ISBN: 978-628-96613-3-0. ISSN: 2414-6390. Digital Object Identifier: https://dx.doi.org/10.18687/LACCEI2026.1.1.875

Molasses-to-Rum Conversion: An Industrial Framework for Diversification and Competitive Growth

Fabricio Flores[1,1]; Allison Rodriguez[1,2]
Faculty Mentor: Raúl Figueroa, MSc[1,3]; Ramón Ordoñez, PhD[1,4]; Lessy Salmeron, MSc[1,5]
[1] *Universidad Nacional Autónoma de Honduras, Francisco Morazán, Honduras*
fgflores@unah.hn, asrodriguezv@unah.hn, rfigueroa@unah.edu.hn, ordonez.r08@gmail.com , lessys.salmeron@unah.edu.hn

Abstract: ***This study evaluates the technical and industrial feasibility of producing rum from sugarcane molasses in Honduras as a strategy for agro-industrial diversification and circular economy integration. Laboratory-scale fermentation, distillation, and accelerated aging were experimentally evaluated using molasses as the primary substrate. Fermentation achieved an ethanol yield of 77% of theoretical conversion, while batch distillation produced a heart fraction with 42% v/v ethanol. To assess industrial scalability, the process was modeled in Aspen Plus, integrating fermentation, multistage distillation, and energy balances. Simulation results indicate that an industrial plant processing 9,650 $t \cdot y^{-1}$ of molasses could produce approximately 2.5 million liters of rum annually. Sensitivity analyses of distillation columns were used to examine the influence of reflux ratio and feed stage on ethanol recovery and separation performance. A preliminary techno-economic assessment indicates that molasses valorization into rum is technically feasible and economically promising for the Honduran industry, while accelerated aging results suggest potential for rapid sensory differentiation under controlled laboratory conditions.***

Keywords: ***rum production, molasses valorization, Aspen Plus simulation, accelerated aging, circular economy.***

I. Introduction

The rum industry holds significant global relevance, particularly in tropical regions where sugarcane is abundant. In Honduras, molasses is traditionally used for animal feed or exported without added value, despite its high concentration of fermentable sugars [1]. In this sense, a technical and economic pathway to repurpose molasses into competitive rum products could create new economic opportunities while contributing to industrial diversification and circular economy development.

This project aims to develop a scalable, cost-effective rum production model based on strategic molasses transformation into high-value alcoholic products integrating experimental fermentation and distillation practices with computational modeling to design a lab-scale rum production framework. Engineering tools such as Aspen Plus were employed to simulate industrial scaling scenarios, assess feasibility across multiple production levels, evaluate fermentation performance, and estimate theoretical ethanol yields.

II. Need Statement

Despite Honduras's robust sugarcane industry, which produces over 5.4 million metric tons annually, molasses remains largely underutilized and is primarily directed toward animal feed, fertilizer production, or low-value export. With an average yield of 30–40 kg of molasses per metric ton of processed cane, national production exceeds 189,000 metric tons, yet lacks industrial transformation into value-added products [2]. This represents a missed opportunity, as molasses contains approximately 50% fermentable sugars, making it an ideal substrate for ethanol and rum production [3].

Although rum production has been industrialized in Caribbean countries since the 18th century, Honduras has not developed a specialized sector for this purpose. Currently, molasses is exported at approximately US$0.203 per kilogram, while its conversion into rum could increase its market value by up to 100 times [4]. Given that 62.9% of Honduran households live in poverty, developing a rum production sector could contribute to local economic activity through value addition, employment generation, and industrial diversification [5]. In this context, the Latin American craft rum market, valued at US$96.1 million in 2024, is projected to reach US$130.5 million by 2030 [6].

Laboratory results and Aspen Plus simulations indicate a potential yield of 479.63 L of ethanol per ton of molasses using *Saccharomyces cerevisiae*, supporting the valorization of this byproduct. This study evaluates rum production from sugarcane molasses through an integrated experimental and simulation-based approach within a circular economy framework. Rather than relying on traditional long-term barrel aging, the process incorporates a **reflux-based accelerated aging technique**, enabling the development of characteristic rum profiles within significantly shorter processing times, while maintaining process efficiency and scalability.

III. Market background

Market analysis shows distinct consumer preferences by aging profile, with intermediate segments favoring rums aged 4–7 years [7].

A. Molasses Available for production

Molasses availability is anchored in the annual output of 23,100 metric tons from *"Compañía Azucarera Tres Valles"* [2]. A redistribution model proposes allocating 41.77% of this molasses to rum production, reducing export, fertilizer, and livestock allocations proportionally as shown in Table 1 [1]. This strategy ensures that rum production integrates into the national economy without compromising existing uses.

Table 1
ECONOMIC SECTORS OF MOLASSES

Economic sector	Current Percentage	Projected Percentage
Export	58.31%	30.30%
Fertilizers	21.23%	11.47%
Livestock	20.46%	11.47%
Rum	0%	41.77%

B. *Rum Demand*

Demand projections further validate the initiative. With an estimated per capita rum consumption of 3.2 liters annually, Honduras faces a national demand of 33.6 million liters in 2025 [1]. Incorporating a 25% export target raises total production requirements to 42 million liters. This gap highlights the need for expanded production capacity and positions Honduras to meet both domestic and regional demand through strategic molasses valorization [8].

IV. PROCESS FOUNDATIONS

The Honduran sugar industry generates several coproducts of industrial relevance beyond refined sugar, including bagasse, filter mud, vinasse, and molasses. These streams support environmental sustainability and offer opportunities for circular economy integration. Bagasse, containing 40–60% cellulose, is widely used for cogeneration and bioenergy, while molasses, composed of approximately 45.5% sucrose and 20–30% glucose and fructose, is particularly valuable due to its high fermentable sugar content [9].

A. *Fermentation Biochemistry*

Rum production relies on alcoholic fermentation by *Saccharomyces cerevisiae*, converting fermentable sugars into ethanol. Yield and quality depend on sugar concentration, nutrient supplementation, pH, temperature, and yeast viability. Previous studies indicate that molasses should be diluted to 15-20 °Brix and pH adjusted to 5.0-5.5, with supplementation of urea of phosphates to prevent incomplete fermentation [10]. Fermentations conducted at 18% sugar concentration with urea and diammonium phosphate in 65 m^3 fermenters achieved 9.3% v/v ethanol, with fermentation efficiency of 83.6% and residual sugars of only 1.32% [11]. This corresponds to 93 liters of ethanol per 1,000 liters of diluted must, approaching the theoretical maximum of 110 liters, demonstrating notable efficiency.

