Evaluation of Young Coconut Husks for Bioethanol Production

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Abstract: *Bioethanol is a renewable energy fuel that can be used in place of gasoline, a fossil fuel. Bioethanol has been produced over time from sugar and starch feedstock. However, because these raw materials are food sources, the feedstock may compete with food supply. Recent research has concentrated on producing bioethanol from non-food sources, particularly agricultural and forestry waste. A young coconut is an immature coconut that is typically harvested before it has reached full maturity. Its husks are inedible to humans and animals, and they pose a significant environmental challenge due to their slow decomposition.This study investigates the potential of young coconut husks, an agricultural waste, for bioethanol production. The research uses the Designer Energy Ltd procedure for biomass analysis and ChemCAD for simulating bioethanol yield. The findings reveal that young coconut husks, containing 33.27 cellulose, 12.85 hemicellulose, and 30.84 lignin, can be a viable feedstock for bioethanol production. The study contributes to the development of sustainable energy solutions.*

Keywords: Bioethanol, Energy Efficiency, Optimization, YCH, Yield

1. Introduction

The development of renewable energy sources is critical because it is a promising alternative that will allow us to reduce our reliance on fossil fuels [1]. Biofuels have received a lot of attention as the demand for energy resources has increased, as have concerns about greenhouse gas emissions. Biofuels, unlike other green energy resources, can provide liquid fuels, which are required for transportation [2]. Biofuels are classified into three groups based on their feedstocks and method of production: first, second, and third generation biofuels. First-generation biofuels are made from edible biomass, such as starch from potatoes, wheat, barley, and corn or sugars from sugarcane and sugar beet[3]. This initially demonstrated a promising capability in reducing fossil fuel combustion and lowering atmospheric levels of CO_2 that crops consume as they grow (Jeswani et al., 2020). Concerns have been raised, however, about the use of edible crops as feedstocks and the effects on croplands, biodiversity, and food supply. The second generation of biofuels are based on more efficient renewable alternatives by utilizing inedible lignocellulosic biomass such as switch grass, sawdust, low-priced woods, crop wastes, and municipal wastes [4] . The production of biofuels from waste contributes to waste reduction, proper waste disposal, and sanitation. Bioethanol is a liquid biofuel that can be produced from a variety of low-cost substrates and can replace gasoline as a transportation fuel. As ethical concerns have accelerated the shift to non-food feedstock for bioethanol production, second generation bioethanol production fills the impractical gap left by first generation bioethanol production by employing non-edible feedstock derived from agricultural and forestry wastes [5].Young coconut husks are among the most commonly produced wastes, particularly along the coasts of Eastern Africa. This study is much focused on investigating the chemical composition of these husks and their ability to produce bioethanol.

Bioethanol production from lignocellulosic biomass has primarily occurred in Brazil, the United States, China, and India. However, there has been little research and adoption of bioethanol production from lignocellulosic biomass in Kenya [6]. Pretreatment, saccharification, fermentation, and ethanol dehydration are steps in the production of bioethanol from lignocellulosic biomass. Lignocellulose is the main structural component of plant cell walls and is made up of three different polymers: polysaccharides (cellulose and hemicelluloses) and lignin. Only cellulose and hemicelluloses can be used to produce bioethanol from lignocellulose structural polymers [7]. The husk accounts for about 80% of the green coconut mass[8] and it is often discarded in inappropriate locations, causing pollution and increasing handling costs for farmers[9]. Kenya has the potential to industrialize the production of coconut value-added products in order to diversify product utilization and the overall economy. The potential of young coconut husk to be used as feedstock in bioethanol production is one of the technological developments and advances in product utilization in coconut by products. However, coconut wastes in Kenya remain largely unexplored for bioethanol production, despite their significant contribution to environmental pollution due to their slow natural degradation. With so much emphasis on producing sustainable and renewable fuels, unexplored feedstock must be thoroughly researched.

Bioethanol production from lignocellulosic biomass constitutes pretreatment, saccharification, fermentation and ethanol dehydration. Pretreatment of lignocellulose biomass

is critical for the disintegration of its three components and subsequent high-efficiency conversion to bioenergy [10]. Hydrolysis comes after the pretreatment process and it involves the conversion of polymeric carbohydrate (cellulose and hemicellulose) to produce sugar monomers which are fermented to produce bioethanol. Cellulose is a major component of lignocellulosic agricultural wastes with high variation in their chemical composition[11]. As a result, it is critical to investigate the chemical composition of the husk because the percentage of cellulose can vary depending on variety and geographical location. Given the large amounts of waste generated by coconuts, there is a possibility of establishing pilot plants for bioethanol production, given the existence of industrial technologies for bioethanol production from lignocellulosic biomass. Considering the global importance of bioethanol production and the expected increase in lignocellulosic bioethanol production volumes in future climate change mitigation scenarios, detailed analyses of the effects of different feedstocks on conversion yields, emission factors, and mass and energy balances are required [12].Prior to establishing the plant, process simulation allows for the study of yield, plant efficiency, and a thorough understanding of the conversion to bioethanol. Furthermore, for the production process to be cost effective, process optimization should be prioritized.

