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Rum Production from Sugarcane Juice: Fermentation, Distillation, and Analysis

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Abstract **– Rum, a globally recognized distilled alcoholic beverage, is primarily derived from sugarcane juice. This study explores the fermentation of sugarcane juice using *Saccharomyces cerevisiae*, followed by distillation, to assess chemical composition, microbial activity, and process optimization. Wort prepared from sugarcane juice was fermented under controlled conditions, then distilled using a borosilicate glass setup. Analytical techniques showed significant variation in ethanol content levels between fresh and aged mashes. This work underscores the role of fermentation management and yeast in influencing rum's sensory and chemical quality, offering insights into sustainable and high-quality rum production.**

Keywords **– Distillation, Ethanol, Fermentation, Sugarcane, Yeast.**

I. INTRODUCTION

Rum, a traditional spirit derived from sugarcane, carries significant cultural and economic importance, particularly in countries like Brazil. It can be made from either fermented sugarcane juice or the viscous byproduct of sugar production. Historically, the fermentation process for rum has relied on spontaneous methods using native microbiota. However, in contemporary practices, there has been a shift towards using selected yeast strains, particularly Saccharomyces cerevisiae, to achieve more consistent ethanol yields and flavor profiles (Stewart et al., 2013; Campos et al., 2010). The chemical complexity of rum, characterized by volatile congeners and phenolic compounds, is heavily affected by the fermentation conditions, the composition of raw materials, and the distillation methods used.

The purpose of this study is to explore the controlled fermentation of sugarcane juice with S. cerevisiae, followed by small-scale distillation. This will allow for an analysis of the chemical profile of the resulting rum and shed light on its implications for quality control and potential industrial scalability.

II. MATERIALS AND METHODS

2.1. Raw Material Preparation

Sugarcane juice was sourced from the local market of Ballarpur, District Chandrapur, Maharashtra, India. It was boiled with distilled water to a density of 1.020 g/cm³ and adjusted to an initial pH of 4.85 using sulfuric acid. Nutrients such as diammonium phosphate and yeast-assimilable nitrogen were added. The sugarcane juice was then fermented using active dry yeast (S. cerevisiae). Successful fermentation of sugarcane juice at the laboratory scale involves a carefully selected set of materials and equipment. The primary substrate is fresh, filtered sugarcane juice, which serves as the fermentable sugar source. For fermentation, active dry yeast or a lab strain of Saccharomyces cerevisiae is used due to its high ethanol yield and tolerance. To support yeast growth, ammonium sulfate or diammonium phosphate (DAP) is added as a nitrogen source, while dilute sulfuric acid or lactic acid is used to adjust the pH of the juice.

Table 1. Parameters for Fermentation of Sugarcane Juice

Parameter	Details/Range	Purpose/Notes
Substrate	Fresh sugarcane juice (filtered)	Rich in fermentable sugars (sucrose, glucose, fructose)
Volume per batch	1–2 L (in 2–5 L flask)	Maintain 50–60% headspace for foam and gas release
Initial °Brix	16–18 °Bx	Adjust with distilled water if needed
Initial pH	4.5–4.8	Adjust with dilute sulfuric or lactic acid
Yeast strain	*Saccharomyces cerevisiae*	Common industrial strain or lab strain
Inoculum dose	1–2% (v/v)	Prepared as active yeast suspension
Fermentation temperature	28–32 °C	Optimal for yeast metabolism
Fermentation duration	48–72 hours	Monitor progress via gravity and gas production
Nutrient supplement	DAP or ammonium sulfate (0.2–0.3 g/L)	Enhances yeast growth and ethanol yield
Aeration	Anaerobic (use cotton plug or airlock)	Prevents unwanted aerobic microbial growth
Monitoring tools	pH meter, hydrometer/refractometer, thermometer	For tracking fermentation progress

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End-point indicator	Specific gravity ~0.995; constant reading for 24 h	Ethanol production complete
Post-fermentation analysis	Ethanol %, residual sugar, pH, sensory (optional)	For product characterization and process optimization

Distilled water is required for diluting the juice and rehydrating the yeast. Essential laboratory equipment includes 2–5 L conical flasks or fermentation vessels, a pH meter, hydrometer or densimeter (to monitor °Bx or specific gravity), thermometer, airlock or cotton plug, and optionally a magnetic stirrer. An incubator or a controlled ambient room is used to maintain the optimal fermentation temperature.