B. *Biotechnology*

Yeast selection is critical for fermentation performance and final product quality. Optimal fermentation temperatures vary by strain but generally range between 28-35 °C with best results achieved slightly below the upper limit. *Saccharomyces cerevisiae* remains the most widely used yeast in rum production due to its high fermentative capacity and ethanol tolerance [12]. Recent studies have explored mixed cultures, such as *Debaryomyces polymorphus*, which improve organoleptic properties while reducing ethanol yield and enhancing resistance to sulfates [13]. Genetic engineering of *Saccharomyces cerevisiae* has also been investigated to increase tolerance to weak acids such as acetic and formic, involving redox mechanisms that improve process robustness [14]. Enzymatic interventions, including polyphenol oxidases and pectin transaminases, have been tested to increase fermentation temperatures and lipid content, though results showed induced fermentation percentages and higher contamination risks [15].

C. *Distillation Technologies*

Process design for rum production must integrate key unit operations such as fermentation, distillation, and vinasse treatment. The choice of distillation technology, batch pot stills versus continuous Coffey columns, significantly influences volatile composition and sensory quality. Continuous distillation generally offers higher energy efficiency, while batch distillation provides distinctive flavor profiles [16]. Sensory analyses highlight the importance of molecular aromatic balances generated during fermentation and transformed during distillation and aging, with compounds such as (E)-β-damascenone and ethyl esters shaping the final product [17].

D. *Rum Aging*

Alcoholic beverages aging is based on mass transfer phenomena by wood degradation. Under heat action, hemicellulose and lignin present on wood decompose, releasing phenolic aldehydes such as vanillin and syringaldehyde, as well as furfurals and lactones, which contribute notes of vanilla, caramel, and coconut [18]. In a reflux system, the distillate with wood chips is subjected to continuous heating in a flask, while the condensed vapors return to the liquid, maintaining a constant volume and promoting sustained extraction. This mechanism intensifies the leaching of phenolic and volatile compounds since the thermal energy lowers the activation barrier for hydrolysis and oxidation reactions, accelerating processes that occur slowly in barrels through diffusion and micro-oxygenation [19]. The most volatile compounds, such as furfural and lactones, are released more readily in this environment, generating concentrated aromatic profiles in less time. This method innovates by reproducing and accelerating chemical transformation typical of traditional aging, but with experimental control and energy efficiency [19]. This fast method offers an alternative to incorporate organoleptical trademarks without incurring the great expenses linked to the traditional aging process.

E. *Energy Integration and Simulation*

Engineering platforms such as AspenTech enable modeling of mass and energy balances, phase equilibria, chemical kinetics, reactors, exchangers, and multiphase streams, while supporting optimization, effluent analysis, and economic evaluation [20]. Energy efficiency evaluations on sugar mills had been conducted through simulation, for instance, cogeneration studies in sugar mills demonstrate that bagasse is a critical energy input, with measures such as moisture reduction and residual heat utilization improving overall system efficiency [21]. Novel plant designs must incorporate variables such as fermentation type, distillation technology, energy recovery from coproducts, sustainable digestion and advanced oxidation to reduce pollutant loads while generating energy, reinforcing the integration of product quality with environmental sustainability [22].

F. *Circular Economy and Bioeconomy*

The economic viability of rum production in Honduras can be strengthened through a circular economy approach that maximizes coproduct utilization and reduces environmental impact. Rum production aligns with bioeconomy principles, as molasses and process residues can be transformed into valuable inputs, including bioenergy and oleo-chemical materials such as biodegradable waxes [9], [23]. In a context of growing global demand for premium rum, integrating efficiency and sustainability strategies enables the conversion of agro-industrial waste into value-added products, reinforcing both competitiveness and resource efficiency.

V. Experimental Methodology

The experimental sequence was conducted as an exploratory trial without replicates due to laboratory constraints as presented in Fig. 1. Process consistency was assessed through continuous monitoring of pH, °Brix, density, and qualitative observations. Future work should include replication and statistical analysis to strengthen reliability. These values are critical for calculating the proportions of water and molasses required to achieve optimal fermentation conditions [24].

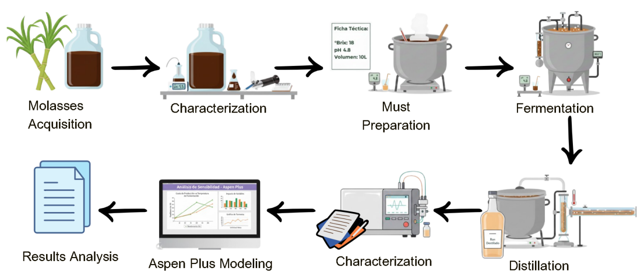


Fig. 1 Methodological design sequence.

Laboratory measurements, as shown in Fig. 2, indicated an initial pH of 4.94, a density of 1.433 g/mL, and a sugar concentration of 77 °Brix. Based on literature references, the target concentration was adjusted to 18 °Brix [25], which required the addition of approximately 3.28 kg of water per kilogram of molasses. This dilution ensured that the fermentable sugars were within the optimal range for yeasts metabolism, while maintaining a manageable osmotic pressure for microbial activity.

Fig. 2 Laboratory glassware used for physicochemical parameter measurement of molasses.

A. *Must Preparation*

The preparation of the fermentable wort consisted of mixing molasses with water in proportions calculated to achieve the desired concentration of fermentable sugars. To determine the amount of water needed, equation (1) was applied: Determination of the amount of water in the wort [25].

$$W = M_m \left((Brix_i / Brix_t) - 1 \right) \qquad (1)$$

Where M_m represents the mass of molasses, $Brix_i$ the initial °Brix, $Brix_t$ the target °Brix, and W the mass of water added. This allowed for precise adjustment of the dilution. Subsequently, the mixture was subjected to heat treatment to ensure sterilization. The resulting wort had a density of 1.071 g/mL and a final pH of 4.91, values that confirmed the accuracy of the preparation process. The resulting wort pH was not adjusted to 5.0, as studies recommend, due to its proximity to such value to prevent chemical contamination due to pH adjustments. Finally, inoculation was carried out using a commercial yeast (Saccharomyces cerevisiae, Alcatec Turbo Yeast 48), following the manufacturer's recommendations. These recommendations specified only hydration with no nutrient supplementation due to yeast fermentation efficiency in a harsh ethanol environment.

