Bioethanol Production from Coconut Husk Using Alkaline Pretreatment and Acid Hydrolysis

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ABSTRACT

This study investigates the potential of coconut husk (Cocos nucifera) as a feedstock for bioethanol production, focusing on the effects of alkaline pretreatment with potassium hydroxide (KOH) and acid hydrolysis with sulfuric acid (H_2SO_4) on ethanol yield. The coconut husk was subjected to 5% KOH pretreatment followed by acid hydrolysis with 4% and 5% H_2SO_4, enhancing cellulose accessibility and releasing fermentable sugars. Fermentation using Saccharomyces cerevisiae was performed at 37°C for varying periods (5 to 11 days). The highest ethanol yield of 5.72% was achieved after 11 days of fermentation with 5% H_2SO_4. Physicochemical analysis of the bioethanol produced showed properties within expected ranges for fuel-grade ethanol. These results highlight the viability of coconut husk as a sustainable, cost-effective raw material for bioethanol production, offering a renewable energy source while addressing agricultural waste management.

1. Introduction

The increasing global demand for energy, coupled with the environmental challenges posed by fossil fuel consumption, has spurred interest in renewable energy sources. Among these, bioethanol has emerged as a promising alternative, primarily due to its potential to reduce greenhouse gas emissions and decrease dependence on petroleum-based fuels. Bioethanol is typically produced through the fermentation of sugars derived from a variety of feedstocks, including food crops such as sugarcane, corn, and potatoes, as well as lignocellulosic materials like agricultural waste. Lignocellulosic biomass, in particular, is of great interest because it is abundant, cost-effective, and can be processed into bioethanol through established biochemical routes [Quintero et al., 2011; Sarkar et al., 2012].

Coconut husk (Cocos nucifera), a lignocellulosic by-product of coconut processing, is particularly appealing for bioethanol production [Abbasi et al., 2010]. Despite its wide availability in tropical regions, the majority of coconut husk is discarded after the extraction of coconut milk. This agricultural waste contains high levels of cellulose and hemicelluloses, making it a suitable substrate for bioethanol production. Moreover, utilizing coconut husk for bioethanol production can help mitigate the environmental impact of coconut processing by providing a sustainable outlet for waste material. Given its abundant presence and relatively low cost, coconut husk presents a viable raw material for developing renewable bioethanol production systems, contributing both to energy sustainability and waste management [Lathika et al., 2005; Demirbos et al., 2009;

Vaithanomsat et al., 2011; Ding et al., 2012; Soares et al., 2016; Nguyen et al., 2017; Bolivar-Telleria et al., 2018; Karun et al., 2019; Archana et al., 2020].

The production of bioethanol from lignocellulosic materials involves several key processes, including pretreatment, hydrolysis, and fermentation. The first step, pretreatment, is crucial for breaking down the complex lignocellulosic structure to make the cellulose and hemicellulose more accessible for further conversion into fermentable sugars. Common pretreatment methods include alkaline and acid treatments, which serve to break the lignin bonds and release the sugars locked within the biomass. After pretreatment, hydrolysis is performed to convert the cellulose and hemicellulose into simpler sugars, such as glucose, which can then be fermented by microorganisms to produce ethanol.

Fermentation, typically carried out using yeast strains such as Saccharomyces cerevisiae, is the next critical step in the bioethanol production process. Yeast fermentation converts the sugars into ethanol and carbon dioxide, with the ethanol being the desired product. The final step in the process involves distillation, which separates and purifies the ethanol from the fermentation broth, yielding a high-concentration ethanol product suitable for use as a fuel or fuel additive [Kádár et al., 2004; Plessas et al., 2007; Talebnia et al., 2010; Gonçalves et al., 2016].

This study investigates the production of bioethanol from coconut husk, focusing on the application of alkaline pretreatment with potassium hydroxide (KOH), acid pretreatment with sulfuric acid (H_2SO_4), hydrolysis, and fermentation using baker's yeast. The aim is to evaluate the potential of coconut husk as a cost-effective, renewable feedstock for bioethanol production, while also contributing to the management of agricultural waste. The effectiveness of the different pretreatment methods in enhancing sugar yield, as well as the overall efficiency of the bioethanol production process, is explored. The results of this study could provide valuable insights into the scalability of coconut husk as a bioethanol feedstock and support its adoption as part of a more sustainable energy solution.

