FACULTY OF SCIENCE AND EDUCATION

DEPARTMENT OF CHEMISTRY

BIOETHANOL PRODUCTION FROM WASTE PINEAPPLE PEELINGS AS A VALUE ADDITION APPROACH TO WASTE MANAGEMENT

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A RESEARCH PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF CHEMISTRY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A BACHELOR'S DEGREE IN SCIENCE AND EDUCATION OF BUSITEMA UNIVERSITY

August, 2026

DECLARATION

I, **NAMULINDA MABLE**, declare that this research project is my original work and has not been submitted to any other institution for academic credit.

Signature: ....

Date: ..11/09/2026..........

Namulinda Mable

APPROVAL

This research project has been submitted with the approval of the supervisor.

Supervisor's name: MR. ENUSU JAMES

Signature: ……………………

Date: 11-09-2026…………………

DEDICATION

This project is devoted to my beloved parents, family and my friends for their continuous financial support, mentorship and their endless love. Special thanks to my mother and father for the continuous love, support, encouragement and endless prayers from my primary up to now and pray that may the almighty god grant her good health so that she can witness my success.

I also dedicate this research work to my supervisor Mr. Enusu James for his endless guidance throughout the research study.

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ABSTRACT

Bioethanol production from agricultural wastes has gained increasing attention as a sustainable approach to renewable energy generation and environmental conservation due to the increasing accumulation of agricultural and fruit wastes and inadequate waste management and poor disposal practices. This study focuses on the production of bioethanol from agricultural fruit waste with a specific focus on pineapple peelings as a value addition approach to waste management. Large quantities of pineapple peelings are discarded from homes, markets and fruit processing industries, leading to environmental pollution from unpleasant odors and poor waste disposal practices, so, there is need to develop a cost-effective and eco-friendly method to manage wastes and value to them through fermentation process and produce sustainable bioethanol. Pineapple peelings contain considerable amounts of fermentable sugars that can be converted into useful products like bioethanol. The main objectives of the study were: to produce and determine the concentration of bioethanol from fresh and dried pineapple peelings then compare the yield. Ripe pineapple peelings, both dried and fresh were subjected to pretreatment by pounding and blending respectively to form fine mixture and powder, then acid hydrolysis using 5 % sulphuric acid to break the complex carbohydrates into fermentable sugars, then added sodium hydroxide to neutralize the acid. Fermentation was then carried out using yeast, baker's yeast (saccharomyces cerevisiae) and distillation to obtain bioethanol. The findings revealed that both fresh and dried pineapple peelings successfully produced bioethanol, although dried pineapple peelings yielded higher concentration of ethanol compared to fresh peelings. This difference was attributed to the higher concentration of fermentable sugars present in the dried substrate due to reduced moisture content. The study therefore demonstrates that pineapple peel waste can effectively be utilized for bioethanol production, thereby reducing environmental waste while generating a valuable renewable energy. Therefore, the study demonstrates the potential of converting agricultural waste into economically and environmentally beneficial products.

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CHARPTER ONE: INTRODUCTION

1.1 Background to the Study

Agricultural waste encompasses a wide range of residues throughout farming and food processing systems around the world (El-Ramady et al., 2022). Agricultural activities generate large quantities of waste including crop residues such as stalks, husks, roots and leaves produced after harvest of fiber crops and grains when useful portions are removed (Obi et al., 2016). During industrial processing and consumption of fruits further contribute to organic waste such as peels, pulp, seeds and cores particularly from tropical fruits like pineapple, mango, banana and citrus which are produced when the raw produce is peeled, milled to make juices and canned products (Nzelibe & Okafoagu, 2007). Other forms include livestock wastes from animal husbandry such as manure and bedding materials which accumulate from feeding and housing activities (A M Agapkin et al, 2022).

Agricultural wastes are typically garbage which is wet, decomposable waste often organic such as food scraps, fruit peels and crop residues, they are often biodegradable and if unmanaged can pose serious environmental and health hazards (Kumari & Raghubanshi, 2023). Decomposing organic waste releases greenhouse gases, contaminates soil and water through leaching of nutrients and pathogens, bad odors and attracts pests contributing to climate change, pollution and public health risks like waterborne diseases and infections. Furthermore, burning crop residues to clear fields emits particulate matter and toxic gases posing respiratory health risks (Rao et al., 2024).

However, these wastes can be managed through practices like field application of crop residues, value addition, reusing and controlled decomposition and can reduce some negative impacts (Nunez-delgado, n.d.). Some advanced approaches like biogas production are emerging but remain underutilized in many developing regions due to technological and economic constraints (Bušić et al., 2018). Value addition provides a practical solution by transforming fruit wastes and other agricultural wastes into useful products increasing their economic and environmental value (Sánchez et al., 2021).

Fruit related wastes like peels, seeds, pulp and cores are generated during harvesting, processing, storage and distribution of fruits, they are produced when fruits are peeled for juice, canned, dried or processed into other products (Wadhwa et al., 2015). The major sources of these wastes include fruit processing industries such as pineapple, banana, mango and citrus as well as household and market disposal (Upadhyay et al., 2010).

Pineapple peels among the wastes is estimated around 40 % (Chalchisa & Dereje, 2021) generated during processing and consumption , in places such as fruit markets, juice-processing industries and households where they cause significant environmental, health and waste-management challenges like bad odors, attracts pests and rodents and greenhouse gas emission (Hossain & Fazliny, 2016). Pineapple peel waste is valuable and rich in fermentable sugars and nutrients making it an ideal raw material for production of bioethanol, an alcohol produced through fermentation of biomass offering a sustainable approach to waste management.