B. *Fermentation System Setup*

The yeast was previously hydrated in warm water to activate the cells and ensure high viability, as shown in Fig. 3, thus promoting the rapid onset of metabolic activity [10], [11]. Fermentation was conducted in a closed system equipped with a CO_2 trap in "S" configuration, partially filled with disinfectant solution to maintain anaerobic conditions. The fermenters consisted of borosilicate glass flasks of 3.78 liters capacity, as shown in Fig. 3, sealed with perforated stoppers to accommodate gas traps. The system was sterilized with ethanolic solution prior to inoculation. Fermentation was carried out at ambient laboratory temperatures (24-25 °C) for 45-72 hours, with continuous monitoring of °Brix, density and pH every 17 hours. Observations included foam formation, aroma development and changes in sweetness, which provided qualitative indicators of fermentation progress.

Fig. 3 from Left to Right Yeast Activation, Fermentation System.

C. Monitoring and Observations

Experimental monitoring revealed that both fermentation systems had a stable 24-25°C temperature range, pH values within the optimal range (4.5-5.0), average densities of 0.9073 g/mL and descending °Brix from 14.3 to 11.8 in a four-day continuous monitoring every twelve hours, confirming favorable conditions for yeast activity. However, fermentation stopped around the third day, likely due to repeated opening of the system, which altered anaerobic conditions. This altered yeast metabolism activated respiratory pathways diverting sugars toward biomass formation rather than ethanol production. Sensory analysis also detected a salty flavor, attributed to mineral additives present in the commercial yeast formulation. To isolate the system for correct fermentation with no opening, a third closed system was prepared under identical conditions, which confirmed that nutrient imbalances or thermal stress, rather than oxygen exposure, were responsible for the reduced efficiency.

D. Distillation Process

Following fermentation, the must was subjected to distillation using a stainless-steel pot and a Liebig condenser as shown in Fig. 4. The system operated within ethanol boiling range (78-95 °C), with fractions collected as heads, hearts, and tails. Analytical measurements indicated that the heart fraction contained ethanol at 42% v/v, with a total recovery of 730 mL from a 9L batch. The overall alcohol yield was 9.82%ABV, corresponding to a sugar conversion efficiency of approximately 77.8%. By-products included 39 mL of methanol in heads, 115 mL of heavier alcohols in tails, and 6.4 L of vinasse, which represents a potential substrate for energy recovery or wastewater treatment.

E. Accelerated Aging Simulation

To simulate barrel aging, an accelerated extraction process was performed using wood chips of mahogany (*Swietenia spp.*) and cedar (*Cedrela odorata*). Such a solid-liquid extraction process has proven to be an effective strategy in whiskey production with oak wooden chips, providing a more cost-effective and accessible alternative while maintaining quality and commercial acceptance [27]. As shown in Fig. 4, a solid-liquid ratio of 10 g/400 mL was applied, with reflux carried out for 40-45 minutes to promote the transfer of phenolic compounds, terpenes, and flavonoids into the distillate. Sensory evaluation after 24 hours revealed distinct profiles: mahogany imparted dark brown coloration with woody and toasted notes reminiscent of chocolate ("El líder"), while cedar produced a lighter amber tone with herbal and spiced aromas ("La Foránea") as shown in Fig. 5. These results confirmed the potential of accelerated extraction techniques to replicate aspects of traditional barrel aging, while highlighting the influence of wood species on flavor development.

Fig 4. From Left to Right; Molasses distillation setup and Reflux system for accelerated aging simulation.

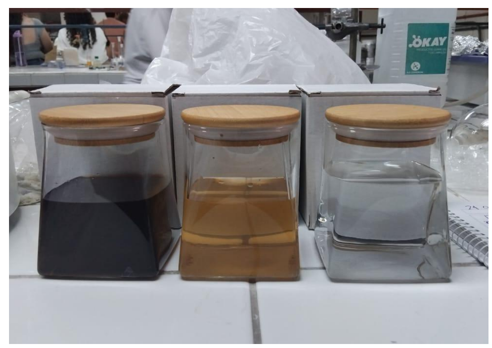


Fig 5.Appearance of accelerated reflux aged rums, from left to right: a) Mahogany "El Líder", b) Cedar "La Foránea", c) Non-reflux aged sample named "El Chele".

F. Rum Chromatography

The final distillates were analyzed using gas chromatography at InPlasa laboratories, employing a Thermoscientific TR-Wax column and Trace 1300/1600 detector. Chromatographic profiles, shown in Fig. 6, identified ethanol as the domain compound in the heart fraction, alongside minor volatile congeners responsible for aroma and flavor complexity. No methanol traces were detected in any of the analyzed samples. Comparative analyses with commercial rum samples demonstrated that the laboratory-produced distillate achieved similar volatile profiles, validating the experimental methodology.

VI. Industrial Scale-Up and Process Simulation

The industrial process begins with the use of pure molasses sourced from Tres Valles sugar mill, stored at ambient temperature. To ensure consistency and compliance, international standards were adopted for raw material handling, processing, and commercialization. These include ISO 9001, ISO 22000, Codex guidelines, ISO 45001, ISO/IEC 17025, AOAC methods, ISO 4833 and ISO 6579. This framework guarantees that the industrial rum production process aligns with global quality and safety requirements.

