cluster 2: 27 points, Cluster 3: 39 points. As can be seen, the distribution of points is quite balanced among the clusters, with a slight variation in sizes, which is desirable in many clustering contexts. The Silhouette Score is 0.357, indicating a reasonable level of separation and cohesion between the clusters. A value closer to 1 indicates ideal separation, while values closer to 0 or negative indicate overlapping or poorly defined clusters. The score of 0.357 suggests that the clusters are moderately well-defined.

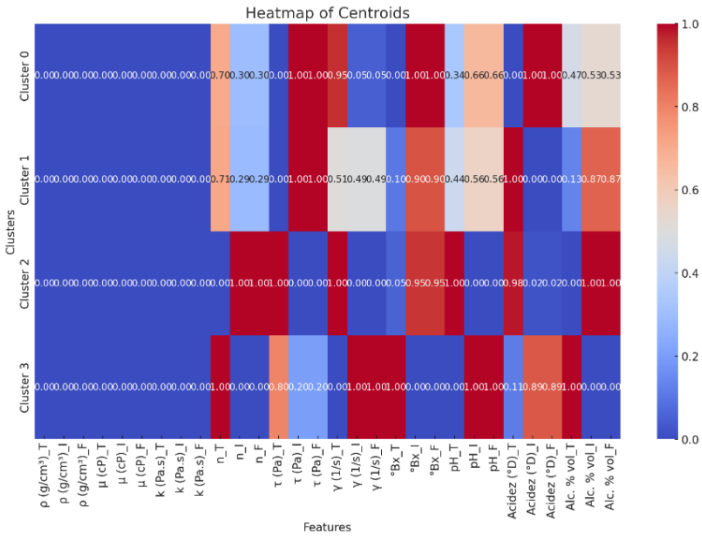


**Figure 3**: Heatmap of the Centroids. Source: Developed by the author.

The heatmap displays the normalized characteristics of the centroids for each cluster. Darker cells indicate lower values, while lighter cells represent higher values. As observed, the physicochemical properties have significantly different values, which influences the formation of clusters.

Observing the averages of each attribute that defines the centroids, it can be stated that the values for ρ (g/cm³), μ (cP), and k (Pa.s) are uniform across all clusters, indicating that these properties do not vary significantly between clusters or are not determinants in the formation of clusters under the current model.

Variables such as n and τ (Pa) show more significant variation between clusters, indicating differences in the physical properties of the beverages that impact their grouping. The values related to °Bx, pH, Acidity (°D), and Alc. % vol also shows variations associated with differences in the chemical composition or the manufacturing process of the beverages. The analysis shows that the clusters formed reflect variations in certain physical and chemical properties of the beverages. The evaluation using the Silhouette Score reveals that the clusters are reasonably well-defined, although there is room for improvement in the separation between them.

Next, a violin plot is presented that shows the distribution of the first two principal components for each cluster. These visualizations are useful for understanding how points are dispersed within each cluster and for comparing variability between clusters.

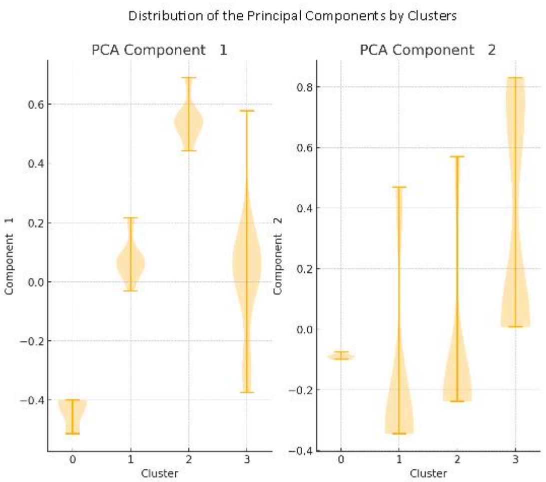


**Figure 4**: Violin plots for clusters. Source: own elaboration.

As observed in Figure 4:

- ❖ Component 1: Some clusters have a wider distribution, indicating a greater dispersion of data, while others are narrower.
- ❖ Component 2: Similar to Component 1, variability and dispersion vary among the clusters.

These differences highlight distinctive characteristics between groups, given by the manufacturing process that imparts different properties to each beverage. Finally, for a hierarchical view of how the clusters might be related, Figure 5 shows a dendrogram.

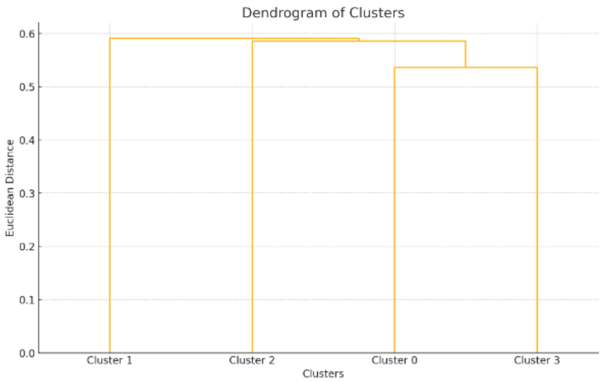


**Figure 5:** Dendrogram. Source: own elaboration.

The dendrogram shows clusters 1 and 2 as being closest to each other, indicated by the lower height of the linkage that connects them (low Euclidean distance). This demonstrates that the data points in these two clusters are more similar to each other compared to points in other clusters. Regarding the merging of Cluster 1 and Cluster 2 with Cluster 0: After Cluster 1 and Cluster 2, the next to join in the hierarchy is Cluster 0. The height at which Cluster 0 joins the group formed by Cluster 1 and Cluster 2 is noticeably higher than the height at which these two clusters join together. This indicates that Cluster 0 while sharing some similarities with Clusters 1 and 2, is generally less similar to these clusters than they are to each other. Finally, Cluster 3 joins the group formed by the other three clusters at the highest point on the dendrogram. This indicates that Cluster 3 is the least similar to any of the other clusters.

