

Design and Modeling of the Fermentation Process for the Production of Artisanal Aguardiente in the Association of Indigenous Councils of Northern Cauca (ACIN) Using Aspen Plus Simulation and Experimental Validation

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INTRODUCTION & AIM

Artisanal “*Chirrincho*” is a traditional sugarcane spirit produced by Indigenous Nasa communities in Northern Cauca, where it holds cultural, social, and economic importance. However, the fermentation and distillation processes are carried out using empirical practices that lack standardization, resulting in variability in alcohol yield, presence of unwanted by-products such as methanol, and inconsistencies in sensory quality. These issues limit product competitiveness and challenge its compliance with national technical standards for sugarcane spirits. This study aims to design and model the fermentation and distillation stages for the production of artisanal aguardiente using Aspen Plus simulation, and to validate the model experimentally, in order to improve process efficiency, product quality, and production consistency while preserving its cultural essence.

METHOD

The study was conducted using a mixed experimental–computational approach. First, samples of fermented sugarcane juice and distilled artisanal aguardiente produced by the Association of Indigenous Councils of Northern Cauca (ACIN), were collected and subjected to physicochemical characterization, including: pH, °Brix, reducing sugars, total acidity, ethanol concentration, methanol, furfural, and volatile compounds. These experimental data were used to parameterize and construct a process model in Aspen Plus, representing the fermentation and distillation stages under steady-state conditions. The model incorporated key operational variables such as temperature, substrate concentration, fermentation time, yeast dosage, and distillation cut points. To assess accuracy, simulation outputs were compared with laboratory measurements, and model reliability was evaluated through statistical validation using Analysis of Variance (ANOVA) to determine whether differences between simulated and experimental results were statistically significant ($\alpha = 0.05$).

RESULTS & DISCUSSION

Temperature had a strong effect on fermentation performance. The constant 35°C condition showed the highest metabolic activity, with rapid biomass growth, fast sugar consumption, and the highest ethanol production (≈ 79.7 g/L). The 32°C and 25→32°C ramp strategies achieved moderate yields, while 30°C and stepwise control resulted in minimal ethanol formation, indicating limited yeast activation. Overall, higher temperature mainly accelerated the rate of fermentation rather than changing the final conversion efficiency, confirming 35°C as the optimal operational condition for producing artisanal sugarcane spirit.