1.2 Statement of the Problem

Large quantities of pineapple peel waste are generated from markets, households and fruit-processing industries. Most of these wastes are discarded without proper utilization, leading to accumulation and disposal challenges. As pineapple peels are highly biodegradable, their decomposition can result in environmental pollution.

Despite these challenges, pineapple peels contain considerable amounts of fermentable sugars that can be converted into valuable products such as bioethanol. However, their potential for value addition remains largely unexploited. Therefore, there is a need to investigate the production of bioethanol from pineapple peel waste as a sustainable approach to waste management and resource utilization.

1.3 Objectives of the Study

1.3.1 General objective

To evaluate the bioethanol production from different waste pineapple peelings.

1.3.2 Specific objectives

1. To produce bioethanol from waste pineapple peelings when fresh and dried.
2. To compare bioethanol yield from fresh and dried waste pineapple peel

1.4 Justification of the Study

Pineapple peelings are largely discarded from processing as waste in many areas like market places, households and around juice processing industries. These peels accumulate and are left to decompose openly leading to the emission of greenhouse gases like carbon dioxide and methane. This practice not only contributes to environmental pollution and unpleasant odors but also represents a significant loss of valuable biomass that could otherwise be utilized for useful purposes. The lack of effective waste management strategies for pineapple peelings exacerbates these environmental and economic challenges, highlighting the urgent need for sustainable value addition approaches.

The study aims to convert pineapple peel waste into bioethanol, offering a waste management strategy to reduce organic waste thereby reducing an environmental burden. The peelings will be pretreated, hydrolyzed to reduce sugars and then fermented using yeast where the sugars present in the peelings can be efficiently bio-converted into ethanol thus reducing waste related waste. Furthermore, by comparing ethanol yields from fresh and dried peels will identify the more efficient feedstock preparation method thus supporting sustainable energy development adding value to agricultural waste.

CHAPTER TWO: LITERATURE REVIEW

Agricultural waste remains one of the main pollution challenges against the sustainable development goal (SDG) 'clean water and sanitation' (Rao et al., 2024). The accumulation of organic residues from farming and processing activities has intensified globally, necessitating the development of sustainable waste management strategies that align with the principles of circular economy (Tropea et al., 2014). Among the various types of agricultural waste, fruit wastes, particularly pineapple peelings, have gained increasing attention due to their high organic content, biodegradability and potential for conversion into valuable products (Idayanti et al., 2022). Using this waste by conversion into value added products may be an excellent solution to environmental pollution (Antunes-ricardo, 2023).

2.1 Chemical Composition of Pineapple Peel Waste

The pineapple peel alone accounts for around 30-40 % of the total fruit weight and 70.7 % carbohydrate content for dried (Mala et al., 2024). It consists of lignocellulose nature; pineapple peel waste shows significant potential to produce bioethanol leading to the use of this waste (Hossain & Fazliny, 2016).

The pineapple peel comprises of a complex mixture of polymers of plant carbohydrates including fermentable sugars, oligosaccharides and polysaccharides such as celluloses, hemicelluloses, pectin substances, resistant starch and inulin associated with other non-carbohydrate components (Animesh et al., 2022). The characterization study of pineapple peel revealed that pineapple peel contains approximately 30.56 % hemicellulose, 50.90 % cellulose and 26.40% lignin (Victoria et al., 2024).

The lignocellulosic nature of the peel, comprising cellulose and hemicellulose collectively known as holocellulose are the major structural components releasing fermentable hexoses (glucose, mannose, galactose) and pentoses (xylose, arabinose) upon hydrolysis, while pectin contributes additional fermentable sugars (Østby, 2023). The abundance of the fermentable compounds gives pineapple peel waste a significant potential for bioethanol production (Idayanti et al., 2022).

2.1.1 Lignocellulose

Lignocellulose refers to all plant dry matter (biomass) which is the most abundant renewable raw material. It is one of the alternative feedstocks for bioethanol production (Remsion, 2019). Lignocellulose sources are mainly virgin biomass, energy crops and waste biomass. Each source has the potential to serve as a raw material for bioethanol production depending on polysaccharide content, plant species and individual parts of the plant (Zoghlami & Paës, 2019).

Structure of the lignocellulose complex is composed of three polymers: polysaccharides (cellulose and hemicelluloses) and lignin a complex aromatic polymer (Frasca, 2024). The amount of the polymer depends on the biomass origin (Hu et al., 2020). However, cellulose and hemicelluloses usually constitute about two thirds of its total dry mass and can be used to produce bioethanol because they are long-chain polysaccharides hydrolyzed into a mixture of fermentable pentoses and hexoses that can be further converted to ethanol molecules (Broda & Yelle, 2022).