The purpose of this study is to assess the bioethanol production potential of young coconut husks of the East African Tall type variety. This will provide access to a much broader range of non-food feedstock as well as a resourceful way of disposing of agricultural waste, which has been a major environmental problem. In light of current biofuels research, young coconut husks have been characterized to determine their chemical composition. The Bioethanol yield of the process was evaluated using simulation. Following that, the process was optimized in terms of acid concentration for hydrolysis and fermentation PH.

2. Bioethanol Production

The chemical composition of lignocellulosic biomass must be determined in order to develop a viable pretreatment technology to break its rigid structure and ferment the sugars into bioethanol. Chemical analysis of the husks was done using the Designer Energy Ltd[13], an improved method that is based on the isolation of holocellulose, i.e. total polysaccharides containing both cellulose and hemicelluloses. Because of the numerous available pathways, technologies, unit operations, and parameters, the flowsheet for lignocellulose conversion to bioethanol is developed using process simulators, the study employed CHEMCAD [14]. The optimization was carried out in a laboratory experiment, following the stages of bioethanol production, which included pretreatment, hydrolysis, fermentation, and ethanol recovery. According to [15], alkaline pretreatment is preferable due to biomass delignification and crystallinity reduction. Most studies on bioethanol production from coconut husk use enzymatic hydrolysis; however, due to its high cost, enzymatic hydrolysis is the economic bottleneck of lignocellulosic bioethanol production [16].Effective lignin removal and increased ethanol yield from coconut fiber using alkaline

pretreatment and acid hydrolysis was reported by [17]. This knowledge aids in the simulation and optimization of key production stages.

3. Methodology

In this section biomass characterization, simulation of the bioethanol yield and experimental evaluation of bioethanol production from young coconut husks are presented.

3.1 Young coconut husks characterization

Young coconuts of the East African Tall type, a coconut variety generally found along Eastern Africa, were used in this study. The young coconuts are mostly sold along the streets for their sweet water and the flesh (kernel) withother parts mostly discarded. The husk is the biggest portion of the waste generated by the young coconuts. The coconut husk/coir is the part of the coconut fruit that produces fibre which is mostly used for making ropes, door mats and rugs. The husks were washed, dried and grinded to increase their surface area. Approximately 50 g biomass sample was extracted by the Soxhlet extraction method with an organic solvent (ethanol).Thereafter, the extract was separated from the ethanol using a rotary vacuum evaporator (HS-2005S). The ethanol solvent was removed and the biomass sample left in the flask as a solid residue for further analysis to determine the content of lignin, cellulose and hemicelluloses.

3.1.1 Chemical Analysis of sample:
The sample was analyzed step wisely through the procedure for quantitative analysis of polysaccharides and lignin in plant biomass developed by Designer Energy Ltd [18]as shown in Figure 1.The process is based on isolating holocellulose, which is composed of total polysaccharides containing both cellulose and hemicelluloses. After mild acid hydrolysis of holocellulose, hemicelluloses were extracted, and the cellulose content was measured. After two stages of acidic hydrolysis of the biomass, the acid-insoluble lignin content was determined using an improved technique. To avoid component loss, final products were isolated using a centrifugation process.
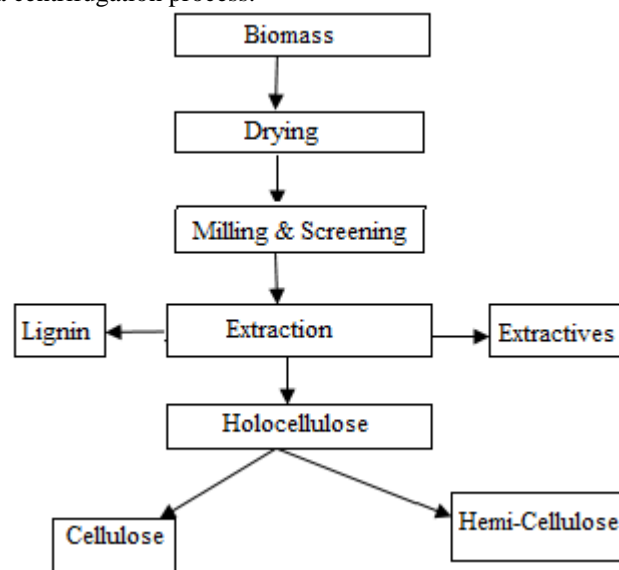

Figure 1: Scheme of chemical analysis of biomass

3.1.2 Determination of the content of acid-insoluble lignin

Young coconut husk extracts, 0.3 g, was mixed with 5 ml of 72 wt. % sulfuric acid in 100-ml Erlenmeyer flask and pre-hydrolyzed at 25°C for 2 hours using a water bath. The concentrated acid was diluted with 45 ml distilled water, and the sample was then hydrolyzed with dilute acid on a heating plate at boiling temperature for 2 hours using a reflux condenser. Six samples were prepared for the lignin determination. After cooling at room temperature for 30 min, the acidic dispersion of lignin was poured out into 50 ml PP- tubes and centrifuged at rcf of 4500 g for 15 min.