2. Materials and Methods

2.1. Preparation of Raw Material

Tender coconuts were procured from Tharamangalam, Salem, Tamil Nadu, India. The outer husk, or coconut fibre, was carefully separated from the inner fruit and cut into smaller, uniform pieces to facilitate processing. The coconut fibre was then stored at room temperature to prevent microbial contamination or degradation prior to further use.

2.2. Alkaline Pretreatment and Acid Hydrolysis

For the pretreatment of the coconut fibre, a 100g sample was subjected to alkaline treatment using a 5% KOH solution. The treatment was performed in an autoclave at 121°C for 15 minutes under pressure. This process aimed to break the lignin bonds, thereby improving the accessibility of cellulose and hemicellulose for subsequent hydrolysis. After pretreatment, the fibre was washed thoroughly to neutralize any residual alkali and then dried at 85°C for 4 hours to remove moisture.

Following the alkaline pretreatment, two different acid hydrolysis conditions were applied to the dried coconut fibre. For sample A, 4% H_2SO_4 was used, while for sample B, a 5% H_2SO_4 solution was employed. Both samples were subjected to hydrolysis in an autoclave at 121°C for 15 minutes. This acid treatment facilitated the breakdown of hemicellulose and the release of fermentable sugars, primarily xylose, which are essential for the fermentation process [Vaithanomsat et al., 2011; Goncalves et al., 2015].

2.3. Fermentation

Once the acid hydrolysis was complete, the resulting slurry was cooled and its pH was adjusted to the optimal range for yeast fermentation (4.5-5.0) using a KOH solution. The pH adjustment was necessary to create a suitable environment for the growth of Saccharomyces cerevisiae, the baker's yeast used in this study. Baker's yeast was prepared by dissolving 5g of yeast in 100mL of sterile water, and this was then added to the cooled hydrolyzed slurry. The mixture was stirred at 150 rpm to ensure homogeneity.

Fermentation was carried out at a constant temperature of 37°C for varying durations (5, 7, 9, and 11 days), with samples taken at regular intervals to monitor the progress of fermentation. During this time, yeast consumed the available sugars and produced ethanol as a metabolic by-product. After fermentation, the slurry was filtered to remove solid residues, and the filtrate was subjected to purification by distillation to separate ethanol from the remaining liquid [Ding et al., 2012].

2.4. Distillation

Following fermentation, the ethanol-water mixture was subjected to simple distillation. This process utilized the difference in boiling points between ethanol (78.37°C) and water (100°C) to separate the ethanol from the aqueous solution. The ethanol, which has a lower boiling point than water, evaporated first, was condensed, and collected as the distillate, while the water remained in the distillation flask. This method allowed for the concentration and purification of ethanol for further analysis.

2.5. Analytical Methods

The presence of ethanol in the distillate was confirmed using the refractive index, a common method for detecting ethanol in liquid mixtures. In addition to confirming the presence of ethanol, various physicochemical properties of the distillate, including viscosity, density, boiling point, and flashpoint, were measured to assess the quality and purity of the ethanol produced. Fourier Transform Infrared Spectroscopy (FT-IR) was employed to analyze the functional groups present in the ethanol, providing qualitative information about the chemical composition of the distillate. Additionally, Gas Chromatography (GC) was used to further identify and quantify the individual organic compounds present in the sample, offering a detailed composition analysis of the fermentation product [Vlachos et al., 2006; Cabral et al., 2016; Phwan et al., 2019].

2.6. Determination of Composition in the Sample

Ethanol production, ash content, cellulose content, and glucose concentration were determined to assess the composition of the raw material and the efficiency of the pretreatment, hydrolysis, and fermentation processes. The presence of ethanol in the fermentation samples was monitored at regular intervals (0, 5, 7, 9, and 11 days) by measuring the refractive index, which is directly correlated with ethanol concentration. This method allowed for tracking the production of ethanol over time during the fermentation process.

The inorganic content of the coconut fibre was quantified by determining the ash content. A known weight of the dried fibre sample was incinerated in a muffle furnace at 550°C for 6 hours. The remaining ash was then weighed, and the percentage of ash in the sample was calculated to evaluate the non-organic material in the coconut fibre.