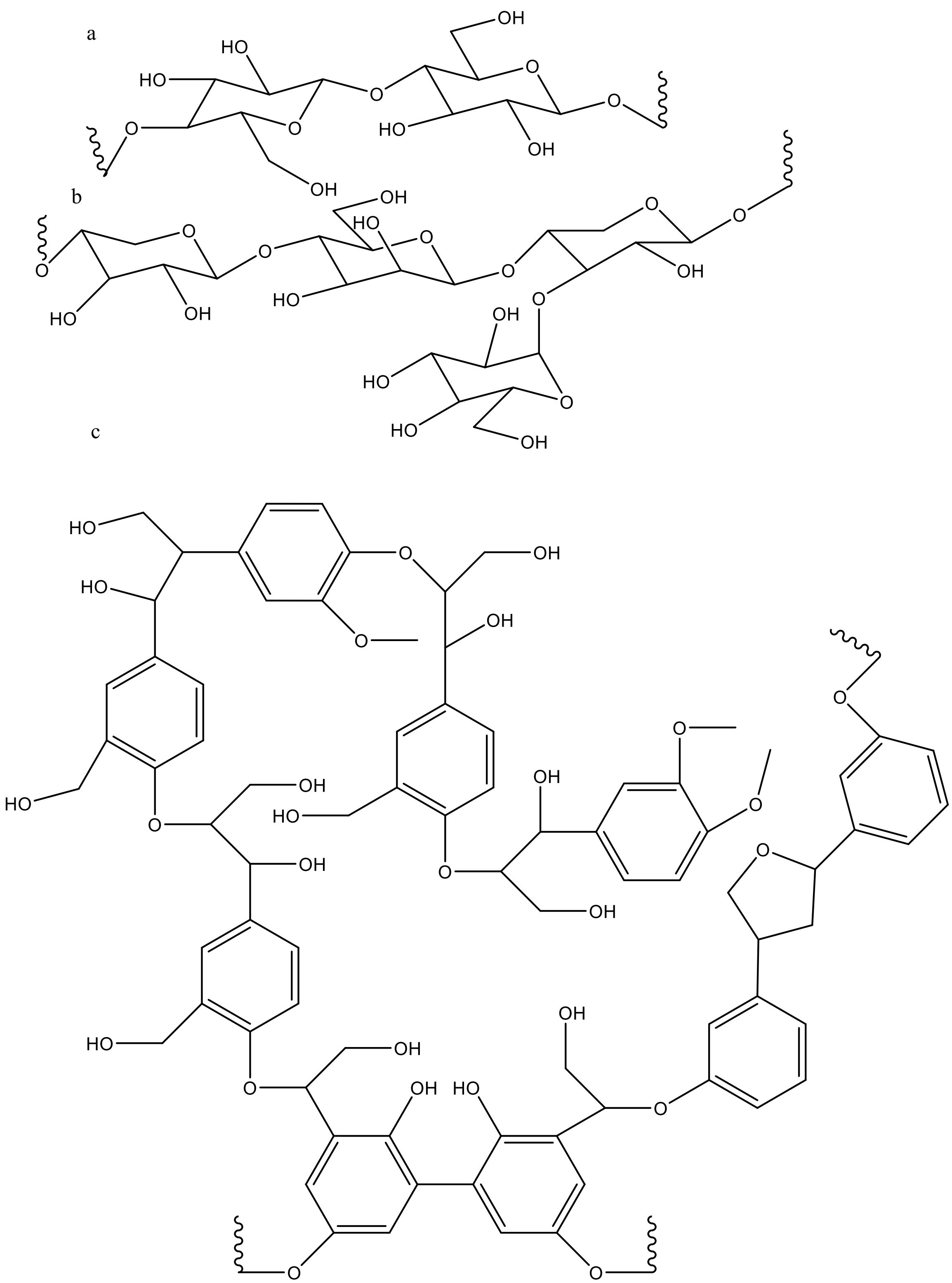

Figure 1: ***Structure of lignocellulose.*** **Adapted from "Lignocellulosic Biomass: Understanding Recalcitrance and Predicting Hydrolysis," by A. Zoghlami and G. Paes, 2019, Frontiers in Chemistry, 7, p.2. Copyright 2019 by Zoghlami and Paes.**

2.1.2 Cellulose

Cellulose is the main structural polysaccharide of a plant cell wall providing it with high tensile strength and rigidity. Its amount ranges from 30-50 % of the dry weight of lignocellulosic biomass (Broda & Yelle, 2022). Cellulose is generally a highly crystalline and high-molecular weight polymer with a strong tendency to form high crystalline fibres (Caulfield, 1990). A cellulose molecule is a long-chain straight linear homopolysaccharide with beta-D-glucopyranose units linked by beta-1,4-glycosidic bonds with the disaccharide cellobiose, made of two beta-glucose molecules connected by a beta-1,4-bond as its repeating unit (Mcnamara et al., 2016).