The sediment of lignin was then washed with hot water (cca 50°C), 5 wt. % sodium bicarbonate and finally with distilled water to a pH 7, separating the liquid phase from lignin by centrifugation. The washed lignin was dried in the PP-tube at 105°Cto constant weight. The percentage of acid-insoluble lignin (AIL) in the extracted biomass sample was calculated by equation (1)[13].

$$AIL = 100\% \ (P - Pt)/Ps \qquad (1)$$

where P is weight of dry acid-insoluble lignin together with PP-tube; Pt is weight of empty PP tube; and Ps is weight of extracted and dried biomass sample.

3.1.3 Determination of holocellulose

Six samples of young coconut husk, 0.5 g, were placed into 100-ml Erlenmeyer flask, and then 40 mL distilled water, 0.5 g sodium chlorite (NaClO$_2$) and 1 mL glacial acetic acid were added into the flask. The flasks covered with Petri dish were put into a water bath having temperature 90°C and treated for 45 min while stirring. Then to the flask an additional portion of 0.5 g sodium chlorite and 1 mL acetate buffer were added, and the treatment continued again for 45 min.

After cooling at room temperature for 30 min, a dispersion of holocellulose was poured out into 50 mL PP-tubes and centrifuged at rcf of 4500 g for 10 min. The sediment of holocellulose was washed with hot water (cca 50°C), and finally with distilled water to a pH 7, separating the liquid phase from holocellulose by centrifugation. The washed holocellulose was dried in the PP-tube at 105°C to constant weight. The percentage of holocellulose (HC) in the extracted biomass sample was then calculated by the equation (2)[13].

$$HC = 100\% \ (P - Pt)/Ps \qquad (2)$$

where P is weight of dry holocellulose together with PP-tube; Pt is weight of empty PP-tube; and Ps is weight of extracted and dried biomass sample.

3.1.4 Determination of cellulose and hemicelluloses

The obtained holocellulose was weighed (P hc) and hydrolyzed with dilute hydrochloric acid to remove hemicelluloses. The dried holocellulose sample was mixed with 45 ml of 2 wt.% HCl in 100-ml Erlenmeyer flask, and the sample was then hydrolyzed with the dilute acid at boiling temperature for 2 hours using a reflux condenser. After cooling at room temperature for 30 min, an acidic dispersion of cellulose was poured out into 50 mL PP-tubes

and centrifuged at rcf of 4500 g for 10 min. The sediment of cellulose was then washed with hot water (cca 50°C), 1 wt.% sodium bicarbonate and finally with distilled water to a pH 7, separating the liquid phase from cellulose by centrifugation. The washed cellulose was then dried in the PP-tube at 105°C to constant weight.

The percentage of cellulose (C) and hemicelluloses (H) in the extracted biomass sample was calculated by equations 3 and 4[13].

$$C = HC \ (P - P_t)/P_{hc} \qquad (3)$$
$$H = HC - C \qquad (4)$$

where HC is percentage of holocellulose; P is weight of dry cellulose together with PP-tube; Pt is weight of empty PP-tube; and P hc is dry weight of holocellulose.

3.2 Simulation of Bioethanol production process

The simulation was done to investigate the production of Bioethanol, material and energy requirement involved in large scale transformation of young coconut husk to Bioethanol. The simulation was done using a PC coupled with application software ChemCAD. The chemical composition of the feedstock charged into the plant was as obtained in the biomass characterization stage. The Bioethanol production steps involved in the conversion of the young coconut husks were feedstock pretreatment, hydrolysis, PH adjustment/neutralization and fermentation. These reactions happened subsequently in the reactors. Table 1shows the reaction sets involved in the simulation with Figure 2depictingthe route chosen for the bioethanol production process.

Table 1: Reaction sets involved in the simulation

Reaction sets	Reaction equations
1) Pre-treatment hydrolyzer reaction(s)	Cellulose + H$_2$O→ Glucose
	Cellulose + 0.5 H$_2$O→ 0.5 Cellobiose
	Hemicelluloses + H$_2$O→ Xylose
	Hemicelluloses → Furfural + 2 H$_2$O
	Acetate→ Acetic acid
2) Hydrolysis reaction(s)	Cellulose + 0.5 H$_2$O→ 0.5 Cellobiose
	Cellobiose + H$_2$O→ 2 Glucose
	Cellulose + H$_2$O → 1 Glucose
	Cellulose + 0.5 H$_2$O → Cellobiose
	Hemicelluloses + H$_2$O → 1 Xylose
	Hemicelluloses → Furfural + 2H$_2$O
3) pH adjustment reaction	2NaOH + H$_2$SO$_4$ → Na$_2$SO$_4$+ 2 H$_2$O
4) Fermentation reaction(s)	Glucose → 2 Ethanol + 2 CO$_2$
	1 Xylose → 5/3 Ethanol + 5/3 CO$_2$
	1 Glucose + 2 H$_2$O→ 2 Glycerol + 2 O$_2$
	1 Xylose + 5/3H$_2$O → 5/3 Glycerol + 5/6 O$_2$

