YAM-BASED VODKA: INNOVATIVE DISTILLATION FROM *DIOSCOREA BULBIFERA* – PROCESS AND CHARACTERIZATION

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Yam (Dioscorea spp.) is an emblematic tuber of the Colombian Caribbean region, historically linked to the arrival of enslaved people on the Caribbean coast. Colombia stands out worldwide for its technological advances in yam cultivation, ranking among the countries with the best yield per hectare, 90% of the national production comes from this region. However, the high perishability, elevated temperatures, lack of transportation infrastructure, and high transportation costs increase losses and reduce profitability. Moreover, the overproduction of tubers has impoverished both farmers and consumers, affecting its consumption in the local diet. In several cultures, local foods such as wheat, potatoes, or sugarcane are used to produce distilled alcoholic beverages. This study presents results on the use of yam as a raw material for a distilled beverage like vodka, which could increase its value. To achieve this, raw yam flour, produced by women from the Afro Yam Gastronomic Association of San Cayetano (Bolívar, Colombia), was hydrolysed, and the mash was fermented at 23°C with two commercial strains of Saccharomyces cerevisiae. After fermentation, a simple batch distillation was carried out in a copper and glass still. Temperature, pH, Brix degrees, and methanol and ethanol contents were evaluated. A sensory analysis using an electronic tongue showed that this alcoholic beverage could be a viable alternative to add value to yam and generate income for the rural community.

1. Introduction

Yam (Dioscorea spp.), a staple crop of significant cultural importance in the Colombian Caribbean, is traditionally consumed in various forms, primarily boiled, fried, or mashed. While its historical connection to Afro-descendant communities through the transatlantic slave trade is undeniable, this study focuses on exploring innovative processing methods to enhance its economic value and contribute to sustainable development in rural areas (Morales Bedoya, 2010). Current research highlights the potential of diverse starch-rich sources for alcoholic beverage production, including potatoes, cassava, and cereals (Jones, 2018; Smith, K., & Brown, 2020), this raw material is an alternately from the sugar cane used for the production of the typical Colombian distillate called "aguardiente". However, the application of yam as a base for distilled spirits, particularly in the context of fostering local economic development, remains relatively unexplored. Existing technologies for starch hydrolysis and fermentation provide a foundation for this investigation (Garcia, L., Rodriguez, M., & Perez, 2019), but the unique characteristics of yam starch, including its gelatinization properties and varietal differences (Espitia, J., Salcedo, J., & Garcia, 2016), necessitate tailored approaches. This study aims to address this gap by developing a vodka-like alcoholic beverage from locally cultivated yam varieties, specifically targeting the criollo yams prevalent in the Montes de María a subregion close to Cartagena de Indias.

This research distinguishes itself by integrating traditional agricultural practices with modern engineering principles to create a value-added product that aligns with community values and market demands. Unlike conventional yam processing, which primarily focuses on direct consumption, this project seeks to diversify yam utilization and generate new economic opportunities. Furthermore, by focusing on a distilled product, this work aims to create a product with longer |+stability and higher value per unit than traditional yam products. The selection of San Cayetano, a district of San Juan Nepomuceno, a municipality of Montes de Maria as the study site is driven by its rich yam cultivation heritage and the need for sustainable economic alternatives. This research will contribute to the understanding of yam starch conversion and fermentation processes, providing a foundation for further development and adoption of similar technologies in other yam-producing regions.

2. Materials and methods

2.1 Characterization of Yam Flour

The yam flour was purchased from the Afro-Yam Gastronomic Association of San Cayetano (Bolívar, Colombia), a group of women producers of yam and cassava flour. Yam flour was obtained by producers through sun drying and milling the dried tuber. Its composition was analyzed, and the results are shown in Table 1.

