



Conversion of Lignocellulosic Biomass into Bioethanol: Production, Yield Assessment and Physicochemical Evaluation of Rice Husk, Corn Cob and Sugarcane Bagasse

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Article History

Received: 12.03.2026
Accepted: 29.04.2026
Published: 21.05.2026

Abstract: This study investigated the production of bioethanol from selected agricultural residues rice husk, corn cob, and sugarcane bagasse with emphasis on yield performance and physicochemical characterization. The biomass samples (500 g each) were subjected to acid hydrolysis using 5% H_2SO_4 to break down lignocellulosic structures into fermentable sugars, followed by fermentation using *Saccharomyces cerevisiae*. Ethanol was recovered through distillation, and all experiments were conducted in triplicate to ensure accuracy and reproducibility. The results showed that sugarcane bagasse produced the highest bioethanol yield ($7.8\% \pm 0.26$), followed by corn cob ($6.8\% \pm 0.20$), and rice husk ($6.5\% \pm 0.20$), indicating superior fermentable sugar availability in sugarcane bagasse. Proximate analysis revealed low moisture content across samples, with sugarcane bagasse exhibiting the lowest value (6.1%). Volatile matter was high in all feedstocks (88.3–92.8%), while ash content remained minimal, confirming their suitability for bioenergy conversion. Compositional analysis indicated cellulose contents ranging from 30–45%, hemicellulose from 18–32%, and lignin from 15–28%, highlighting their potential as lignocellulosic feedstocks. Physicochemical characterization of the produced bioethanol confirmed fuel quality suitability. Density ranged from 0.787 to 0.791 g/cm³, pH from 5.2 to 6.0, viscosity from 1.16 to 1.20 cP, and flash point from 12 to 14 °C. Calorific values increased from 26.8 to 28.5 kJ/g, while ethanol purity ranged from 85% to 94%, with sugarcane bagasse showing the highest quality parameters. Overall, the study demonstrates that agricultural residues, particularly sugarcane bagasse, are promising feedstocks for sustainable bioethanol production, offering a viable pathway for renewable energy development, waste valorization, and environmental sustainability.

Keywords: Bioethanol, lignocellulosic biomass, agricultural residues, sugarcane bagasse, renewable energy, fermentation.

Cite this article:

Medinat, A. B., Pascal Chima, M., and Obaje David, O., (2026). Conversion of Lignocellulosic Biomass into Bioethanol: Production, Yield Assessment and Physicochemical Evaluation of Rice Husk, Corn Cob and Sugarcane Bagasse. *ISAR Journal of Agriculture and Biology*, 4(5), 9-14.



Introduction

The increasing global demand for energy, coupled with the depletion of fossil fuel reserves and rising environmental concerns, has intensified the search for sustainable and renewable energy alternatives. Conventional petroleum-based fuels remain the dominant source of energy for transportation, electricity generation, and industrial operations. However, the scarcity and fluctuating prices of these fuels have imposed significant economic burdens on households, industries, and national economies. Furthermore, the continuous utilization of fossil fuels contributes substantially to greenhouse gas emissions, environmental pollution, and climate change, thereby necessitating the development of cleaner and renewable energy sources (Kaniapan et al., 2022; Koul et al., 2022; Li et al., 2017).

In many developing countries, including Nigeria, agricultural activities generate large quantities of residues such as rice husk, corn cob, and sugarcane bagasse. These agro-residues are commonly regarded as waste materials and are often disposed of through open burning or indiscriminate dumping. Such disposal practices contribute to environmental degradation, air pollution, and waste management challenges. Despite their environmental implications, these agricultural wastes possess significant lignocellulosic components that make them promising feedstocks for biofuel production, particularly bioethanol (Saha, 2018; Limayem & Ricke, 2012).

Bioethanol is a renewable and environmentally friendly fuel that can serve as an alternative or supplement to conventional fossil fuels. It has gained considerable attention due to its biodegradability, lower carbon emissions, and potential to enhance energy security. Bioethanol can be produced from various biomass materials through fermentation processes involving the conversion of cellulose and hemicellulose into fermentable sugars. The use of agricultural residues for bioethanol production offers additional benefits such as waste reduction, environmental protection, and the generation of value-added products from low-cost raw materials (Kaniapan et al., 2022).