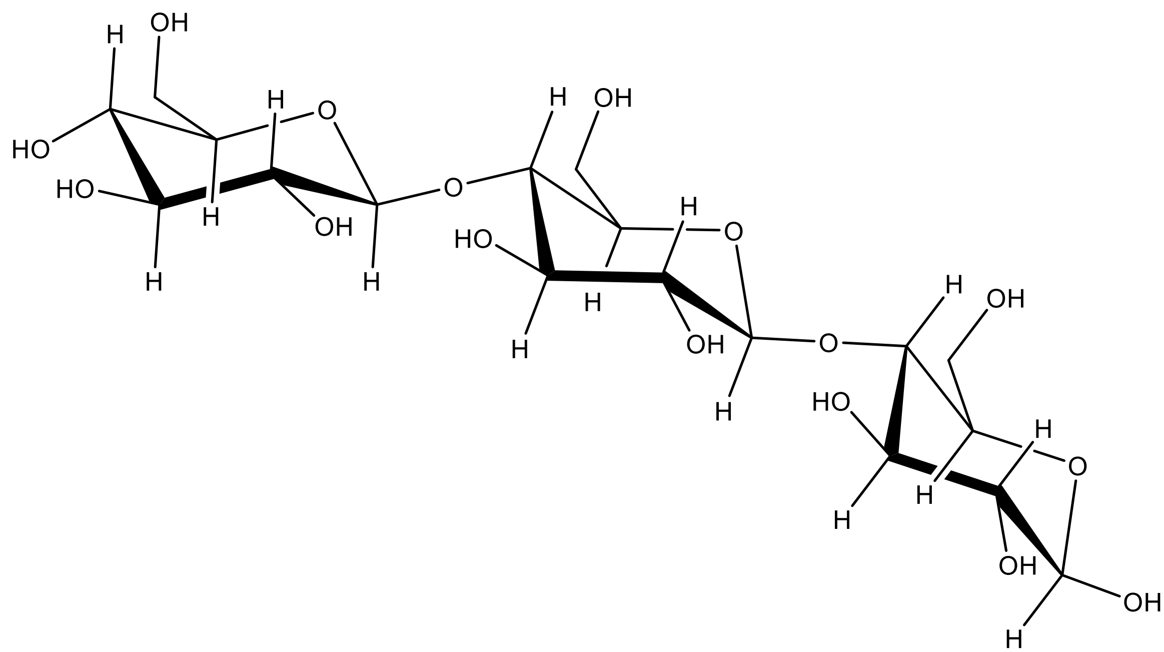

Figure 2: *Structure of cellulose*. Adapted from "Bioethanol Production from Lignocellulosic Biomass- Challenges and Solutions," by M. Broda and D. J. Yelle, 2022, Processes, 10(2), p.3. Copyright 2022 by the authors.

2.1.3 Hemicellulose

Hemicelluloses are the second most abundant amorphous polysaccharide of a plant cell which accounts for 25-35% of lignocellulosic dry biomass (Frasca, 2024). They are short linear and highly branched heteropolysaccharides consisting of various sugar units, both pentoses (beta-D-xylose and alpha-L-arabinose) and hexoses (beta-D-glucose, alpha-D-galactose and alpha-D-mannose), as well as uronic acids (Yoshimi et al., 2025). It has a lower degree of polymerization compared to cellulose and the cellulose-hemicellulose network act as a load-bearing element that strengthens the cell wall (Laine, 2005).

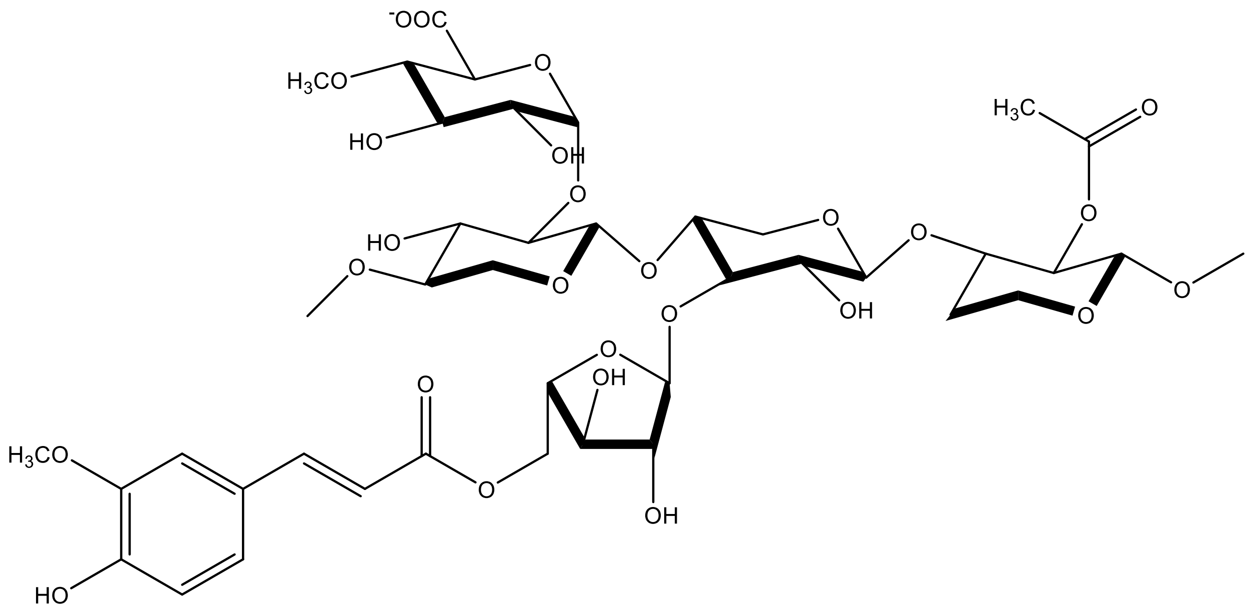

Figure 3: *Structure of hemicellulose.* Adapted from "Hemicellulose- Based Polymers Processing and Application," by L. Hu et al., 2020, American Journal of Plant Sciences, 11(12), p.2070. Copyright 2020 by Hu et al.

2.1.4 Lignin

Lignin is the third component of lignocellulosic biomass constituting about 15-20 % of its dry mass (Beckham, 2018). It is an amorphous, hyper-branched and cross-linked three-dimensional network polymer with no regular repeating elements (Vanholme et al., 2010). All these together with a crystalline cellulose and low surface are available for enzymes, make lignin complex and resistant to separation and depolymerization. Therefore, processing lignocellulosic biomass for bioethanol production is challenging, requiring high proper knowledge and technologies that employ a combination of chemicals, enzymes and heat (Subramaniam et al., 2022).