Table 1: Composition of yam flour

Parameters	Methods	Results	Units
Moisture	Gravimetry – Dried in hoven a 105°C	12.9	g/100g
Total solid	AOAC 925.10. Ed 21:2019 (Gravimetry)	87.1	g/100g
Total carbohydrates	Calculated by difference	81.8	g/100g
Total protein	ISO 1871:2009 (Kjeldahl)	3.3	g/100g
Total fat	(Soxhlet ethereal extraction)	0.3	g/100g
Total fiber	(Hydrolysis acid, alkaline and calcination)	0.6	g/100g
Ash	(Gravimetry - calcination at 600°C)	1.7	g/100g

2.2 Enzymatic Hydrolysis

For enzymatic hydrolysis of yam flour, tap water directly from the Cartagena de Indias water supply (Colombia) was used. Thermostable alpha-amylase and glucoamylase from LD Carlson Company (Kent, OH) were used for starch hydrolysis like in the work of Mason *et al.*, 2023). Alpha-amylase is a thermostable powdered enzyme used to hydrolyze long-chain yam starch into dextrin. A dosage of 5.4 g was used for 3.5 L of a yam flour mixture (15%) and water, which was left for 1 hour at 95°C.
Glucoamylase is an enzyme used for the hydrolysis of short-chain dextrin into fermentable sugars. A dosage of 3.6 g was used for 3.5 L, and it was left for 1 hour at 60°C. After these 2 processes the wort was obtained and was ready for the fermentation process.

2.3 Fermentation of wort

To the wort container, 0.63 g of Springferm (Fermentis Lesaffre, Marcq-en-Baroeul Cedex, France) and 0.63 g of diammonium phosphate as a nitrogen source for the yeast were added. The following commercial yeasts were used: Red Star Premier Classique (PC) at a dose of 0.26 g/L, a yeast selected for wine production, and SafBrew HA-18 (HA-18) (Fermentis Lesaffre, Marcq-en-Baroeul Cedex, France) at a dose of 1.6 g/L, a yeast selected for high-alcohol beer production, each previously activated in 0.5 L of wort. The fermentation process was carried out over 7 days at 23°C.

2.4 Distillation of fermented wort

A simple distillation was carried out using a 5 L copper still (Maritas Stills, S.L. Palmeira, Ribeira - A Coruña, Spain) and a laboratory glass simple distiller with a 100 mL flask volume.

2.5 Ethanol content

An alcoholmeter was used to estimate the alcohol content of the alcoholic beverages. The alcoholmeter is calibrated for 20°C to determine the alcohol percentage in distilled liquors (AOAC Method 957.03).(Icontec, 1997)

2.6 Methanol content

Methanol content was analyzed using gas chromatography coupled with mass spectrometry, following the NTC 4118:1997 method (Icontec, 1997).

2.7 Electronic Tongue

The analysis was performed using the SA402B Taste Sensing System (INSENT Japan) electronic tongue, which is composed of a system of electrochemical sensors. These sensors have different types of artificial lipid membranes to determine the quality of food and beverages in terms of taste variability, following the same logic of human perception. The electronic tongue is equipped with 5 sensors (taste sensors) capable of responding similarly to molecules characterized by the same taste note (Table 2) (Liu *et al.*, 2020). For the analysis of these

distillates, the ethanol content was adjusted to 2.5% to ensure equal values for all samples, and three replicas were made for each sample.
To validate the method and the discriminative capacity of the electronic tongue, two different distillations were performed: one using a copper alembic and the other in a 100 mL laboratory glass distiller.
Electronic tongue analysis was performed as reported by the work of M. Laureati, S. Buratti, A. Bassoli, G. Borgonovo, 2010).
The data obtained from the electronic tongue analysis were processed using Principal Component Analysis (PCA) with XLSTAT statistical software (Liu *et al.*, 2020).

Table 2: Electronic tongue sensors and corresponding taste

Sensors	Taste Information from Relative Value	Taste Information from CPA Value
AAE	Umami	Richness
CT0	Saltiness	None
CA0	Sourness	None
C00	Bitterness	Aftertaste Bitterness
AE1	Astringency	Aftertaste Astringency

3. Results and discussion

The composition of yam flour was moisture 12.9 g/100g, total solids 87.1 g/100g, total carbohydrates 81.8 g/100 g, total proteins 3.3 g/100 g. The low protein content makes supplementation with nitrogen sources necessary to meet the yeast's needs for the alcoholic fermentation.