However, the production of bioethanol in Nigeria has largely relied on food-based feedstocks such as cassava, maize grains, and sugar crops. The utilization of these food materials for fuel production has raised concerns regarding food security, increased production costs, and competition between food and fuel demands. These challenges have limited the large-scale adoption and economic sustainability of bioethanol production within the country (Igwebuike et al., 2024; Edeh, 2020; Ohimain, 2010; Oni et al., 2020). Consequently, there is growing interest in exploring non-food agricultural residues as alternative feedstocks for bioethanol production.

Nigeria, particularly agriculturally productive regions such as Nasarawa State, generates substantial quantities of rice husk, corn cob, and sugarcane bagasse annually (Ohimain, 2016; Food and Agriculture Organization, 2018). These residues are abundant, inexpensive, and renewable, yet they remain largely underutilized. Their high lignocellulosic composition makes them suitable candidates for bioethanol production. Nevertheless, there is limited empirical information regarding the efficiency of converting these agro-wastes into bioethanol and the physicochemical quality of the resulting fuel products under local conditions.

Therefore, there is a need to investigate the feasibility of producing bioethanol from rice husk, corn cob, and sugarcane bagasse and to evaluate the physicochemical properties of the bioethanol produced. Such evaluation is necessary to determine whether the bioethanol meets established fuel quality standards and can serve as a viable renewable energy source. This study seeks to contribute to sustainable energy development by assessing the potential of selected agricultural residues as alternative feedstocks for bioethanol production in Nigeria.

Materials and Methods

Study Area

This study was conducted in Nasarawa State, North-Central Nigeria, an agriculturally productive region known for large-scale cultivation and processing of rice, maize, and sugarcane. Samples were collected from Lafia, Karu, and Keffi Local Government Areas, where rice mills, maize farms, and sugarcane processing activities generate substantial quantities of agricultural residues. These residues, particularly rice husk, corn cob, and sugarcane bagasse, are commonly discarded or openly burned, contributing to environmental pollution and waste management challenges. Their abundance and accessibility make the region suitable for bioethanol production studies.

Materials and Sample Collection

The major feedstocks used for this study were rice husk, corn cob, and sugarcane bagasse. Rice husk was obtained from Bukan Sidi Rice Mill in Lafia, corn cob from a maize farm in New Karu, and sugarcane bagasse from sugarcane juice vendors in Karu, Nasarawa State. Other materials used included dilute sulfuric acid (H_2SO_4), sodium hydroxide (NaOH), hydrogen peroxide (H_2O_2), ammonia solution (NH_4OH), yeast (*Saccharomyces cerevisiae*), and distilled water.

Sample Preparation and Hydrolysis

The collected biomass samples were air-dried at room temperature for seven days to reduce moisture content. The dried samples were ground using a Kenwood blender and sieved to obtain uniform particle sizes of ≤ 2 mm. The powdered samples were stored in airtight containers prior to analysis.

Hydrolysis was carried out following the method of Adiya et al. (2022) with slight modifications. About 500 g of each biomass sample was treated with 500 mL of 5% sulfuric acid and sterilized at 168 °C for 25 minutes. The mixtures were cooled and allowed to hydrolyze for seven days. After filtration, the pH was adjusted to 6.5 using NaOH to create favorable conditions for fermentation. Benedict's test was subsequently conducted to confirm the presence of reducing sugars.

Fermentation and Ethanol Recovery

Fermentation was performed using *Saccharomyces cerevisiae* activated in peptone water. Approximately 3 g of yeast was added to each hydrolyzed substrate and allowed to ferment, with carbon dioxide evolution used as an indicator of fermentation activity. Following fermentation, the broth was filtered and distilled at 78–80 °C using a Liebig condenser to recover ethanol. Distillation continued until no further ethanol was detected. The ethanol obtained was stored in amber bottles at 4 °C prior to characterization.

Bioethanol yield was calculated using the expression:

Bioethanol Yield (%) = Volume of ethanol obtained / Volume of hydrolysate used $\times$ 100

Physicochemical Characterization of Bioethanol

The produced bioethanol samples were characterized for density, pH, viscosity, flash point, calorific value, and ethanol purity using standard ASTM procedures. Density was determined using the pycnometric method at 25 °C, while pH was measured with a calibrated digital pH meter. Viscosity measurements were conducted using an Ostwald viscometer maintained at constant temperature conditions.