Cellulose content was determined using a standard two-step analytical procedure. First, hemicellulose and lignin were extracted through acid or alkali treatments. Then, the remaining

cellulose was quantified using the anthrone reagent method, which provided an estimate of the cellulose fraction remaining in the coconut fibre after the pretreatment process.

The glucose concentration in the hydrolyzed samples was quantified using the dinitrosalicylic acid (DNS) method, which is based on the reduction of the DNS reagent by glucose. The glucose concentration was determined by comparing the color intensity of the reaction to a standard glucose solution.

These analyses provided essential information on the composition of the raw coconut fibre, the effectiveness of the pretreatment and hydrolysis methods, and the overall yield of ethanol during fermentation. The results helped evaluate the potential of coconut husk as a sustainable feedstock for bioethanol production and highlighted the impact of different pretreatment conditions on the final ethanol yield [Taherzadeh et al., 2008; Hallac et al., 2011; Van Wychen et al., 2016].

3. Results and Discussion

The results from this study demonstrate that the pretreatment and fermentation processes significantly influenced the yield and quality of bioethanol produced from coconut husk. The alkaline pretreatment with 5% KOH effectively reduced the lignin content in the coconut fibre, enhancing the accessibility of cellulose for hydrolysis. Acid hydrolysis with H_2SO_4 further facilitated the breakdown of hemicelluloses, releasing fermentable sugars. The fermentation process was monitored over different time intervals, and the ethanol yield progressively increased, with the highest yield obtained after 11 days of fermentation.

3.1. Refractive Index (Ri)

The refractive index (Ri) of both Sample A (4% H_2SO_4) and Sample B (5% H_2SO_4) was measured before and after fermentation (summarized in Table 1), as it serves as a simple indicator of ethanol concentration in the fermentation broth. The Ri values in Figure 1 showed a slight but consistent increase over time, confirming the production of ethanol during fermentation. As fermentation progressed, ethanol accumulation led to a gradual increase in the refractive index. At the start of fermentation (day 0), the Ri values for both samples were nearly identical (0.336 for Sample A and 0.337 for Sample B). By day 11, the refractive index for Sample A reached 0.342, and for Sample B, it was 0.345, reflecting the increase in ethanol concentration over the fermentation period. This trend suggests that the fermentation process was successful and that ethanol was produced steadily over the course of the experiment.

Table 1: Refractive index of Samples A & B

No of days	Sample A	R_i value	Sample B	R_i value
0	A1	0.336	B1	0.337
5	A2	0.340	B2	0.341
7	A3	0.341	B3	0.343
9	A4	0.342	B4	0.345
11	A5	0.342	B5	0.345