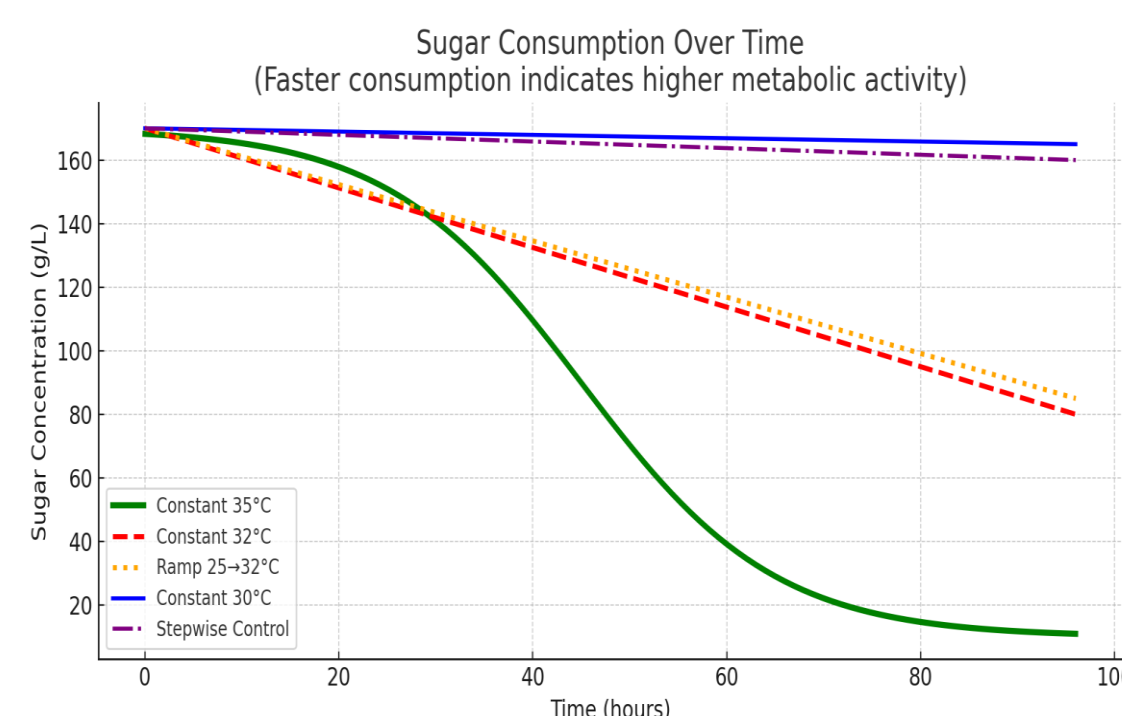


Figure 4. Sugar consumption over time

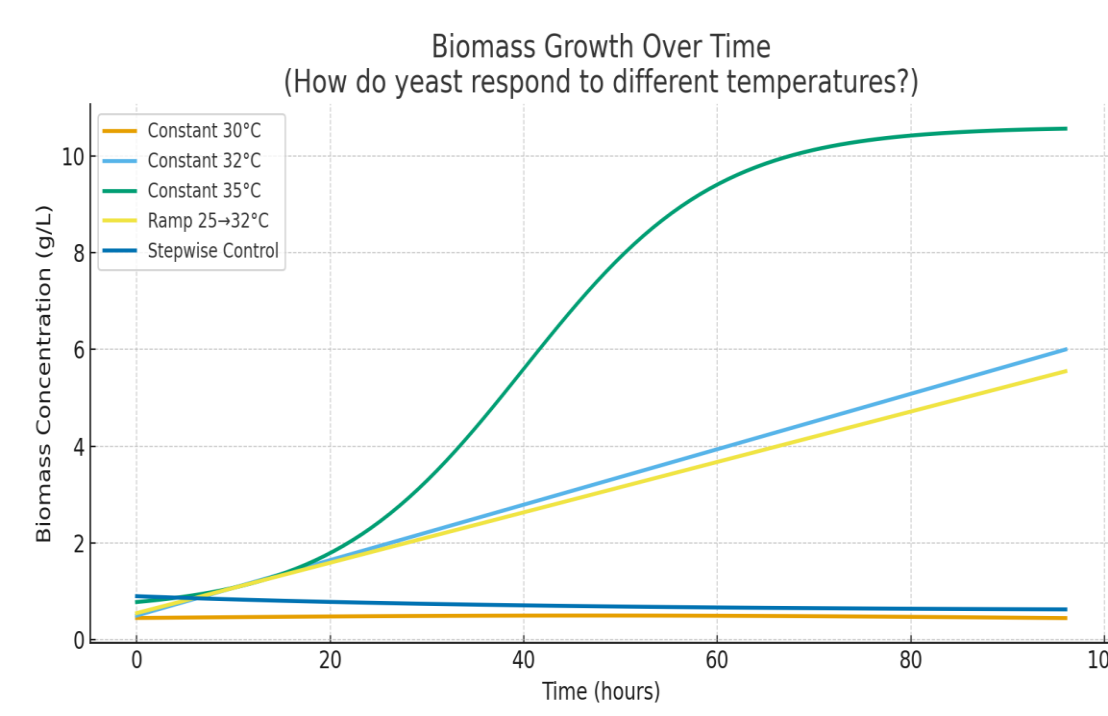


Figure 5. Biomass Growth Over Time

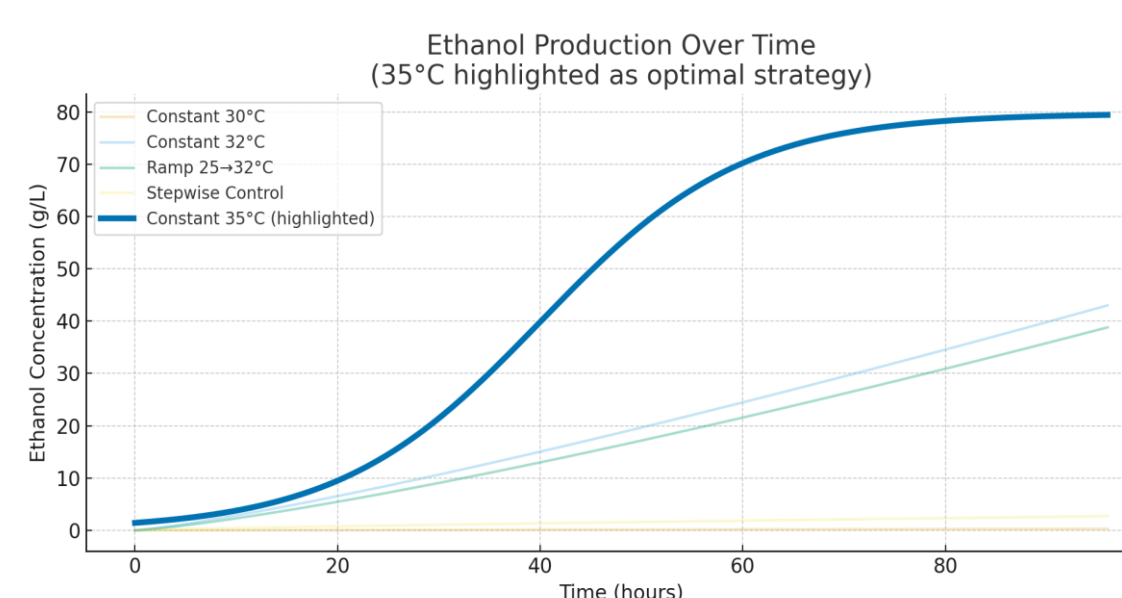


Figure 6. Ethanol Production Over Time

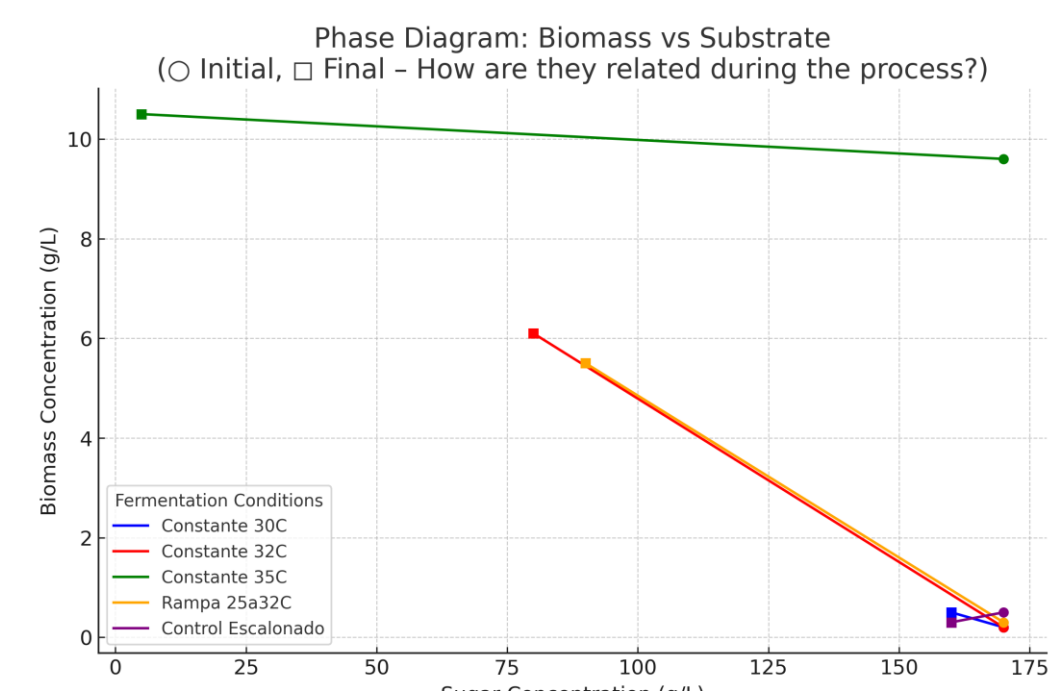


Figure 7. Phase Diagram: Biomass vs Substrate

CONCLUSION

1. Temperature as the Key Driver of Fermentation Performance
Temperature showed the strongest influence on fermentation outcomes, with higher temperatures increasing metabolic activity, conversion efficiency, and ethanol yield. Therefore, temperature control is the most critical operational parameter for improving process reproducibility and product quality in artisanal production.
2. Optimal Sugar Concentration (~16%) Maximizes Ethanol Yield
Although initial sugar content and ethanol production showed a moderate correlation, optimization revealed that the best fermentation efficiency occurs at ~16% initial sugars. Lower concentrations limit yeast activity, while higher levels cause osmotic inhibition. This defines a practical formulation guideline for ACIN fermentation processes.

FUTURE WORK / REFERENCES

Optimize real-time fermentation control, validate the process at pilot-scale in ACIN, and refine distillation cut-points to enhance safety and product quality, and develop hands-on educational modules to strengthen local knowledge in fermentation control, process hygiene, and sustainable production practices.

- Mohd Ariff, M. A., Mohd Nasir, N. A., Abdul Rashid, Z., & Rohman, F. S. (2023). Optimization of an Industrial Methanol Reactor Using Aspen Plus Simulator and Design Expert. *ESTEEM Academic Journal*, 19, 37-50.
- Smith, D., Johnson, T., & Rivera, L. (2021). Traditional Alcoholic Fermentation and Modern Industrial Practices: Bridging the Gap for Quality Improvement. *Journal of Fermentation Technology*, 33(4), 412-428.