Flash point determination was carried out using the Pensky–Martens closed-cup apparatus in accordance with ASTM standards to evaluate the volatility and safety characteristics of the fuel. Calorific value was determined using a bomb calorimeter, where the heat released during combustion was measured and expressed in kJ/g. Ethanol purity was analyzed primarily using gas chromatography equipped with a flame ionization detector (FID), while hydrometric methods were employed where necessary.

Chemical Composition Analysis

The lignocellulosic composition of the biomass feedstocks was evaluated by determining hemicellulose, cellulose, and lignin contents using detergent fiber analysis methods. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) methods were employed for hemicellulose determination, calculated as:

Hemicellulose (%) = NDF - ADF

Cellulose content was determined from the difference between acid detergent fiber and acid detergent lignin fractions, while lignin content was measured using the Acid Detergent Lignin (ADL) method based on the Van Soest fiber fractionation procedure. All analyses were carried out in triplicate to ensure accuracy and reproducibility of results.

The characterization of the feedstocks and produced bioethanol provided essential information regarding the suitability of rice husk, corn cob, and sugarcane bagasse as alternative raw materials for sustainable bioethanol production.

Lignin, Ash, and Extractives Determination

Lignin content of the lignocellulosic feedstocks was determined using the Acid Detergent Lignin (ADL) method. The acid detergent fiber residue was treated with 72% sulfuric acid and hydrolyzed under controlled conditions to remove cellulose, leaving lignin as the insoluble fraction. The residue was filtered, washed to neutrality, oven-dried at 105 °C, and weighed. To improve accuracy, the residue was further ashed in a muffle furnace at 550 °C to correct for mineral content. Lignin content was calculated as the difference between the ADL fraction and ash content. All analyses were performed in triplicate for rice husk, corn cob, and sugarcane bagasse. The lignin fraction represented the non-carbohydrate structural polymer that resists enzymatic hydrolysis and influences bioethanol conversion efficiency.

Ash content was determined using the standard dry ashing method. Approximately 2.0 g of each biomass sample was weighed into pre-weighed porcelain crucibles and initially charred to prevent sample loss. The samples were then combusted in a muffle furnace at 550 $\pm$ 25 °C for 4–6 hours until a light grey residue was obtained. After cooling in a desiccator, the crucibles were reweighed, and ash content was calculated as the percentage inorganic residue remaining after combustion. The ash fraction represented the mineral composition of the biomass, which affects pretreatment and fermentation performance during bioethanol production.

Extractives content was determined using the Soxhlet solvent extraction method (TAPPI T204). About 2.0–5.0 g of each sample was extracted continuously for 6–8 hours using an ethanol–toluene solvent mixture (2:1 v/v). The extraction removed soluble compounds such as waxes, fats, sugars, tannins, and resins. After extraction, the residue was dried to constant weight, and extractives content was calculated from the observed weight loss. The extractive fraction represented the easily soluble organic compounds that may influence pretreatment efficiency, fermentation activity, and overall ethanol yield. All analyses were conducted in triplicate to ensure accuracy and reproducibility.

Proximate Analysis of Feedstocks

Proximate analysis was carried out on rice husk, corn cob, and sugarcane bagasse to determine their fundamental compositional and thermal properties relevant to bioethanol production. The parameters analyzed included moisture content, volatile matter, ash content, and fixed residue.

Moisture content was determined by drying 500 g of each sample in a hot air oven at 105 °C until constant weight was achieved. The reduction in weight after drying was recorded as moisture content. Volatile matter was determined by heating the oven-dried samples in covered crucibles at approximately 950 °C in a muffle furnace. The weight loss, excluding moisture, represented the volatile organic fraction of the biomass.

Ash content was measured by combusting the samples in uncovered crucibles at 550–600 °C until complete oxidation of organic matter occurred, leaving only inorganic residue. Fixed residue (fixed carbon equivalent) was calculated indirectly by subtracting the sum of moisture content, volatile matter, and ash content from 100%.

All analyses were performed in triplicate, and mean values were reported. The proximate analysis provided important information regarding the composition, thermal stability, and suitability of the selected agricultural residues for sustainable bioethanol production.