The dendrogram reveals a data structure where Cluster 1 and Cluster 2 represent subgroups within a broader category of data due to their proximity. Cluster 0 and especially Cluster 3 contain data points that are significantly different and represent wider variations within the dataset. The great height at which Cluster 3 joins the rest suggests substantial differences in the data characteristics of this cluster compared to the other clusters.

## 5 Discussion

Table 3 presents the evaluation of each treatment using measurement instruments. These were conducted at a temperature of 17.9°C with a relative humidity of 59.6%, where yuca and chonta chichas containing enzymatic preparations stood out, yielding the following results: burned chicha with a density of $\rho$=1.0319 g/cm³, apparent viscosity $\mu$= 0.18 cP, consistency index k= 0.0138 Pa.s, flow behavior n= 0.0004, shear stress $\tau$= 0.0138 Pa, and deformation rate $\gamma$=77 (1/s). Followed by white chicha with a density $\rho$= 1.0124g/cm³, apparent viscosity $\mu$=1.13 cP, consistency index k=0.1072 Pa.s, flow behavior n=0.0305 adi, shear stress $\tau$= 0.1203 Pa, and deformation rate $\gamma$=50 (1/s).

Subsequently, for wiwis chicha, it presents a density $\rho$=1.0280 g/cm³, apparent viscosity $\mu$=2.92 cP, consistency index k=0.2203 Pa.s, flow behavior n=0.0021 adi, shear stress $\tau$=0.2223 Pa, and deformation rate $\gamma$=76 (1/s). Finally, chonta chicha has a density $\rho$=1.0207 g/cm³, apparent viscosity $\mu$=1.13 cP, consistency index k=0.0122 Pa.s, flow behavior n=0.0020 adi, shear stress $\tau$= 0.0123 Pa, and deformation rate $\gamma$=50 (1/s).

Thus, fermented beverages of yuca and chonta exhibited rheological indices characteristic of a non-Newtonian fluid with pseudoplastic properties (n>0). Therefore, the presence of enzymes in the chichas positively influenced their production, improving the quality and sensory characteristics of the beverages; specifically, increasing the content of soluble solids for better fermentation processes.

When comparing these data with the results obtained with the Neutrosophic C Means algorithm compared to instrumental data, it can be said that according to experts, the data presented show:

- ❖ Different properties of fermented beverages, with a specific focus on yuca and chonta chichas with enzymes.
- ❖ Burned Chicha: Properties such as high density and low viscosity, indicate a more liquid and less

viscous flow.

- White Chicha: Lower density compared to Burned Chicha, but with significantly higher viscosity and higher values of consistency, shear stress, and a slower flow.
- Wiwis and Chonta Chicha: Both exhibit non-Newtonian fluid characteristics with pseudoplastic properties. Notably, Wiwis Chicha has a relatively high viscosity and high shear stress compared to Chonta Chicha.

The clusters identified through the analysis reflect groupings based on characteristics similar to those reported instrumentally, although the specific measurements in clustering are neutrosophic representations and not absolute values. Each cluster represents a group with similar physicochemical properties. The distribution of chichas in clusters shows similarities with the characteristics highlighted by the instruments, such as density and viscosity. For example, chichas with higher density and viscosity might be grouped, reflecting their behavior under controlled conditions.

Instrumental data suggest that the addition of enzymes improves important characteristics such as consistency and flow ability. Clusters reflect these improvements, and it is possible to identify which clusters correspond to chichas treated with enzymes. Neutrosophic analysis reveals more subtle variations in degrees of truth, indeterminacy, and falsehood that are not captured by direct instrumental measurements.

Thus, the comparison between instrumental results and those obtained through neutrosophic clustering helps validate or refine the understanding of the properties of the beverages. While instrumental measures provide concrete data under specific conditions, clustering reveals broader patterns or relationships between different samples and conditions.

## 6 Conclusion

It can be said that the use of enzymatic preparations in yuca and chonta chichas has significantly improved the rheological characteristics of the beverages, making them more fluid and enhancing their texture and smoothness on the palate. This suggests that enzymes help break down structural components of yuca and chonta, facilitating a more desirable texture profile and a better sensory experience.

Traditionally, some fermented beverages may require chewing to initiate fermentation. The use of enzymes not only improves quality but also modernizes and sanitizes the production process by eliminating the need for chewing, which is crucial for product acceptance in broader markets and for complying with food safety and hygiene regulations.

The chichas analyzed exhibit typical non-Newtonian fluid behaviors of a pseudoplastic type. This is relevant for the food industry, as these properties affect the handling, processing, and sensory qualities of the beverages. The ability to predict and control this behavior is crucial for ensuring the consistency and quality of the final product.

The application of advanced rheological techniques, such as the use of concentric cone geometries and parallel plate setups with rotational rheometers, allows for precise evaluation of properties such as viscosity and density. This precision is vital to ensure that modifications in the production process (such as the addition of enzymes) have the desired effect and to maintain strict quality control.

The results point to the need to continue exploring and optimizing the use of enzymes in the production of traditional fermented beverages. Future research could focus on comparing different types of enzymes and their concentrations to determine the most effective ones for each type of beverage.

Standardization of processes and adaptation to modern regulations can help expand the market for these traditional beverages, improving not only quality but also acceptability in different cultural and geographic contexts.

These studies demonstrate the value of combining modern scientific methods with ancestral traditions, which can result in the preservation and innovation in the production of traditional beverages with significant improvements in quality and market acceptance.

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