3.2.1 Process Flow Description

The feedstock was fed in a mixer at 180 kg/h, 25°C, 101.3 kPa, and water at 90 kg/h, 25°C, and 101.3 kPa, was mixed in a mixer and heated to 91 ^{o}C at 228.5280 kg/h, 101 kPa; these were fed together into the pre-treatment reactor where sulfuric acid at 90 kg/h, 25°C, and 101.3kPa was fed.The products from the acid pre-treatment reactor were first heated to 91 ^{o}C, and then fed into the acid hydrolysis and fermentation reactor together with dilute sulfuric acid at 90

kg/h,25℃, and 101.3 kPa, and enzyme (91.68% water) at 5.94 kg/hr,25℃, and 101.3 kPa. The products from the fermentation reactor were fed into a filter, where the products were filtered into a solid fraction and a liquid fraction. The liquid fraction, i.e. the filtrate, was sent to the pH adjustment reactor using NaOH in order to neutralize the acidity. The pH adjustment reactor effluent was cooled to 30 ℃ and sent to the purification section.

In the purification section, a flash separator was used in order to separate CO_2 and O_2 from the beer. The flash chamber separated gases from non-gases. The beer was channeled to a distillation column where ethanol was separated from components heavier than it in order to remove the stillage (waste). The ethanol obtained was further sent to a component separator to remove any gases dissolved. Bioethanol was then obtained at 25℃, 101.3kpa and16.49993kg/hr. The material and energy required to keep the plant running was evaluated by carrying out a material and energy balance analysis with the aid of ChemCAD.
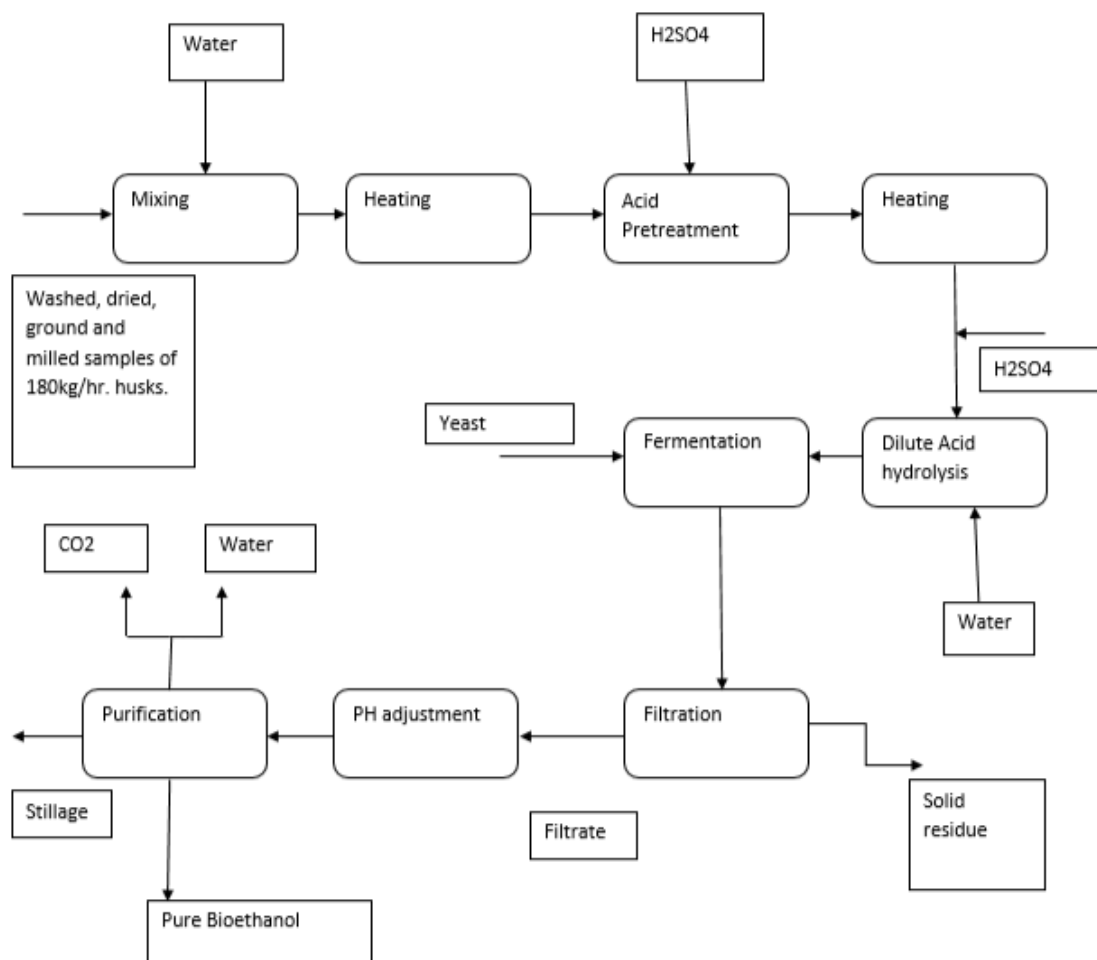