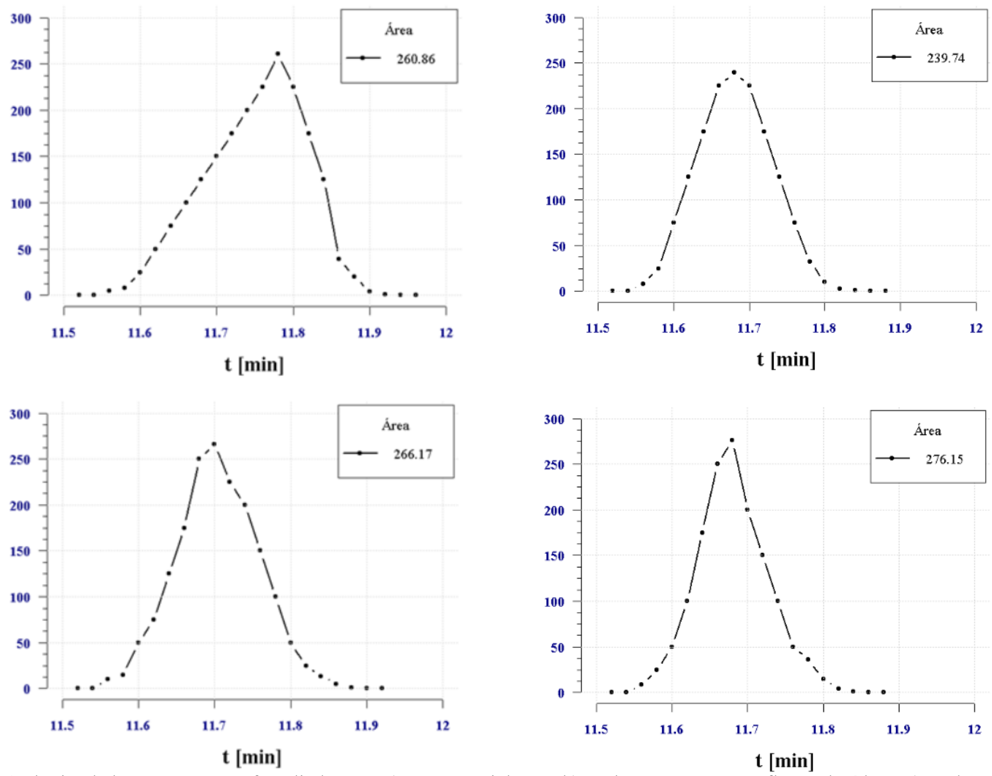
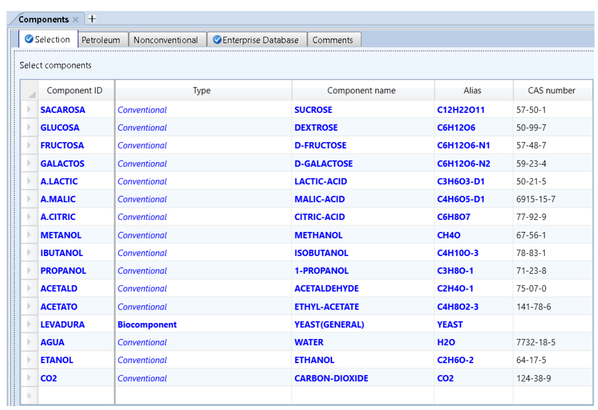


Fig. 6 Obtained chromatograms of studied rums: a) Commercial rum; b) Mahogany contact reflux "El Líder", c) Cedar contact reflux "La Foránea", c) Non-reflux aged "El Chele".

A. *Aspen Plus Simulation Framework*

Industrial scale-up was modeled using Aspen Plus 14.2 with NRTL thermodynamic model to improve distillation accuracy. Fermentation reactions were defined for sucrose, glucose, fructose, and galactose under anaerobic conditions with *Saccharomyces cerevisiae*. Secondary reactions, including esterification of acetic acid with ethanol to form ethyl acetate, and oxidation pathways leading to lactic and acetic acids, were incorporated to reflect realistic byproduct formation. Model validation was performed by comparing simulation outputs with laboratory-scale results. The simulation accounted for both major and minor components, as shown in Fig. 7, adjusting mass fractions to match laboratory results and literature references [26]. This allowed evaluation of fermentation efficiency in sugar conversion and distillation performance in separating ethanol from congeners.


Components | Selection | Petroleum | Nonconventional | Enterprise Database | Comments

Select components

Component ID	Type	Component name	Alias	CAS number
SACAROSA	Conventional	SUCROSE	C12H22O11	57-50-1
GLUCOSA	Conventional	DEXTROSE	C6H12O6	50-99-7
FRUCTOSA	Conventional	D-FRUCTOSE	C6H12O6-N1	57-48-7
GALACTOS	Conventional	D-GALACTOSE	C6H12O6-N2	59-23-4
A.LACTIC	Conventional	LACTIC-ACID	C3H6O3-D1	50-21-5
A.MALIC	Conventional	MALIC-ACID	C4H6O5-D1	6915-15-7
A.CITRIC	Conventional	CITRIC-ACID	C6H8O7	77-92-9
METANOL	Conventional	METHANOL	CH4O	67-56-1
IBUTANOL	Conventional	ISOBUTANOL	C4H10O-3	78-83-1
PROPANOL	Conventional	1-PROPANOL	C3H8O-1	71-23-8
ACETALD	Conventional	ACETALDEHYDE	C2H4O-1	75-07-0
ACETATO	Conventional	ETHYL-ACETATE	C4H8O2-3	141-78-6
LEVADURA	Biocomponent	YEAST(GENERAL)	YEAST	
AGUA	Conventional	WATER	H2O	7732-18-5
ETANOL	Conventional	ETHANOL	C2H6O-2	64-17-5
CO2	Conventional	CARBON-DIOXIDE	CO2	124-38-9

Fig. 7 Aspen Plus components used on simulation.

B. *Unit Operations and Process Design*

The process shown in Fig. 8 was divided into five operational zones: storage (A), mixing (M), reaction (R), distillation (D), and post-treatment (P). Storage tanks and all input fluxes were calculated and dimensioned to handle annual molasses inputs of 9,650 tons based on the market demand research [2], with auxiliary tanks for water and yeast. Mixing units and heat exchangers ensured proper dilution and pre-treatment of feed streams. The fermentation reactor (R01) was modeled as a stoichiometric unit with a residence time of

72 hours, achieving a sugar conversion efficiency of 77% as the one achieved during laboratory trials. Distillation was carried out in three fractionating columns: D01 for separating vinasse, D02 for methanol removal, and D03 for refining ethanol and minimizing heavier alcohols. Post-treatment included dilution and stabilization to achieve the target ethanol concentration in the final rum product. Simulation results are shown in Table 2.

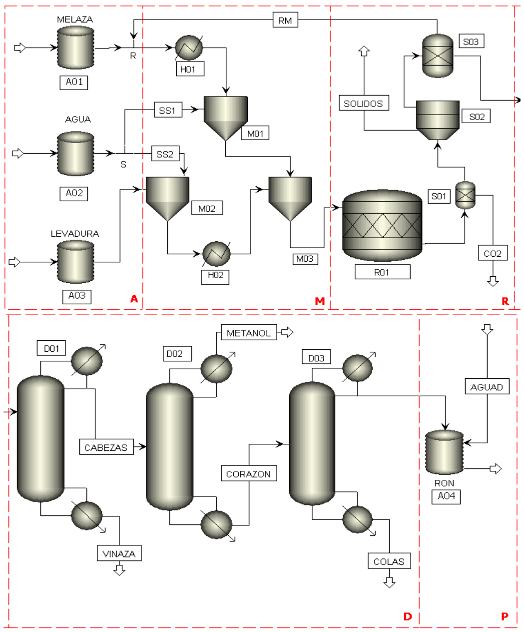


Fig. 8 Aspen Plus Process Flow Diagram part a) Storage, Mixers and reactor b) Distillation and post-treatment.