Figure 1 shows the results related to the determination of Brix degrees over time during the saccharification process with the addition of α-amylase for 1 hour at 95°C and glucoamylase for 1 hour at 60°C. An increase in soluble solids can be observed due to the action of the enzymes; these values start form 2.5 °Brix and after 1 hour increase to 22.07 °Brix. Subsequently, the temperature is reduced to 60°C, and glucoamylase is added, reaching 23.27 °Brix.

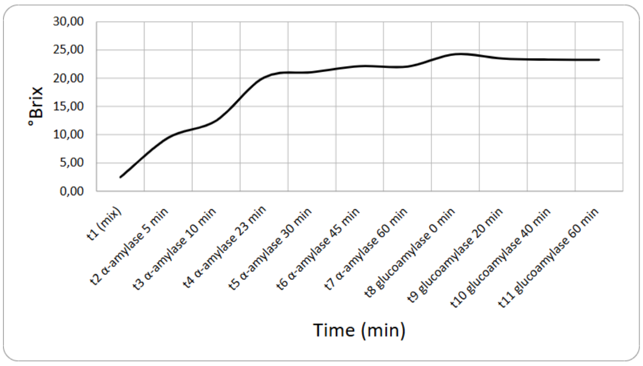

Figure 1: Brix degrees during the liquefaction and saccharification process with the addition of α-amylase and glucoamylase.

In Figure 2, the evolution of the Brix degrees during fermentation using two commercial yeasts, Premier Classique (PC) and SafBrew HA-18 (HA-18), is presented. In the case of the PC yeast, a continuous decrease is observed up to a value of 5.7°Brix at 192 hours. For the evolution observed with the HA-18 yeast, which also contains glucoamylase, there is a decrease in the Brix degrees until the third day and then an increase, probably due to the glucoamylase content; finally, it continues to decrease to reach a final value of 5.8°Brix.

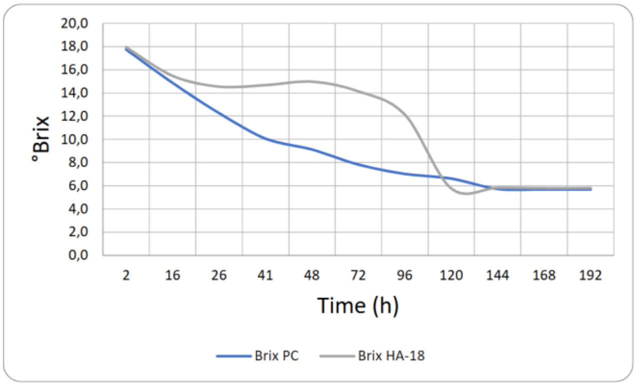

Figure 2: Brix degrees during the fermentation process using two commercial yeasts: Premier Classique (Brix PC) in blue and SafBrew HA-18 (Brix HA-18) in grey line.

The monitoring of the Brix degrees during the hydrolysis and fermentation process is a simple method to track the fermentation process with different commercial yeast. The pH was also monitored at all stages of the process, as shown in Figures 3 and 4. In Figure 3, it can be observed that the pH was constant at 6.13 during the α-amylase action time. After that, it reduces to 5.93 at this value until fermentation begins, but after 12 hours, the pH drops to 5.2 for the PC yeast, and to 5.1 for the HA-18 yeast. For the PC yeast, the pH remains relatively constant around values of 4.9–5 throughout the process, and only in the last two days does it drop to a value of 4.2. For the HA-18 yeast, the pH remains constant around values of 5.1 – 5.2 throughout the process, and only in the last two days does it drop to 4.8.