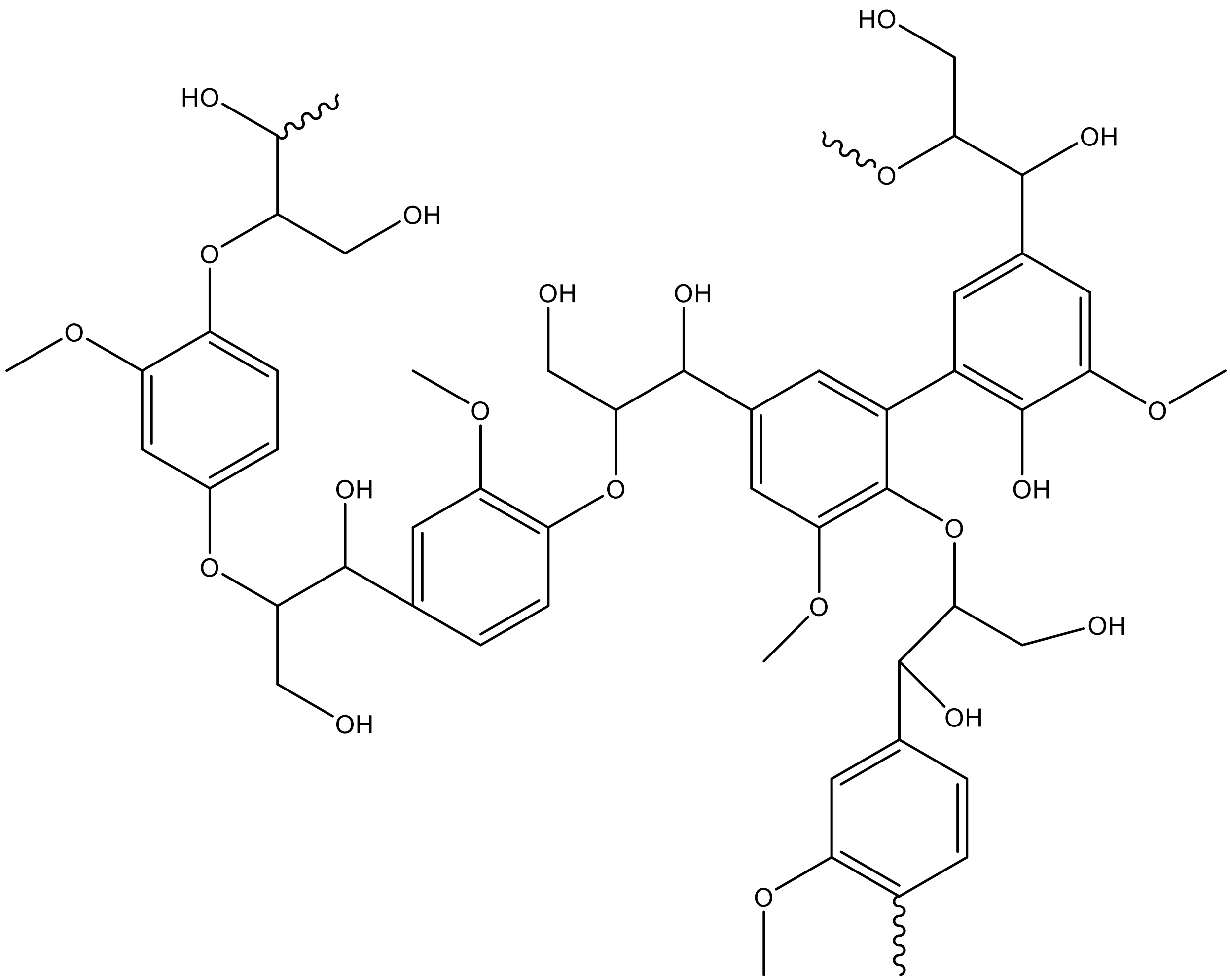

Figure 4: ***Structure of lignin*****. Adapted from "Lignin Biosynthesis and Structure," by R. Vanholme et al., 2010, Plant Physiology, 153(3), p.896. Copyright 2010 by American Society of Plant Biologists.**

2.2 Enzymes Present

Cellulases are a group of hydrolytic enzymes that hydrolyze the beta-glycosidic bonds of cellulose to produce simple sugars (Animesh et al., 2022). Glycoside hydrolyses like xylanase, Manase and xyloglucanase are able to cleave the backbone of hemicellulosic polysaccharides (Østby, 2023).

The production of bioethanol from pineapple peel waste involves a series of biochemical conversions in which fermentable sugars are transformed into ethanol through the action of microorganisms and enzymes.(Tropea et al., 2014). The process starts with the hydrolysis of the complex carbohydrates into simple fermentable sugars (Adiya et al., 2022). During acid hydrolysis, the glycosidic bonds of cellulose and hemicellulose are cleaved under elevated temperatures and acidic conditions releasing monomeric sugars such as glucose, xylose, arabinose, mannose and galactose (Atul. U, Jeewan. P, 2003). During enzymatic hydrolysis, specific enzymes are employed; cellulases hydrolyze cellulose to glucose while hemicellulases breakdown hemicellulose into its constituent pentoses and hexoses (Pendse et al., 2023). For sucrose present in the peel, the enzyme invertase (produced by the yeast) hydrolyzes the bond of sucrose into glucose and fructose, a process that occurs at a pH of 4.5-5.5 (Sources & Vasi, 2021).

The resulting fermentable sugars are then converted to ethanol by yeast (saccharomyces cerevisiae) through glycolysis to pyruvate, which is decarboxylated to acetaldehyde and reduced to ethanol by alcohol dehydrogenase, under anaerobic conditions at 30-35 ℃ (Nonato & De Souza Figueiredo, 2024).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Collection and Pretreatment

The pineapple peel wastes were collected from different markets and trading centers around Tororo district using polythene bags.