Table 2

SIMULATED INPUT AND RESULTS

Tag	Equipment	Mass Flow [kg/h]	Parameters	Main Mass fraction
A01	Storage	9987.76	T= 25°C P= 1 bar	0.58 Sucrose
A02	Storage	2857.68	T= 25°C P= 1 bar	1 Water
A03	Storage	140	T= 25°C P= 1 bar	1 Yeast
S	Static mixers	2857.68	Split fraction 0.039	-
R01	Reactor	3953.23	Pressure drop=0	-
H01	Heat Exchanger	1074.46	T= 60 °C Pressure drop =0	-
H02	Heat Exchanger	132.54	T=30 °C Pressure drop =0	-
M01	Dynamic mixers	3820.69	Pressure drop =0	-
M02	Dynamic mixers	132.54	Pressure drop =0	-
M03	Dynamic mixers	3953.23	Pressure drop =0	-
S01	Relief Valve	3953.23	Split Fraction $CO_2 = 1$	1 CO_2
S02	Centrifuge	3629.47	Fraction L-L and S-S 0.999	0.854 Yeast
S03	Clarifier	3604.8	Split Fraction Sugars	-
D01	Fractional Distillation	3529.1	N= 10 with total condenser Pressure= 1 bar with Drop=0	0.902 Water
D02	Fractional Distillation	1667.5	N= 10 with total condenser Pressure= 1 bar with Drop=0	0.023 Methanol
D03	Fractional Distillation	1275.62	N= 10 with total condenser Pressure= 1 bar with Drop=0	0.0046 Propanol
A04	Storage	276.041	Pressure Drop =0	0.4228 Ethanol

C. *Sensitivity Analysis of Distillation Columns*

Sensitivity analyses were performed on the distillation towers to optimize operating parameters. For D01, the optimate distillate flow was identified at 20-30 L/min, balancing ethanol recovery with minimal sugar and congener carryover as shown in Fig. 9. In D02, the feed stage shows in Fig. 10 its optimal value on the third stage, however, this value was changed to the fourth stage to compensate for ethanol losses on previous 2 analyses. In D03, reflux ratio of 79 and feed stage at the sixth tray provided the best separation of ethanol from Isobutanol and propanol as shown in Fig. 11 and Fig. 12 respectively. These adjustments ensured compliance with ISO limits for volatile compounds in rum, while maintaining energy efficiency and product quality.

Experimental fermentation achieved approximately 77% of theoretical ethanol yield, while distillation produced a heart fraction with 42% v/v ethanol. These values were used as reference points to evaluate the accuracy of the Aspen Plus model, which reproduced the main process trends with acceptable agreement. Furthermore, sensitivity analyses of reflux ratio and feed stage were used to assess the robustness of the separation performance. Such simulation compares the 479.63 L of ethanol per ton of molasses (42%v/v) produced by the following model, and the 575 L of ethanol per ton of molasses (40%v/v) commonly produced by rum industries to analyze its viability [28].

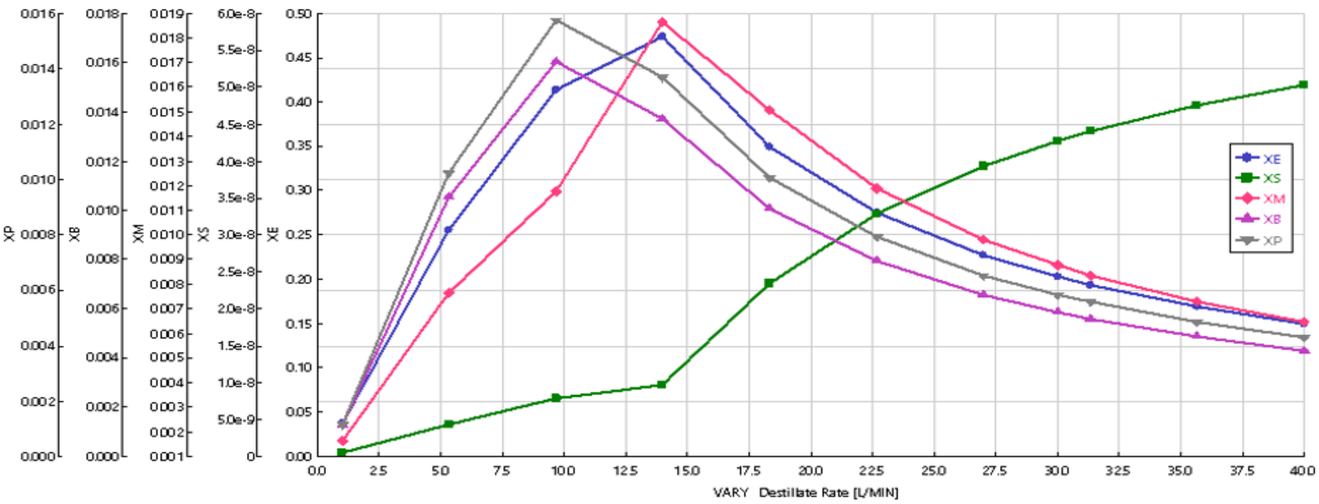


Fig. 9 Aspen Plus D01 STDVOL-D sensitivity analysis.

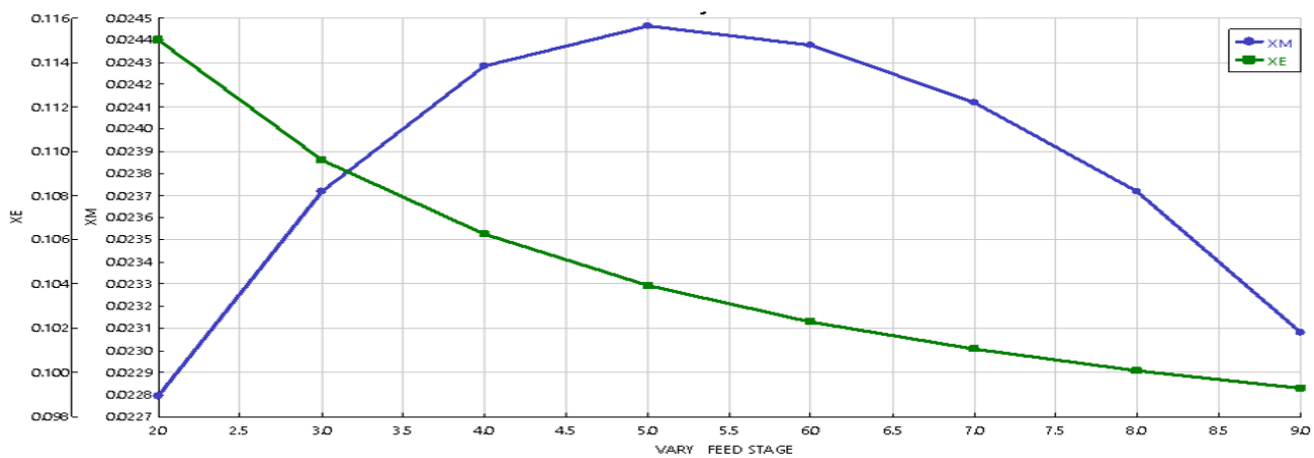


Fig. 10 Aspen Plus D02 Feed Stage sensitivity analysis.