Results and Discussion

Results

The results obtained from the chemical composition of the biomass feedstocks, bioethanol yield, physicochemical properties, and proximate analysis of the produced bioethanol are presented in Tables 4.1–4.4.

Table 4.1: Chemical Composition of Biomass Feedstocks (%)

Component (%)	Corn Cob (Mean ± SD)	Sugarcane Bagasse (Mean ± SD)	Rice Husk (Mean ± SD)
Cellulose	38.33 ± 2.04	40.45 ± 0.16	30.35 ± 0.96
Hemicellulose	28.32 ± 2.04	25.30 ± 2.99	18.22 ± 0.96
Lignin	15.18 ± 0.22	18.22 ± 1.34	20.25 ± 0.83
Ash	2.50 ± 0.17	1.40 ± 0.06	15.20 ± 0.17
Extractives	3.60 ± 0.06	2.50 ± 1.83	2.40 ± 2.73

Table 4.2: Bioethanol Yield from Selected Biomass Feedstocks

Feedstock	Hydrolysate Volume (mL)	Ethanol Volume (mL)	Bioethanol Yield (%)	Mean Yield (%) ± SD
Rice Husk	500	30	6.0	6.5 ± 0.02
Corn Cob	500	34	6.8	7.0 ± 0.06
Sugarcane Bagasse	500	38	7.8	7.8 ± 0.04

Table 4.3: Physicochemical Properties of Produced Bioethanol

Parameter	Rice Husk	Corn Cob	Sugarcane Bagasse
Density (g/cm³)	0.787	0.789	0.791
pH	5.2	5.5	6.0
Viscosity (cP)	1.20	1.18	1.16
Flash Point (°C)	14	13	12
Calorific Value (kJ/g)	26.8	27.3	28.5
Ethanol Purity (%)	85	90	94

Table 4.4: Proximate Analysis of Produced Bioethanol

Proximate Parameter	Corn Cob Bioethanol (%)	Rice Husk Bioethanol (%)	Sugarcane Bagasse Bioethanol (%)
Moisture Content	8.4 ± 1.43	10.2 ± 2.15	6.1 ± 3.88
Volatile Matter	90.1 ± 1.43	88.3 ± 2.15	92.8 ± 3.88
Fixed Residue	1.15 ± 0.03	1.02 ± 0.05	0.89 ± 0.03

Discussion and Summary

The chemical composition of the biomass feedstocks revealed that sugarcane bagasse had the highest cellulose content (40.45%), followed by corn cob (38.33%), while rice husk had the lowest (30.35%). High cellulose content indicates greater potential for fermentable sugar production, which is essential for bioethanol yield. Rice husk exhibited the highest lignin (20.25%) and ash content (15.20%), suggesting stronger recalcitrance and reduced digestibility compared to the other feedstocks.

Bioethanol yield results showed that sugarcane bagasse produced the highest ethanol yield (7.8%), followed by corn cob (7.0%), while rice husk recorded the lowest (6.5%). This trend aligns with the cellulose availability and lower inhibitory ash content in sugarcane bagasse, making it a more efficient substrate for fermentation.

Physicochemical characterization indicated that all ethanol samples had densities within the acceptable range for bioethanol, with values increasing slightly from rice husk to sugarcane bagasse. The pH values ranged from mildly acidic to near-neutral conditions, while viscosity values were low and typical of ethanol-based fuels. Flash point values confirmed the high volatility of the produced ethanol, which is characteristic of biofuels.

Calorific value increased progressively from rice husk (26.8 kJ/g) to sugarcane bagasse (28.5 kJ/g), indicating higher energy content in ethanol derived from feedstocks with better fermentable sugar composition. Similarly, ethanol purity improved from 85% in rice husk to 94% in sugarcane bagasse, further confirming the superiority of sugarcane bagasse as a feedstock for high-quality bioethanol production.

Proximate analysis of the produced ethanol showed high volatile matter content across all samples (>88%), indicating good fuel

volatility and combustion potential. Moisture content was relatively low, with sugarcane bagasse ethanol showing the least moisture, which enhances fuel stability. Fixed residue values were minimal, indicating high fuel cleanliness and efficient conversion.

Overall, the results demonstrate that sugarcane bagasse is the most efficient feedstock among the three studied materials for bioethanol production, followed by corn cob, while rice husk exhibited the least efficiency due to its higher lignin and ash content.

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