2.2. Methodology

To begin, fresh sugarcane stalks are thoroughly washed and crushed using a sugarcane press or mechanical juicer to extract the juice. The raw juice is then passed through a muslin cloth or Whatman filter paper to remove fibers, dust, and solid impurities. For enhanced microbiological safety, an optional pasteurization step can be conducted by heating the juice to 65–70 °C for 10–15 minutes, which helps reduce the indigenous microbial load without significantly degrading the sugars. The filtered and optionally pasteurized juice is then cooled to room temperature before further processing.

Juice Conditioning and Yeast Inoculation Before inoculation, the sugarcane juice is adjusted for optimal fermentation. The sugar concentration is brought to 16–18 °Bx using distilled water, ensuring a fermentable sugar range that supports ethanol production without stressing the yeast. The pH is adjusted to 4.5–4.8 using dilute sulfuric or lactic acid, creating an environment unfavorable to bacterial contaminants. To enhance yeast metabolism, 0.2–0.3 g/L of DAP or ammonium sulfate is added as a nutrient supplement. In parallel, the yeast inoculum is prepared by rehydrating active dry *S. cerevisiae* in warm sterile water (35–40 °C) for 10–15 minutes. The rehydrated yeast is then inoculated into the juice at a concentration of 1–2% v/v, e.g., 10 mL yeast slurry per 1 L juice.

Fermentation Conditions and Monitoring Fermentation is carried out under anaerobic conditions in cotton-plugged or airlock-equipped conical flasks. The flasks are kept at a controlled temperature of 28–32 °C for 48–72 hours, depending on the yeast strain, sugar content, and nutrient availability. The fermentation progress is monitored by measuring the temperature and specific gravity at 12-hour intervals using a thermometer and hydrometer. A declining specific gravity indicates sugar consumption and ethanol production. During active fermentation, CO_2 bubbles and frothing may be observed. Optionally, magnetic stirrers can be used to enhance homogeneity, though they are not necessary for successful fermentation.

Fermentation Completion and Post-Fermentation Analysis

The fermentation is considered complete when the specific gravity drops to ~0.995 or remains unchanged over 24 hours, indicating that most sugars have been converted to ethanol. Other signs include cessation of CO_2 production and a noticeable alcoholic aroma. Post-fermentation analysis includes measuring ethanol content by distillation and specific gravity or using more advanced methods like HPLC or GC. Residual sugars can be assessed using the DNS method or a refractometer, while pH measurements often show a slight decrease compared to initial values. Optionally, microbial analysis can be conducted through plate count techniques to evaluate any contamination. Throughout the process, strict aseptic practices must be followed, with sterilization of all glassware and proper disposal of fermentation waste to ensure hygiene and safety.

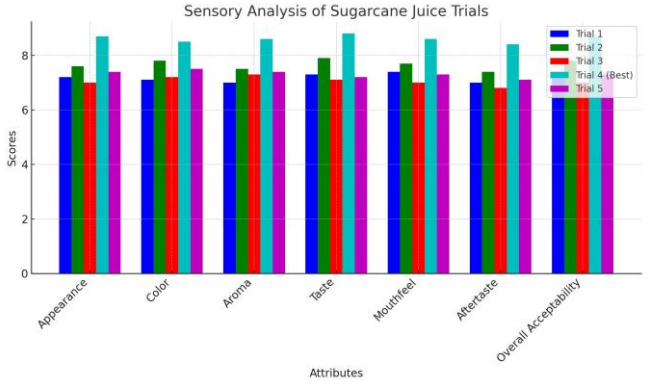
III. RESULTS AND DISCUSSION

3.1. Fermentation Efficiency and Alcohol Yield

All fermentation processes successfully reached final densities of less than 1.000, demonstrating an impressive level of sugar conversion nearing completion. The average ethanol concentration in freshly produced distillates was recorded at 40.2% ABV (alcohol by volume). In contrast, the aged samples presented a marginally higher alcohol content, averaging 41.5% ABV. This increase in ethanol concentration in the aged products can be attributed to the extended contact with the lees, which are the residual yeast and sediment remaining after fermentation. This prolonged interaction likely contributed to a more complex flavor profile and enhanced alcoholic strength in the final product.