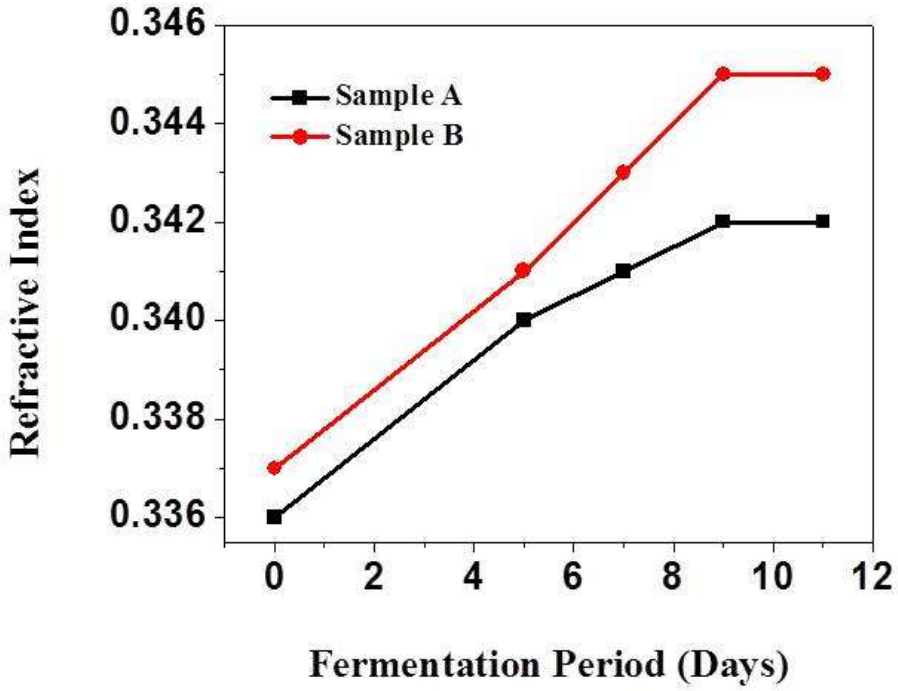

Fig. 1: Calibration plot between fermentation period and refractive index

3.2. Properties of Bioethanol

The properties of the bioethanol produced were compared with known values to assess its quality and suitability for use as a fuel. The experimental values for viscosity, density, boiling point, flashpoint, and calorific value were determined (summarized in Table 2), and these properties were found to be within the expected ranges for bioethanol. The FT-IR spectra in Figure 2 for both samples showed a prominent absorbance peak between 3000-3500 cm^{-1}, which is characteristic of hydroxyl (–OH) groups, confirming the presence of alcohol in the bioethanol produced. This result aligns with the successful fermentation of the sugars present in the coconut husk into ethanol.

Table 2: Properties of Ethanol produced

S.NO	Parameter	Units	Actual values	Experimental values
1.	Viscosity 40℃	m^2/s	1.525	4.8
2.	Density 15℃	g/cm^2	0.789	0.91
3.	Flashpoint	℃	68.3	65.7
4.	Boiling point	℃	78.37	78
5.	Specific gravity	-	0.787	0.789
6.	Water content	-	-	0.08
7.	Calorific value	mJ/kg	29.3	32.5

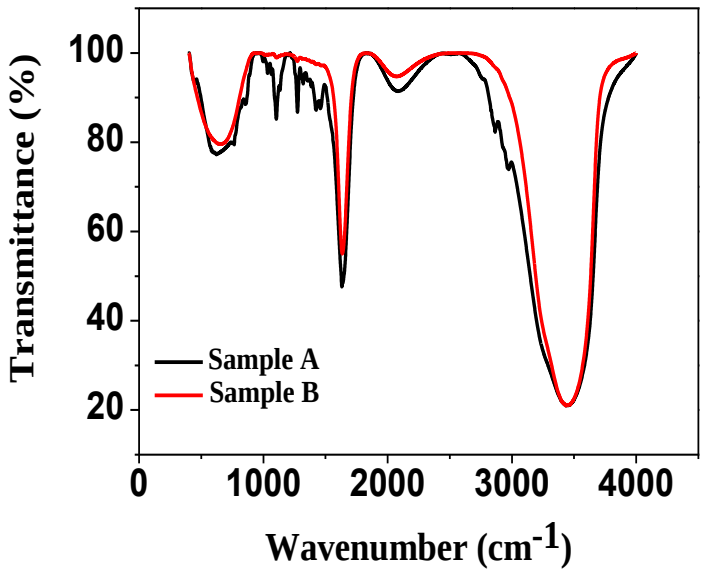

Fig. 2: FT-IR Spectra of obtained sample A and sample B

3.3. Composition of Coconut Fibre

The initial composition of coconut husk fibre was analyzed and summarized in Table 3. Figure 3 revealing cellulose content of 18.65% in Sample A (4% H_2SO_4) and 19.58% in Sample B (5% H_2SO_4). Additionally, the ash content was found to be 1.24% in Sample A and 1.10% in Sample B, while glucose content was 6.68% in Sample A and 7.04% in Sample B. After the fermentation process, the ethanol content increased significantly, reaching 5.34% in Sample A and 5.72% in Sample B, indicating the successful conversion of glucose into ethanol. These results confirm that both pretreatment methods (alkaline and acid) were effective in breaking down the lignocellulosic material and releasing fermentable sugars, which were subsequently converted to ethanol during fermentation.