Figure 2: Process Flow Diagram for Bioethanol Production from Young Coconut Husk

3.3 Experimental Evaluation

Evaluation of bioethanol production in a laboratory setup helps determine the yield and other factors that would also affect the production process in an industrial scale plant. In this view, it is necessary to take into account the factors affecting hydrolysis and fermentation in bioethanol production from young coconut husks. Figure 3shows a flow chart of the procedure used for bioethanol production.
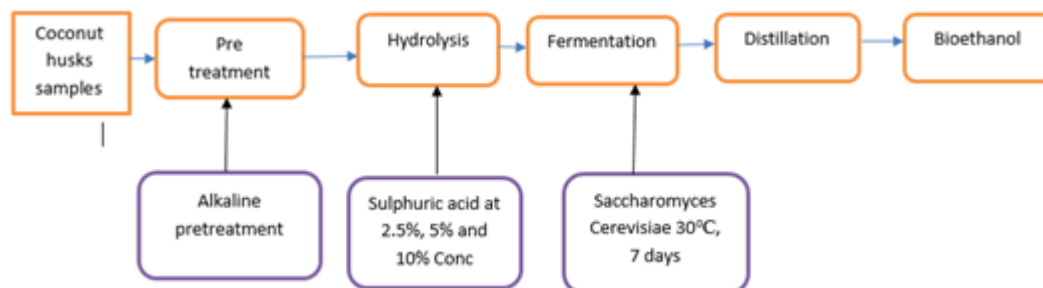

Figure 3: Experimental procedure for bioethanol production flow chart.

The husks were dried, ground and sieved to 40 mesh fraction to provide a good surface area for reaction. The husks were subjected to alkaline pretreatment where its chemical composition is broken down from complex sugars to simple sugars. The cellulose in the husks is converted to glucose and cellobiose. The pretreated sample was hydrolyzed with dilute sulphuric acid at different concentrations of 2.5%, 5% and 10%. The hydrolysates were fermented to bioethanol in 7 days using saccharomyces cerevisiae yeast. The effects of fermentation PH on bioethanol yield was studied at PH of 3.5, 4.5 and 5.5. The variable parameters like acid concentration in hydrolysis and fermentation PH were used to determine the optimum conditions for bioethanol production.

The bioethanol was extracted from the fermented broth through distillation. Gas chromatography-mass spectrometry (GC-MS) was used to confirm the presence of bioethanol in the distillates. GC-MS is an analytical method that combines the features of gas-chromatography and mass spectrometry to identify different substances within a test sample. This process was done with samples in triplicates as presented in the next section.

4. Results and Discussion

This section presents the results of the analysis of the chemical composition, simulation and optimization of bioethanol production from young coconut husks. Equations 1 to 4 were used to calculate the percentage chemical composition in the husks. The husks contained an acid insoluble lignin of 30.84%, holocellulose percentage of 46.13%, 33.27% cellulose and 12.85% hemicelluloses. The amount of cellulose and hemicellulose are an indicative for the viability of production of bioethanol from the husks. The high percentage of cellulose shows the potential of high Bioethanol production from this husk. However, the high lignin content in the young coconut husk shows a need for pretreatment of the raw material prior to the fermentation stage. Din *et al.,*)[19]determined the chemical composition of young coconut husk and got an average cellulose of 33.32%, hemicellulose 14.60% and lignin 32.40%, similarly [20]study revealed the presence of 39.31% cellulose, 16.15% hemicellulose and 29.79% lignin. The difference in the chemical composition of the three studies can be as a result of the different geographical origin of the coconuts as growth of plants is affected by environmental factors. Matured coconut husk chemical composition constitutes cellulose 23.25%, hemicelluloses 14.95% and lignin 38.80% [19]. From this study, young coconut husk has higher cellulose content and a lower lignin content than matured husks. A higher amount of cellulose translates to higher sugar content and thus a better feedstock for bioethanol fermentation. Lignin are an obstruction to bioethanol conversion, feedstock with a lower lignin content are more viable. Figure 4 shows the flowsheet developed in the bioethanol simulation process.
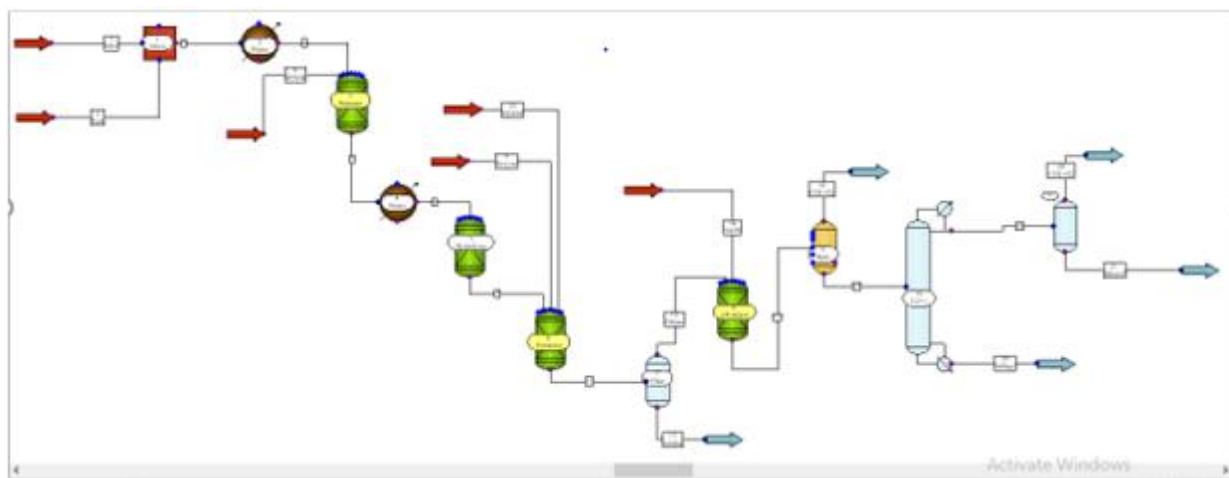