Table 2. Sensory Evaluation of Rum produced from sugarcane juice

Attribute	Trial 1	Trial 2	Trial 3	Trial 4 (Best)	Trial 5
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Appearance	7.2 ± 0.24	7.6 ± 0.20	7.0 ± 0.32	**8.7 ± 0.05**	7.4 ± 0.28
Color	7.1 ± 0.25	7.8 ± 0.22	7.2 ± 0.30	**8.5 ± 0.05**	7.5 ± 0.25
Aroma	7.0 ± 0.26	7.5 ± 0.21	7.3 ± 0.31	**8.6 ± 0.05**	7.4 ± 0.26
Taste	7.3 ± 0.29	7.9 ± 0.18	7.1 ± 0.33	**8.8 ± 0.05**	7.2 ± 0.30
Mouthfeel	7.4 ± 0.23	7.7 ± 0.24	7.0 ± 0.35	**8.6 ± 0.05**	7.3 ± 0.27
Aftertaste	7.0 ± 0.27	7.4 ± 0.20	6.8 ± 0.36	**8.4 ± 0.05**	7.1 ± 0.29
Overall Acceptability	7.2 ± 0.28	7.8 ± 0.19	7.0 ± 0.34	**8.7 ± 0.05**	7.3 ± 0.26



3.2. Microbial Contributions

Saccharomyces cerevisiae showed robust fermentation behavior, with minimal lag phase. Aging with lees contributed to esterification, improving aromatic complexity. Unlike spontaneous fermentations, no off-flavors or lactic acid build-up were detected, emphasizing the importance of selected yeasts and nutrient supplementation.

The sensory evaluation results indicate that Trial 4 is the standout formulation, achieving top scores across all sensory attributes. It particularly shines in Taste (8.8 ± 0.05) and Overall Acceptability (8.7 ± 0.05), with minimal standard deviations (±0.05) reflecting strong consistency across batches. This success is likely attributable to the optimization of ingredients and processing techniques.

In contrast, Trial 3 performed the lowest overall, particularly noted for its Aftertaste score of 6.8 ± 0.36, indicating potential flavor or texture issues that require attention. Trials 1, 2, and 5 performed moderately but exhibited higher variability in scores (±0.18–0.36), hinting at less controlled processes during their production.

A deeper look into the attribute-specific data underscores the strengths and weaknesses of each trial. Trial 4's high ratings in Mouthfeel (8.6 ± 0.05) and Color (8.5 ± 0.05) enhance its sensory attractiveness. Meanwhile, Trial 3's undesirable Mouthfeel (7.0 ± 0.35) and Trial 1's subpar Taste (7.3 ± 0.29) suggest areas for improvement. The significant disparities in Aftertaste scores, with Trial 4 achieving 8.4 compared to the 6.8–7.4 range of the other trials, further highlight the necessity to resolve lingering off-flavors identified in non-optimized formulations. The visual aspects, particularly Appearance/Color, were consistently rated high in Trial 4, emphasizing the importance of aesthetics in consumer choices.

Looking ahead, it's crucial to replicate the successful parameters of Trial 4 to sustain its exemplary standards. For Trials 1–3 and 5, focused adjustments—such as refining ingredient ratios or processing durations—are necessary to minimize variability and enhance important attributes like aftertaste and mouthfeel. Implementing statistical analyses, such as ANOVA, will help validate the performance differences and guide iterative testing to elevate all variants to the benchmark set by Trial 4. This strategic approach aims to produce a competitively balanced end product that meets consumer expectations.

IV. CONCLUSION

The study demonstrates that sugarcane , when fermented with selected *S. cerevisiae* strains under controlled conditions, can yield high-quality rum with desirable sensory attributes. The use of borosilicate glass distillation ensures safety and efficiency at laboratory scale. Key aroma compounds like esters and aldehydes were significantly influenced by fermentation time and aging with lees. Analytical techniques confirmed regulatory compliance and provided a robust framework for quality assurance. These insights are valuable for scaling up artisanal rum production while maintaining consistency and safety.

The sensory evaluation results clearly demonstrate that Trial 4 stands out as the optimal formulation, achieving the highest scores in all assessed attributes—taste, mouthfeel, aroma, appearance, and overall acceptability—with minimal variability (±0.05). Its exceptional performance suggests a well-balanced recipe and controlled processing conditions, making it the benchmark for quality.

In contrast, Trials 1, 2, 3, and 5 exhibited inconsistencies, particularly in aftertaste, mouthfeel, and taste, indicating the need for refinement in ingredient selection or processing methods. Trial 3 performed the weakest, highlighting potential flaws in flavor retention and texture. Addressing these issues through targeted adjustments—such as modifying sweeteners, stabilizers, or processing times—could help align these variants with Trial 4's superior quality.

Moving forward, replicating Trial 4's successful parameters while optimizing underperforming trials should be the priority. Further statistical analysis and consumer testing can validate these findings, ensuring the final product meets both sensory and market expectations. By focusing on consistency and sensory excellence, this product can achieve strong consumer acceptance and competitive success.

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