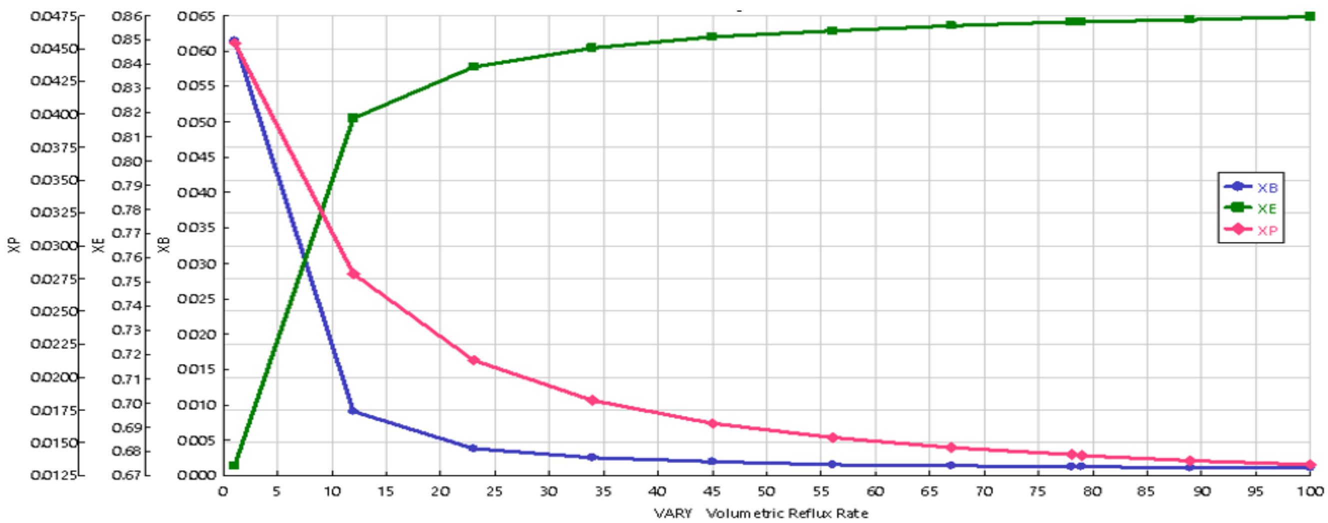


Fig. 11 Aspen Plus D03 STDVOL-RR sensitivity analysis.

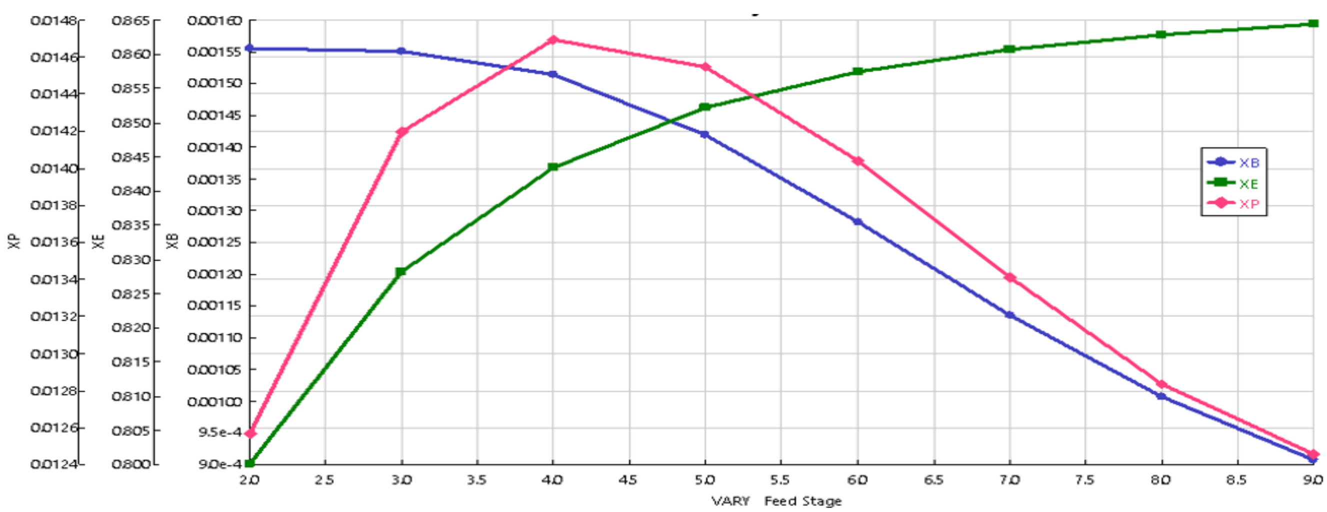


Fig. 12 Aspen Plus D03 Feed Stage sensitivity analysis.

D. *Industrial Results and Normative Compliance*

The simulation yielded a final rum stream of 276 kg/h with an ethanol fraction of 42.3% with water fraction of 55.2%. Byproducts included 391 kg/h of methanol, 1861 kg/h of vinasse, and 24.7 kg/h of biomass. Importantly, the final rum composition in mass fraction shown Table 3 met ISO normative limits: methanol ≤ 0.02, Isobutanol ≤0.05, propanol ≤ 0.05, acetaldehyde ≤ 0.2, and ethyl acetate ≤ 0.2. These results confirm that the industrial process will produce rum of commercial quality while adhering to international standards.