Figure 1. Use of ASPEN for simulation

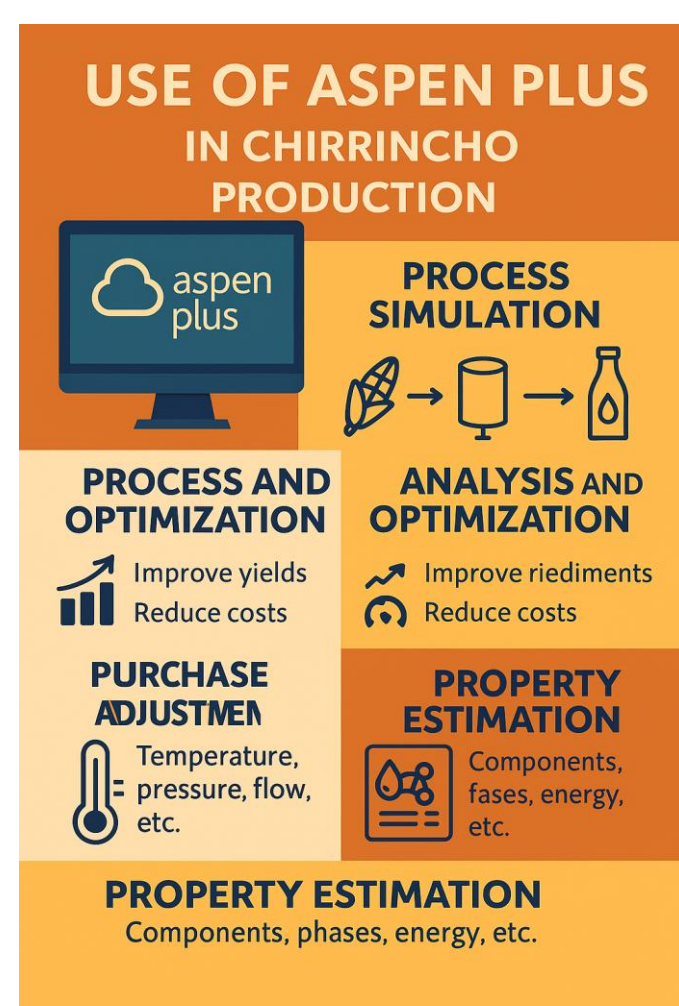


Figure 2. ASPEN for Chirrincho Production

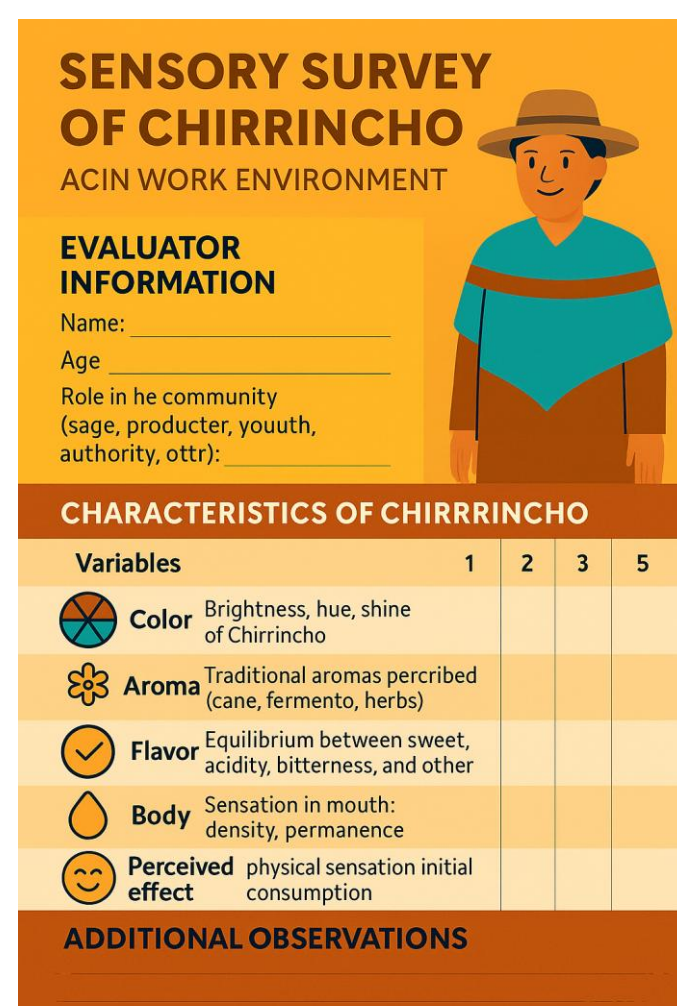


Figure 3. Ancestral evaluation for Chirrincho