The peelings were washed thoroughly with distilled water to remove the dirt. A portion of the peelings was dried in an oven at 60.0 ℃ to reduce moisture. For the fresh sample, 200.0 g of fresh pineapple peelings were first cut into smaller pieces using a kitchen knife, then were blended using a blender to form a fine mixture and placed into a beaker. For the dried sample, the dried peelings were first ground using a mortar and pestle into smaller particles and they were further grinded using an electric grinder to form fine powder. This pretreatment was done to increase surface area for efficient hydrolysis.

3.2 Acid Hydrolysis

A solution of 5 % sulphuric acid (2 L) was prepared by dissolving 100.00 mL of concentrated sulphuric acid in distilled water in a 2 L volumetric flask. For the dried sample, 200.0 g of the fine powder of the dried peelings was weighed using an AX 523 digital analytical balance (Ohaus Corporation Co. ltd, USA) and mixed with 2000.00 mL of 5 % sulphuric acid solution in a clean beaker. For the fresh sample, 200.0 g of the fine mixture (solid content) from the fresh peelings was also mixed with 2000.00 mL of 5 % sulphuric acid solution in a separate clean beaker. Each mixture was heated and maintained at a temperature of 121.0 ℃ using a thermometer for 90 minutes using a hot plate and stirred occasionally using a glass rod to avoid settling of particles and to ensure uniform hydrolysis. After reaction time, the beakers were carefully removed and allowed to cool to room temperature.

3.3 Neutralization

Each hydrolysate was neutralized with 2 M sodium hydroxide to the pH of 5.5 using a pH meter (Hanna HI12963) to create suitable conditions for fermentation. The 2 M sodium hydroxide was prepared by dissolving 40.0 g of sodium hydroxide pellets in 500.00 mL of distilled water. The mixtures were then filtered using a sieve to remove the solid particles.

3.4 Testing for Reducing Sugars

Using a test tube, 2.00 mL of each hydrolysate was placed into separate test tubes. To 2.00 mL of fehling's solution in a test tube, 2.00 mL of each filtrate was added, and the mixture was heat using a Bunsen burner. The blue solution turned to an orange precipitate immediately upon heating indicated a high concentration of reducing sugars in the hydrolysates.

3.5 Fermentation

The filtrates were transferred into fermentation bottles and 10.0 g of baker's yeast (Saccharomyces cerevisiae) was weighed and added to 100.00 mL of water before being added to each filtrate. The fermentation bottles were sealed to maintain anaerobic conditions. The bottles were incubated at a controlled temperature of 35.0 °C, using a thermometer to monitor temperature, and fermentation was allowed to proceed for 5 days. Upon completion of the incubation period, the fermented broth was collected and prepared for distillation.

3.6 Distillation

The fermented samples were transferred into a distillation apparatus including a heating mantle, round bottomed flask, condenser and a collecting beaker were setup, and boiled at 78.0 °C to evaporate the ethanol and the condensate was collected in a clean container. The distillation process was repeated using a rotary evaporator, boiled at 78.0 °C and at 110 rpm. This was repeated two times until a more concentrated sample of bioethanol was collected. A flame test was carried out to confirm that ethanol was produced by heating a small portion of each sample using a Bunsen burner. A Lucas test was carried out to determine the type of alcohol using Luca's reagent (zinc chloride and hydrochloric acid) to each sample.

3.7 Determination of the Concentration of Bioethanol

The concentration of the bioethanol produced from each sample was determined using UV-VIS quantitative analysis using acidified potassium dichromate solution. A quantity of 0.00, 2.00, 4.00, 6.00, 8.00 and 10.00 mL of standard ethanol of 98 % v/v was diluted with 100.00 mL of distilled water to give concentrations of 0,2,4,6,8 and 10 % v/v of standard ethanol. To 3.00 mL of each sample (0,2,4,6,8 and 10 % of standard ethanol) in separate test tubes, 2.00 mL of acidified potassium dichromate was added and mixed. Each mixture was heated gently in a water bath at 60.0 °C for 10 minutes and allowed to cool to allow colour development. The absorbance of each standard was measured at 600 nm using a UV-VIS spectrophotometer, and a standard calibration curve was developed. Then, 3.00 mL of each sample (fresh and dried peelings) was mixed with 2.00 mL of acidified potassium dichromate in separate test tubes, heated gently in a water bath at 60.0 °C for 10 minutes, allowed to cool and their absorbance were measured at 600 nm using UV-VIS spectrophotometer. The concentration of ethanol in each sample was determined by comparing the absorbance values to the standard calibration curve. The ethanol yields from dried and fresh peelings were compared by comparing their absorbances.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Results

4.1.1 Pretreatment

Washing of the pineapple peelings removed visible dirt and impurities. Drying at 60.0 ℃ effectively reduced the moisture content of the sample.

This stage yielded a fine, light-yellow powder was effectively obtained from dried pineapple peelings using a mortar and pestle, then further with an electric grinder and a homogeneous, paste-like smooth slurry was obtained from the fresh peelings using a blender, this increased surface area required for efficient acid hydrolysis.

The dried peelings produced a finer material than the fresh peelings which was suitable for enhanced hydrolysis.

4.1.2 Acid hydrolysis and neutralization

Hydrolysis of both samples from fresh and dried pineapple peelings using 5 % sulphuric acid was successfully achieved after heating at 121.0 ℃ for 90 minutes forming a light brown solution, there was softening and breakdown of the peel particles. Continuous stirring prevented settling of particles and promoted uniform hydrolysis throughout the reaction period.

The acid hydrolysates were neutralized successfully using 2 M sodium hydroxide until a pH of 5.5 was reached. The neutralized hydrolysates provided conditions for yeast fermentation.