Table 3

SIMULATED RUM MASS FRACTIONS

Component	Initial Composition	Final Composition	Normative Composition
Sucrose	0.6041	0	≤ 0.01
Glucose	0.0647	0	≤ 0.01
Fructose	0.0999	0	-
Galactose	0.0005	0	-
Lactic Acid	0.01	0	-
Malic Acid	0.01	0	-
Citric Acid	0.01	0	-
Methanol	0.015	0.0169	≤ 0.02
Isobutanol	0.01	0.00063	≤ 0.05
Propanol	0.01	0.0069	≤ 0.05
Acetaldehyde	0.1	0	≤ 0.02
Ethyl Acetate	0.05	0	≤ 0.02
Water	-	0.5527	-
Ethanol	0	0.4228	0.37 – 0.54

E. *Energy and Utility Integration*

Energy requirements were modeled through steam, refrigeration and fired heaters. Low-pressure steam was used in heat exchangers, refrigerants in condensers, and direct firing in reboilers as shown in Table 4. Mass and energy balance demonstrated negligible errors, validating the robustness of the simulation. This integration highlights the potential of coupling rum production with renewable energy strategies in Honduran sugar mills.

Table 4
UTILITIES

Operation	Utility	Aspen Tag
Heat exchangers	Steam	Low Pressure Steam
Condenser	Coolant	Coolant 1
Reboilers	Flame	Fired Heater

F. *Industrial Viability and Scale-Up Considerations*

Industrial scale-up demonstrates that rum production from molasses can be dimensioned as a continuous process although fermentation remains semi-batch in practice. The simulation results provide a foundation for designing pilot and industrial plants, with clear identification of bottlenecks in fermentation and distillation. Future simulations should incorporate Aspen Dynamics to model batch fermentation kinetics more accurately. Nevertheless, the current design confirms that Honduras can establish a competitive rum industry, leveraging molasses valorization, compliance with ISO standards, and circular economy principles integration.

A preliminary techno-economic assessment suggests that the process is economically viable at industrial scale, with an estimated CAPEX of USD 44.85 million, an internal rate of return of 33–36%, and a payback period of 6–7 years. Although the results indicate strong potential, they are sensitive to key assumptions and should be interpreted as a preliminary feasibility estimate.

VIII. Results

At laboratory scale, fermentation reached 77.06% efficiency and distillation 8.11%, while industrial simulation improved overall efficiency to 43.87% thanks to fractionating distillation towers. The designed plant, with a capacity of 2.518 million rum liters per year, could supply 7.49% of national demand using 41.77% of molasses from a single mill; scaling across multiple mills could cover more than 53%. Sub-products such as biomass, vinasse, and methanol generated USD 12.03 million annually, reinforcing circular economy practices. Risk analysis identified molasses subsidies and machinery failures as critical vulnerabilities, requiring supplier diversification and preventive maintenance.

IX. Conclusions

This work confirms the technical feasibility of producing rum from sugarcane molasses through an integrated experimental and simulation-based approach. Laboratory fermentation achieved ethanol conversion efficiencies of approximately 77%, and batch distillation yielded a heart fraction with an ethanol concentration close to 42% v/v, demonstrating the suitability of molasses as a fermentable substrate.

A reflux-based accelerated aging technique enabled the controlled extraction of wood-derived compounds, generating differentiated sensory profiles within reduced processing times. Although this method does not replicate traditional barrel aging, it provides an effective experimental strategy to simulate selected sensory attributes associated with intermediate-aged rums.

Industrial scale-up was assessed using Aspen Plus by integrating fermentation, multistage distillation, and energy balances. The simulation indicates that a plant processing approximately 9,650 $t \cdot y^{-1}$ of molasses could produce about 2.5 million liters of rum per year while complying with international quality standards. Sensitivity analyses identified operating conditions that improve ethanol recovery and impurity control.

Overall, the results indicate that molasses valorization into rum is technically feasible and consistent with a circular economy framework, providing a solid basis for future pilot-scale validation and process optimization. Preliminary techno-economic insights suggest that industrial-scale implementation may enhance process efficiency and economic performance compared to laboratory conditions; however, these findings are indicative and highly dependent on scale, market conditions, and operational assumptions. Accordingly, further pilot-scale data and detailed financial analysis are required to fully assess economic viability, while the present study establishes a robust technical foundation to support subsequent optimization and decision-making.

IX. Acknowledgements

The authors would like to express their deepest gratitude to MSc. Oscar Ortiz for facilitating contact with sugar mills and providing technical data on molasses composition, and to MSc. Alex Perdomo for connecting us with InPlasa, whose collaboration enabled the chromatographic analysis of our distilled samples.

We also acknowledge the contributions of MSc. Andrés Cruz and Ph.D. Oliver Everett, whose expertise was vital in designing and troubleshooting the distillation towers. Finally, we thank MSc. Rafael Mejía and Ph.D. Marcela Godoy for their support in reactor design and sugar conversion modelling, as well as for his strategic guidance in shaping the project vision.

References

[1] Escalante Andino, K. N., & Mencia Contreras, E. (2013). Estudio de prefactibilidad para la elaboración y distribución de melaza en polvo en Azucarera Tres Valles [Tesis de grado, Universidad Tecnológica Centroamericana]. Repositorio UNITEC. https://repositorio.unitec.edu/server/api/core/bitstreams/afacf443-1aaa-4803-8286-36ba859046f8/content