Figure 4: ChemCAD simulation flowsheet

The feedstock (young coconut husk) flow rate was varied and its impact on bioethanol flow rate studied. Figure 5shows that, as other factors remain constant, varying the feedstock flow rate from 100kg/hrto 2500kg/hr results to an increase in bioethanol flow rate from 9.2kg/hr to 220.8kg/hr. [21]also varied the flow rate of biomass between 10,000kg/hr and 300,000 kg/hr which gave rise to a bioethanol flow rate of between 2134.49kg/hrand 62,707.33 kg/hr. In this study there exists a direct relationship between the flow rates of the feedstock input and the bioethanol output such that as the feedstock flow rate increases the output flow rate also increases linearly.
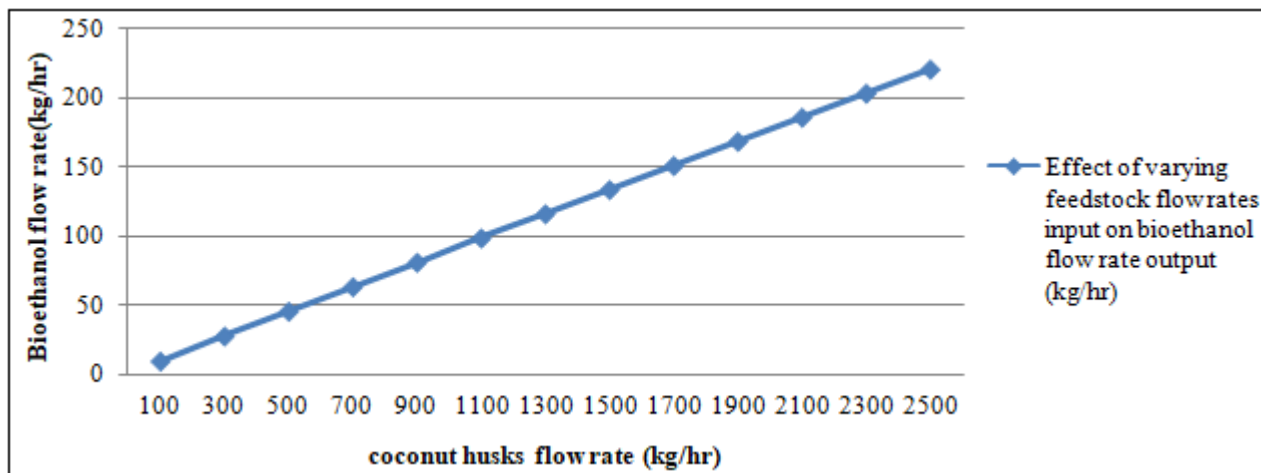
Figure 5: Feedstock flow rate vs Bioethanol flow rate

Figure 6 shows the relationship between bioethanol yield and feedstock flow rate. Bioethanol yield is the percentage of conversion of the feedstock (young coconut husk) to bioethanol. The bioethanol yield decreased from 9.1965% to 8.8338% as the feedstock flow rate was increased from 100kg/hr to 2500kg/hr. A yield of between 9.1965% and 9.0211% was observed at feedstock flow rates of between 100kg/hr and 700kg/hr. At feedstock flow rates of 900kg/hr to 2500kg/hr the yield decreased to between 8.9831% and 8.8338%.