4.1.3 Reducing sugars tests

Positive results were observed from both samples through color changes. Both fresh and dried pineapple peel samples changed from blue solution to an orange precipitate immediately on heating and this confirmed the presence of reducing sugars with high concentration.

4.1.4 Fermentation of the Hydrolysates

This occurred successfully with moderate gas bubble formation from fresh peel hydrolysate and higher gas bubbles from the dried peel hydrolysate and frothing was observed during fermentation confirming active yeast metabolism. The dried pineapple peel hydrolysate showed more active fermentation compared to the fresh peel waste. After 5 days, the broth developed a characteristic odor and the reducing sugar was reduced compared to the initial hydrolysate indicating successful conversion of sugars. Ethanol was detected in the fermentation medium, and the overall yield showed the substrate supported efficient microbial activity, producing a clear distinction between the pretreatment and post treatment samples. After fermentation, distillation was carried out and a colourless condensate was obtained. The flame test gave positive results with each sample burning with a pale blue non-sooty flame, confirming that ethanol was produced and then Lucas's test gave no reaction from both samples confirming the presence of a primary alcohol.

4.1.5 Analysis of Findings

Table 1: Table of the results obtained at wavelength 600 nm

Concentration (% v/v)	**Absorbance**
0	0.012
2	0.153
4	0.307
6	0.486
8	0.658
10	0.823

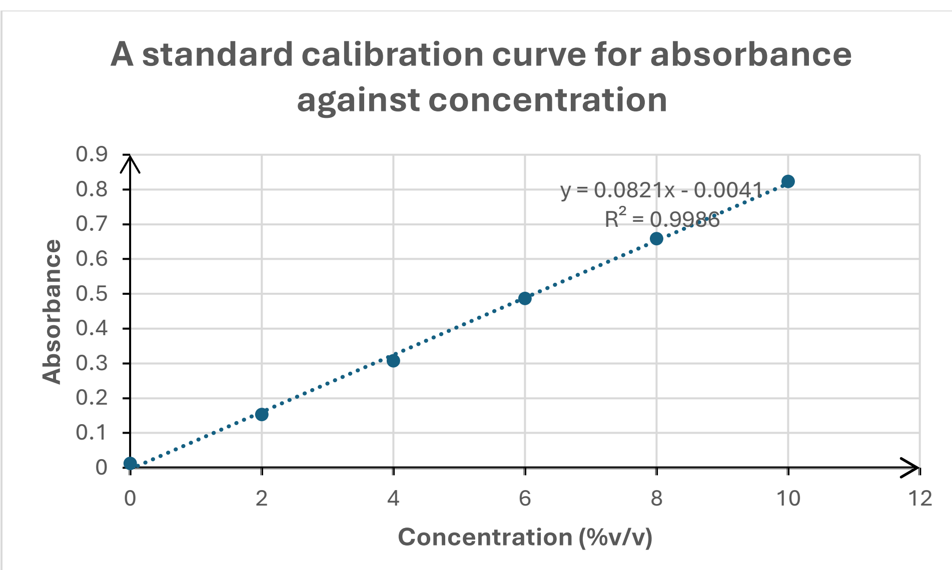

Figure 5: ***A standard calibration curve of ethanol.*** **Created from experimental data obtained in this study.**

From the standard calibration curve;

The regression equation y = 0.0821x-0.0041 and R^2 = 0.9986 where Y represents the optical absorbances at 600 nm and X represents the bioethanol concentration (% v/v).

Concentration from fresh pineapple peelings

At wavelength 600 nm, the absorbance was 0.514

From the graph when absorbance is plotted against concentration, y = 0.0821x-0.0041.

Implying that y is absorbance and x is concentration, if y = 0.514,

Then X = $\frac{0.514+0.0041}{0.0821}$

= 6.310596833 % v/v approximately 6.311 % v/v of bioethanol produced from fresh sample.

Concentration from the dried pineapple peelings

At wavelength 600 nm, the absorbance was 0.706

Using, y = 0.0821x-0.0041, if y = 0.706

Then X = $\frac{0.706+0.0041}{0.0821}$

= 8.649208283 % v/v approximately 8.649 % v/v of bioethanol produced from dried sample.

Table 2: Summary of results from samples

Sample	**Absorbance at 600 nm**	**Concentration (% v/v)**
Fresh peelings	0.514	6.311
Dried peelings	0.706	8.649

4.2 Discussion of results

The results of this study on bioethanol production from ripe fresh and dried pineapple peelings reveal an effective raw material for bioethanol production due to its high carbohydrate and reducing sugar content. The percentage yield of bioethanol obtained from dried pineapple peelings was 8.6 5 % v/v while from fresh ones was 6.31 % v/v, which indicate that dried pineapple peelings performed better than the fresh peelings. However, when compared to the global industrial standard ethanol yields of 8-12 % v/v from agricultural biomass, the fresh pineapple peelings recorded lower concentration. Despite the performance gap, the higher yield in dried peelings can be attributed to the reduction in moisture content during the drying process. Drying concentrates the carbohydrate and sugar content within pineapple peels, thereby increasing the number of fermentable sugars available for yeast fermentation. In contrast, the fresh pineapple peelings contain a high sugar content in water, which dilutes the sugar concentration and may lower fermentation efficiency. As a result, less ethanol was produced from the fresh sample.

The positive results obtained from Fehling's test further confirmed the presence of reducing sugars necessary for fermentation.

The ethanol yields in this study are comparable with findings from other studies on fruit waste bioethanol production, where dried biomass often produces higher ethanol concentration than fresh biomass. The results therefore support the use of agricultural wastes such as pineapple peelings as low-cost and renewable raw material for bioethanol production.