[2] Magda Montoya, Human Development Manager, "Compañía Azucarera Tres Valles" Sugar Mill (October 7, 2025). Personal communication.
[3] Palmonari, A., Cavallini, D., Sniffen, C. J., Fernandes, L., Holder, P., Fagioli, L., Fusaro, I., Biagi, G., Formigoni, A. & Mammi, L. (2020). Short communication: Characterization of molasses chemical composition. Journal of Dairy Science, 103(7), 6244–6249. https://doi.org/10.3168/jds.2019-17644
[4] CISNEROS DE LA CUEVA, S., Álvarez Guzman, C. L., Salmerón, I., Pérez Vega, S. B. & Santiago Adame, R. (2024). Biofuel production from sugar cane molasses using Serratia marcescens. Revista Internacional de Contaminacion Ambiental, 40, 231–242. https://doi.org/10.20937/RICA.55013
[5] Reducción de la pobreza y el desempleo avances positivos en 2024 - INE Honduras - Estadísticas Oficiales. (2024, November 28). INE Honduras - Estadísticas Oficiales. https://ine.gob.hn/2024/11/28/reduccion-de-la-pobreza-y-el-desempleo/
[6] Latin America Craft Rum Market Size & Outlook, 2030. (2025, May 13). https://www.grandviewresearch.com/horizon/outlook/craft-rum-market/latin-america
[7] Business Market Insights, https://www.businessmarketinsights.com/. (n.d.). Perspectivas regionales y globales del mercado de ron de alta gama de América del Norte 2030. Business Market Insights. https://www.businessmarketinsights.com/es/reports/north-america-high-end-rum-market
[8] Dinero HN. (2024, July 28). Honduras entre los países que menos toma alcohol en el Continente. https://dinero.hn/honduras-entre-los-paises-que-menos-toma-alcohol-en-el-continente/
[9] Wani, A. K., Rahayu, F., Fauziah, L. & Suhara, C. (2023). Advances in safe processing of sugarcane and bagasse for the generation of biofuels and bioactive compounds. Journal of Agriculture and Food Research, 12. https://doi.org/10.1016/j.jafr.2023.100549
[10] Mangwanda, T., Johnson, J. B., Mani, J. S., Jackson, S., Chandra, S., McKeown, T., White, S. & Naiker, M. (2021b). Processes, challenges and optimisation of rum production from molasses—a contemporary review. In Fermentation (Vol. 7, Issue 1). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/fermentation7010021
[11] Fadel, M., Keera, A. A., Mouafi, F. E. & Kahil, T. (2013). High Level Ethanol from Sugar Cane Molasses by a New Thermotolerant Saccharomyces Cerevisiae Strain in Industrial Scale. Biotechnology Research International, 2013, 1–6. https://doi.org/10.1155/2013/253286
[12] Mangwanda, T., Johnson, J. B., Mani, J. S., Jackson, S., Chandra, S., McKeown, T., White, S. & Naiker, M. (2021c). Processes, challenges and optimisation of rum production from molasses— a contemporary review. In Fermentation (Vol. 7, Issue 1). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/fermentation7010021
[13] He, X., Guo, X., Liu, N. & Zhang, B. (2007). Ergosterol production from molasses by genetically modified Saccharomyces cerevisiae. Applied Microbiology and Biotechnology, 75(1), 55–60. https://doi.org/10.1007/s00253-006-0807-6
[14] Cámara, E., Olsson, L., Zrimec, J., Zelezniak, A., Geijer, C. & Nygård, Y. (2022). Data mining of Saccharomyces cerevisiae mutants engineered for increased tolerance towards inhibitors in lignocellulosic hydrolysates. In Biotechnology Advances (Vol. 57). Elsevier Inc. https://doi.org/10.1016/j.biotechadv.2022.107947
[15] Morales-Rodriguez, W. J., Morante-Carriel, J., Herrera-Feijoo, R. J., Ayuso-Yuste, M. C. & Bernalte-García, M. J. (2024). Effect of addition of yeasts and enzymes during fermentation on physicochemical quality of fine aroma cocoa beans. Journal of Agriculture and Food Research, 16. https://doi.org/10.1016/j.jafr.2024.101126
[16] Coelho, C., Brottier, C., Beuchet, F., Elichiry-Ortiz, P., Bach, B., Lafarge, C. & Tourdot-Maréchal, R. (2020). Effect of ageing on lees and distillation process on fermented sugarcane molasses for the production of rum. Food Chemistry, 303. https://doi.org/10.1016/j.foodchem.2019.125405
[17] Franitza, L., Granvogl, M. & Schieberle, P. (2016). Influence of the Production Process on the Key Aroma Compounds of Rum: From Molasses to the Spirit. Journal of Agricultural and Food Chemistry, 64(47), 9041–9053. https://doi.org/10.1021/acs.jafc.6b04046
[18] Souza, T. F. C. de, Melo Miranda, B., Colivet Briceno, J. C., Gómez-Estaca, J., & Alves da Silva, F. (2025). The Science of Aging: Understanding Phenolic and Flavor Compounds and Their Influence on Alcoholic Beverages Aged with Alternative Woods. In Foods (Vol. 14, Issue 15). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/foods14152739
[19] Krüger, R. T., Alberti, A., & Nogueira, A. (2022). Current Technologies to Accelerate the Aging Process of Alcoholic Beverages: A Review. In Beverages (Vol. 8, Issue 4). MDPI. https://doi.org/10.3390/beverages8040065
[20] AspenTech Product Portfolio | Asset Optimization Software | Industrial AI Solutions | Sustainability Technology. (n.d.). https://www.aspentech.com/en/products/full-product-listing
[21] Abouelsoud, M., Khalil, M. Y., Ali, R. H. & Maghrabie, H. M. (2025). Performance assessment of a cogeneration system in a sugar cane factory using energy and exergy analysis. Case Studies in Thermal Engineering, 65. https://doi.org/10.1016/j.csite.2024.105622
[22] Peccini, A., Jesus, L. F. S., Secchi, A. R., Bagajewicz, M. J. & Costa, A. L. H. (2023). Globally optimal distillation column design using set trimming and enumeration techniques. Computers and Chemical Engineering, 174. https://doi.org/10.1016/j.compchemeng.2023.108254
[23] Lin, S. Y., Holden, N. M., Thongdara, R., Silalertruksa, T., Gheewala, S. H. & Prapaspongsa, T. (2025). Circular economy models of sugarcane biorefinery towards carbon neutrality and environmental sustainability. Sustainable https://doi.org/10.1016/j.spc.2025.07.008
[24] Mangwanda, T. W., Mani, J. S., Johnson, J. B., Jackson, S., McKeown, T., & Naiker, M. (2023). Physicochemical and Nutritional Analysis of Molasses for Rum Fermentation. 105. https://doi.org/10.3390/foods2023-15137
[25] Mangwanda, T., Johnson, J. B., Mani, J. S., Jackson, S., Chandra, S., McKeown, T., White, S., & Naiker, M. (2021). Processes, challenges and optimisation of rum production from molasses—a contemporary review. In Fermentation (Vol. 7, Issue 1). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/fermentation7010021
[26] Pino, J. A. (2007). Characterization of rum using solid-phase microextraction with gas chromatography-mass spectrometry. Food https://doi.org/10.1016/j.foodchem.2006.09.031
[27] María, M. G. A., Del, B. G. R., & De Valladolid Escuela Técnica Superior De Ingenierías Agrarias, U. (2023). Envejecimiento con sistemas alternativos a la barrica en bebidas alcohólicas de alta graduación: Una revisión. Universidad De Valladolid. https://uvadoc.uva.es/handle/10324/61550
[28] Sugarcane as feed. (n.d.). https://www.fao.org/4/s8850e/s8850e03.htm