A techno-economic study of a large scale second generation bioethanol production plant conducted by [21]varied the flow rate of sila sorghum stalks biomass between 10,000kg/hr and 300,000 kg/hr which gave rise to a bioethanol flow rate of between 2134.49kg/hr and 62,707.33 kg/hr and bioethanol yield of between 21.3449% and 20.90244%. The increase in feedstock flow rate was thus observed to decrease the bioethanol yield slightly. In the case of young coconut husks feedstock, the plant was found to operate optimally at feedstock flow rates of between 100 kg/hr and 300kg/hr. At this flow rate the yield was maintained at a maximum value of 9.2% -0.01%. Feedstock flow rates between 100kg/hrto 700kg/hr produced a yield of about 9% with flow rates above 700kg/hr resulting in a drop of yield to 8%.Thus, to operate the plant at optimum conditions and make it economically viable, feedstock flow rate of 100kg/hr to 300kg/hr was recommended.
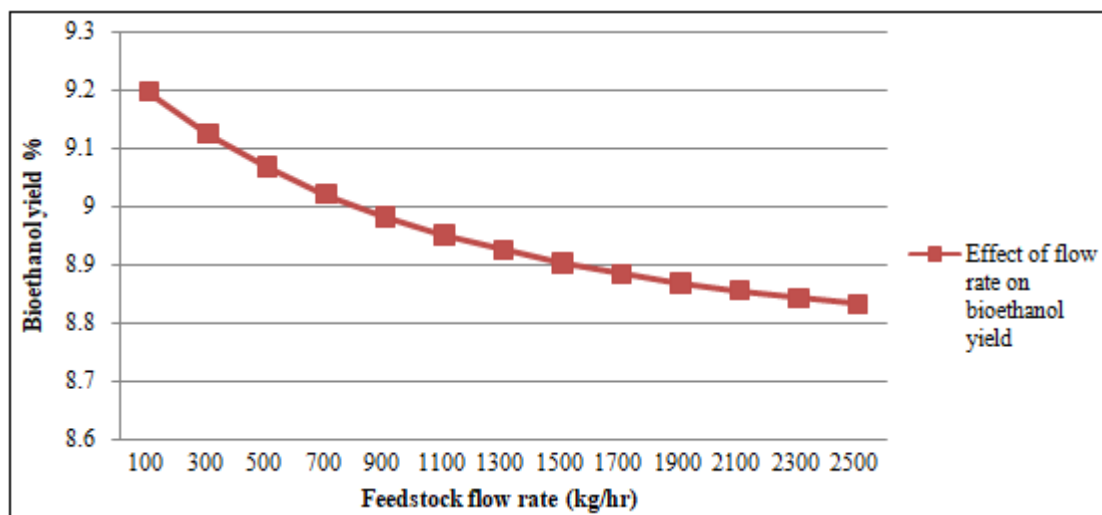

Figure 6: Effect of flow rate on Bioethanol yield

From the simulation, 16.767kg/hr of 99% pure bio-ethanol was produced from 180kg/hr pre-treated, washed, and milled young coconut husk feedstock using 0.494 kg enzyme/hr, this produced a yield of 9.32%. This yield was then compared with Bioethanol production from non-food sources with similar chemical composition. Oyenike *et al*., [22] produced 189g of fuel grade Bioethanol from a kilogram of sorghum bagasses (9408/50000 kg/kg). Moreover, Quintero *et al*., [23] reported 0.20 kg yield for rice husks and 0.27kg for rice hulls. Furthermore, Abemi *et al*[24]reported producing 117g/kg from (8,238/70,000 kg/kg) for the use of molasses, a product from sugarcane refinement process. This implied a yield of 18.9% for sorghum, 20% for rice husks, 27% for rice hulls, 11.7% for molasses and 9.32% from the coconut husks. The low yield from the husks in this study was attributed to its chemical composition and its fibrous nature. Compared with the other wastes, the husks had low cellulose and hemicellulose which are convertible sugars. However, young coconut husks are a good potential for large scale bioethanol production due its production in large quantities and its low value in other uses. In addition, the husks are non-edible, toxic when eaten by

animals and take long to decompose. The other wastes can be used as animal feedstock, farm manure and have many other economic values, in such young coconut husks proves

viable with little competition as a feedstock in this industrial process.
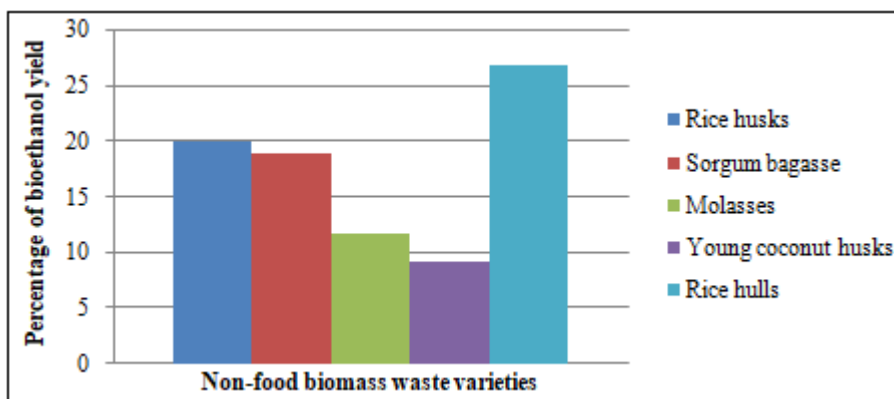

Figure 7: A comparison of Bioethanol yield from a variety of biomass waste

The young coconut husk was evaluated in a laboratory experiment to determine the optimum conditions for hydrolysis and fermentation with respect to acid concentration and fermentation PH. Hydrolysis is a critical step in the conversion of lignocelluloses biomass to bioethanol as it helps in breaking down of complex sugars like polysaccharides into monosaccharides which are simple fermentable sugars. In this study, the effect of acid concentration on bioethanol yield was investigated by hydrolyzing the young coconut husk biomass with sulphuric acid at different concentrations of 2.5%, 5% and 10%.