Table 3: Initial composition of coconut

S.No	Parameters	Dry weight (%)	
		Sample A	Sample B
1.	Cellulose	18.65	19.58
2.	Ash	1.24	1.10
3.	Glucose	6.68	7.04
4.	Ethanol	5.34	5.72

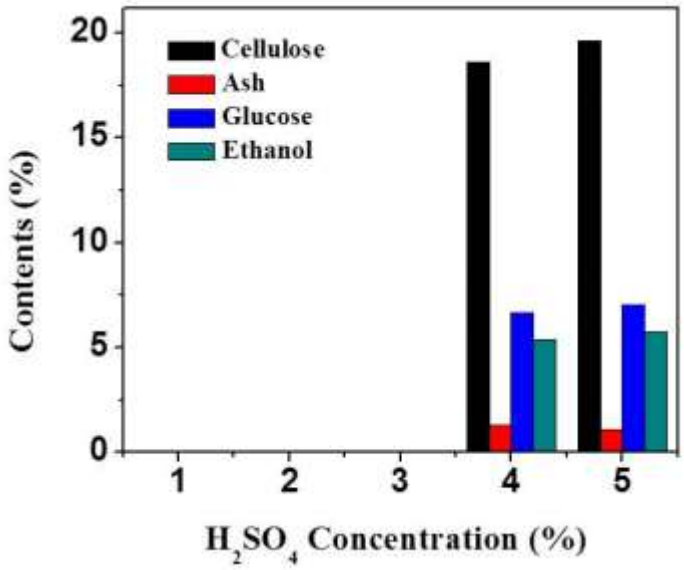

Fig. 3: Illustrates the relationship between H_2SO_4 concentration and the different product contents

3.4. Fermentation Period vs Ethanol Yield

The fermentation period played a critical role in determining the final ethanol yield. As illustrated in Figure 4, ethanol concentration increased progressively over time, with the highest yield achieved after 11 days of fermentation. Sample B (5% H_2SO_4) showed the highest ethanol content of 5.72% after 11 days of fermentation, compared to 5.34% in Sample A (4% H_2SO_4). This suggests that a higher concentration of sulfuric acid (5%) in the pretreatment phase led to more efficient hydrolysis and a higher yield of fermentable sugars, resulting in a greater ethanol output. Furthermore, the longer fermentation period allowed the yeast to metabolize more sugars, reaching the optimal fermentation phase and maximizing ethanol production.

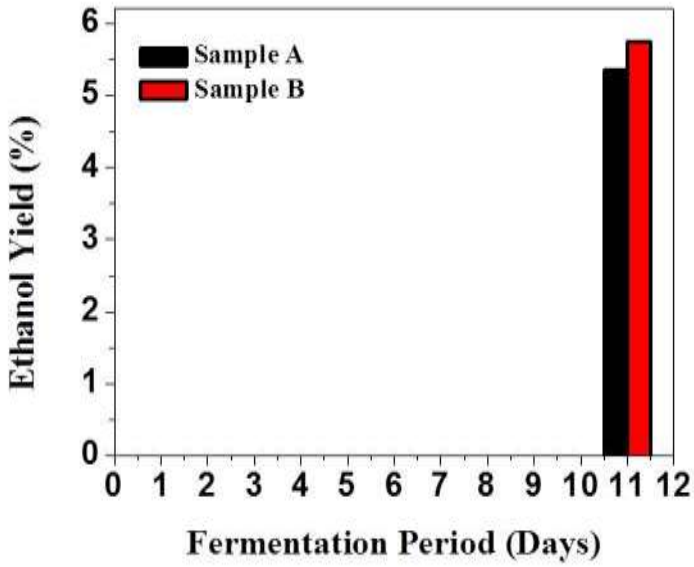

Fig. 4: Illustrates the relationship between fermentation period and ethanol yield

4. Conclusion

This study demonstrates the potential of coconut husk as a sustainable feedstock for bioethanol production. Alkaline pretreatment with 5% KOH and acid hydrolysis using 4% and 5% H_2SO_4 effectively enhanced the accessibility of cellulose and released fermentable sugars, leading to ethanol production. The highest ethanol yield of 5.72% was achieved with 5% H_2SO_4 after 11 days of fermentation, highlighting the importance of H_2SO_4 concentration and fermentation duration. The physicochemical properties of the produced ethanol were within expected ranges, confirming the viability of coconut husk for bioethanol production. These results indicate that coconut husk can be a cost-effective and renewable source for bioethanol, contributing to both energy sustainability and waste management.

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