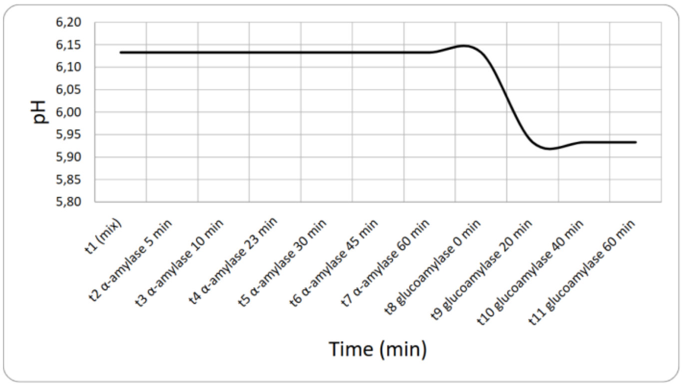

Figure 3: pH during the liquefaction and saccharification process of yam wort.

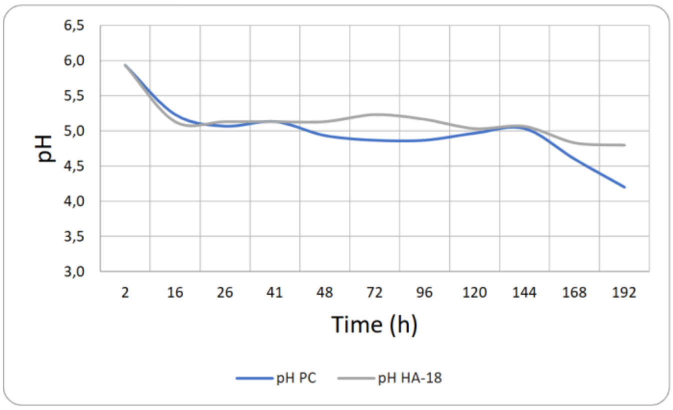

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Figure 4: pH during the fermentation process using two commercial yeasts: Premier Classique (pH PC) in blue and SafBrew HA-18 (pH HA-18) in grey line.

The pH monitoring is also a simple measurement to verify that enzymatic hydrolysis and fermentation are carried out under the appropriate conditions (Arroyo-López *et al.*, 2009; Walker and Stewart, 2016), and to ensure that undesired processes such as acetic acid production do not occur. The reducing sugar method (DNS) was used, which involves sugars with their intact carbonyl group (functional group) of the anomeric carbon (Martinez Trujillo, 2022), which can be an aldehyde or ketone, such as glucose and maltose, sugars derived from starch hydrolysis and that can be fermented by yeasts. The results obtained with this method were 3.2 ± 0.04 g/L for the hydrolyzed wort before fermentation, 0.55 ± 0.05 g/L for the PC yeast, and 0.3 ± 0.04 g/L for the HA-18 yeast. The total acidity was 0.075 ± 0.05 g/L for the hydrolyzed wort before fermentation, 0.9 ± 0.1 g/L for the Premier Classique yeast, and 2.2 ± 0.4 g/L for the SafBrew HA-18 yeast. These values are much lower than the reference values of NTC 1588:2004 (Icontec, 2004) for alcoholic beverages such as wine, expressed in g of tartaric acid/L. The volatile acidity was 0.66 ± 0.2 g/L for the PC yeast and 1.23 ± 0.4 g/L for the HA-18 yeast. These values are lower; only the HA-18 yeast is at the limit (1.2 g/L) of the reference value of NTC 1588:2004 (Icontec, 2004) for alcoholic beverages such as wine, expressed in g of acetic acid/L. The ethanol content was 11% v/v for the PC yeast and 10% v/v for the HA-18 yeast, and the methanol content was 31.8 mg/L in the distillate obtained with both yeasts, values lower than the 100 mg/L maximum accepted value in NTC 305:1999 (Icontec, 1999).