Figure 8: Bioethanol yield at different acid concentrations and PH

Figure 8 shows the quantity of bioethanol produced at different sulphuric acid concentrations. It was observed that the amount of bioethanol produced increased as the acid concentration increased up to 5% concentration, as the concentration further increases to 10% the bioethanol yield gradually declines. At 2.5% H_2SO_4, the yield is at the lowest point at the different PH, as the concentration increases to 5% so does the yield increase. The maximum concentration of 10% produced a lower bioethanol yield from what was achieved at 5%. The optimum condition for acid hydrolysis for bioethanol production from young coconut husks in this

study occurred at a PH 4.5 and 5% dilute sulphuric acid concentration.

The effect of PH on fermentation was also studied due to its influence on the growth of yeast. The fermentation was carried out at a constant temperature of 30°C at varying PH of 3.5, 4.5 and 5.5. As depicted in Figure 9 at an acid concentration of 2.5%, the amount of bioethanol produced at PH 3.5 was 0.8ml which increased to 2 ml at a PH 0f 4.5. However, further increase of PH to 5.5 resulted to a decline in the amount of bioethanol produced to 1.8 ml. At 5% acid concentration the amount of bioethanol produced at PH 3.5 was 1.4ml which increased to 3.6 ml at a PH 0f 4.5 before declining to 3 ml at PH 5.5. At 10% acid concentration the trend was similar with an increase of yield from 1.2 ml to 2.4 ml at PH 3.5 and PH 4.5 respectively. A decline to 2.2 ml is observed at PH 5.5.
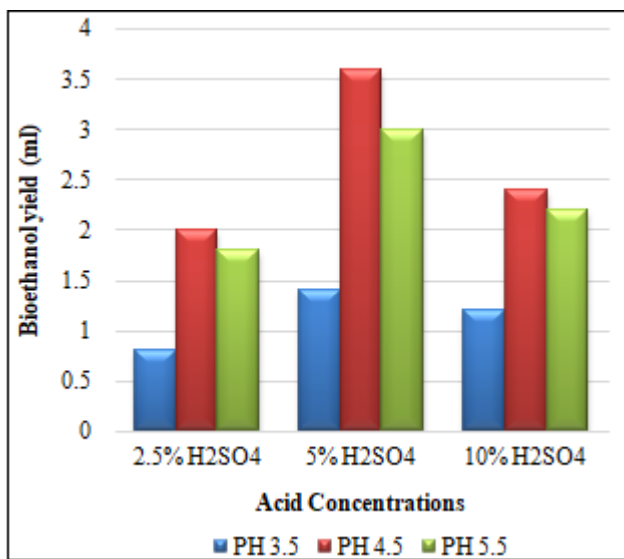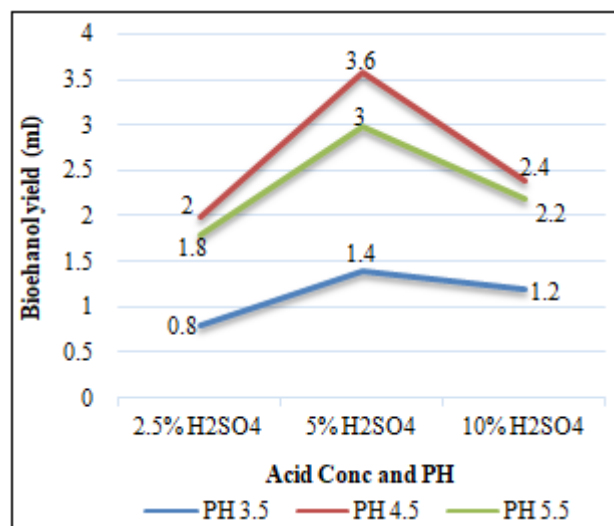

Figure 9: Effect of fermentation PH on bioethanol yield

For all acid concentrations, the trend was similar with the highest amount of bioethanol produced at PH 4.5. The lowest amount of bioethanol was recorded at PH 3.5. When the PH was increased to PH 5.5, the amount of bioethanol production was observed to decline. In this study, the optimum PH was therefore found to be at PH 4.5.

Fermentation is an anaerobic process where sugar molecules are broken down into simpler molecules. In the case of young coconut husk which have complex sugars in nature that is polysaccharides, the sugar molecules were first made accessible through hydrolysis by conversion to monosaccharides which are simple sugars ready for fermentation. At the fermentation stage these sugar molecules were further broken down to simpler molecules to produce bioethanol. This biological process is affected by several factors among them is temperature and PH. Yeast, a fermentation agent is acid tolerant and prefer lower PH conditions for their growth. It was expected therefore that the fermentation would occur best at PH of lower values. In this study the fermentation yeast saccharomyces cerevisiae was found to operate best at PH 4.5.

5. Conclusions

The study reveals that young coconut husks, an agricultural waste, have significant potential as a feedstock for bioethanol production. This finding contributes to the development of sustainable energy solutions and highlights the importance of utilizing agricultural waste for energy production.

Data Availability
The data used to support the findings of this study are included in the article. Should further data or information be required, these are available from the corresponding author upon request.

Conflicts of interest
The authors declare that they have no conflicts of interest regarding the publication of this article.

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