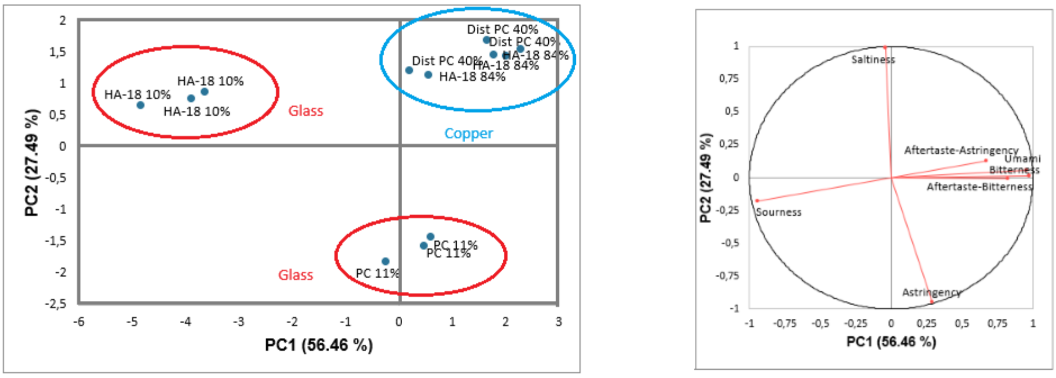

Figure 5: Score and loading plot of the Principal Component Analysis (PCA) of yam distillate samples distilled in copper still (Dist PC 40% and HA-18 84%) in blue circle and distilled in glass (PC 11% and HA-18 10%) in red circle.

The electronic tongue data were elaborated by Principal Component Analysis (PCA). Principal Component Analysis (PCA) is a widely employed statistical technique for dimensionality reduction and feature extraction. It operates by orthogonally transforming a set of possibly correlated variables into a set of linearly uncorrelated variables, termed principal components. These components are ordered by the amount of variance they explain in the original dataset, with the first principal component capturing the maximum variance, and subsequent components capturing progressively less. In Figure 5 is shows the score plot and loading plot of the two principal components (PCs) explaining 83.95% of the total variance. The HA-18 10% sample (HA-18 yeast distilled in glass in the red circle) is discriminated against in the negative part of PC1, which explains 56.46% of the total variance, and it is characterized by sourness and recognized as less bitter and astringent. The second principal component discriminates the glass-distilled PC11% from samples distilled in copper (the HA-18 84% and PC 40%) in blue circle. In particular, the PC 11% samples are characterized by astringency, while the copper-distilled samples (HA-18 84% and PC 40%) are perceived as more bitter and are characterized by umami taste and by bitterness and astringency aftertastes. The ability of the electronic tongue to discriminate glass-distilled samples based on the yeast used was demonstrated, although no significant differences were detected in the copper-distilled samples.

4. Conclusions

It was demonstrated that yam can be used as a substrate to produce fermented beverages, which, after being distilled, generate alcoholic products with higher added value and a higher selling price than the unprocessed product. An efficient methodology was developed for the enzymatic hydrolysis of starch, and two commercial yeast strains were evaluated, observing different fermentation rates between them. In any step of the production of the wort was monitoring the Brix degree and pH, reducing sugar was 3.2 ± 0.04 g/L for the hydrolyzed wort before fermentation, 0.55 ± 0.05 g/L for the PC yeast, and 0.3 ± 0.04 g/L for the HA-18 yeast at the end of fermentation. Total acidity was 0.075 ± 0.05 g/L for the hydrolyzed wort before fermentation, 0.9 ± 0.1 g/L for the PC yeast, and 2.2 ± 0.4 g/L for the SafBrew HA-18 yeast. Volatile acidity was 0.66 ± 0.2 g/L for the PC yeast and 1.23 ± 0.4 g/L for the HA-18 yeast. Ethanol content was 11% v/v for the PC yeast and 10% v/v for the HA-18 yeast, and the methanol content was 31.8 mg/L in the distillate obtained with both yeasts. Furthermore, it was confirmed that the electronic tongue is a useful, simple, and objective tool to distinguish between yam distillates processed in glass and in copper stills. In the future it was possible to produce an aromatized vodka with local herbs and make a sensory evaluation of the products.

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