Several factors like incomplete hydrolysis or fermentation, temperature, pH and yeast activity may have affected the total amount of ethanol produced. Despite these limitations, the results demonstrate that pineapple peel waste has a strong potential for bioethanol production. Therefore, the study showed that dried pineapple peelings are more effective for bioethanol production than fresh pineapple peelings. This highlights the importance of substrate drying in improving bioethanol yield and supports potential utilization of pineapple was in environmental waste management.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The successful production of bioethanol from both samples confirms that pineapple peelings contain significant quantities of cellulose, hemicellulose and simple sugars that can be converted into bioethanol through hydrolysis, fermentation and distillation.

From the study, fresh pineapple peelings produced a less ethanol concentration of 6.311 % v/v while dried pineapple peelings produced a higher ethanol concentration of 8.649 % v/v. These results show that drying the peelings enhances bioethanol production efficiency by increasing the concentration of fermentable sugars and improving substrate suitability for fermentation.

Therefore, dried pineapple peelings are more effective for bioethanol production compared to fresh peelings. The study confirms that agricultural waste, particularly pineapple peelings, can be converted into useful renewable energy contributing to sustainable waste management.

5.2 Recommendation

Pineapple peelings should be considered a viable lignocellulosic feedstock for bioethanol production due to their ability to generate appreciable ethanol yields while simultaneously contributing to sustainable waste management practices.

Dried pineapple peelings should be preferred as a substrate for bioethanol production, as they produced a higher ethanol yield than fresh peelings and therefore demonstrate greater potential for efficient bioethanol production.

However, when compared to the global industrial standard ethanol yields of 8-12 % v/v from agricultural biomass, the fresh pineapple peelings recorded lower concentration, suggesting the need for further optimization of pre-treatment, enzymatic hydrolysis and fermentation process

REFERENCES

A M Agapkin , I A Makhotina, N. A. I. (2022). *The problem of agricultural waste and ways to solve it*. https://doi.org/10.1088/1755-1315/981/2/022009

Adiya, Z. I. S. G., Adamu, S. S., Ibrahim, M. A., Okoh, E. V. C., & Ibrahim, D. (2022). *Comparative Study of Bioethanol Produced from Different Agro- Industrial Biomass Residues*. *7*(2), 143–152.

Animesh, L. M., Sengar, S., & Neog, R. (2022). Pineapple processing waste (PPW): bioactive compounds , their extraction , and utilisation : a review. *Journal of Food Science and Technology*, *59*(11), 4152–4164. https://doi.org/10.1007/s13197-021-05271-6

Antunes-ricardo, M. (2023). *Solid-State Fermented Pineapple Peel : A Novel Food Ingredient with Antioxidant and Anti-Inflammatory Properties*.

Atul. U, Jeewan. P, L. and S. . T. (2003). *Utilization_of_Pineapple_Waste_A_Review (1)*.

Beckham, G. T. (2018). *A Brief Introduction to Lignin Structure*. *19*.

Broda, M., & Yelle, D. J. (2022). *Bioethanol Production from Lignocellulosic Biomass — Challenges and Solutions*.

Bušić, A., Morzak, G., Belskaya, H., & Šantek, I. (2018). *Bioethanol Production from Renewable Raw Materials and Its Separation and Purification : A Review*. *9818*, 0–3. https://doi.org/10.17113/ftb.56.03.18.5546

Caulfield, I. (1990). *THE STRUCTURES OF CELLULOSE*. *197*, 89–98.

Chalchisa, T., & Dereje, B. (2021). *From waste to food : utilization of pineapple peels for vinegar production*. *9*(1), 1–5. https://doi.org/10.15406/mojfpt.2021.09.00254

El-ramady, H., Brevik, E. C., Bayoumi, Y., Shalaby, T. A., El-mahrouk, M. E., Taha, N., Elbasiouny, H., Elbehiry, F., Amer, M., Abdalla, N., & Prokisch, J. (2022). *An Overview of Agro-Waste Management in Light of the Water-Energy-Waste Nexus*.

Frasca, S. (2024). *Lignocellulosic Biomass Components for Materials Applications*.

Hossain, A. B. M. S., & Fazliny, A. R. (2016). *Creation of alternative energy by bio- ethanol* *production from pineapple waste and the usage of its properties for engine*. *2016*(X).

Hu, L., Fang, X., Du, M., Luo, F., & Guo, S. (2020). *Hemicellulose-Based Polymers Processing and Application*. 2066–2079. https://doi.org/10.4236/ajps.2020.1112146

Idayanti, R. W., Arifin, M., Purbowati, E., & Purnomoadi, A. (2022). *Utilization of Pineapple Waste as a Roughage Source Diets for Ruminant : A Review*. *20*(Itaps 2021), 123–130.

Kumari, T., & Raghubanshi, A. S. (2023). *Waste management practices in the developing nations : challenges and opportunities*. 773–797.

Laine, C. (2005). *STRUCTURES OF HEMICELLULOSES AND PECTINS IN WOOD AND PULP*.

Mala, T., Piayura, S., & Itthivadhanapong, P. (2024). Characterization of dried pineapple (Ananas comosus L .) peel powder and its application as a novel functional food ingredient in cracker product. *Future Foods*, *9*(March), 100322. https://doi.org/10.1016/j.fufo.2024.100322

Mcnamara, J. T., Morgan, J. L. W., & Zimmer, J. (2016). *HHS Public Access*. 895–921. https://doi.org/10.1146/annurev-biochem-060614-033930.A

Nonato, S. de M., & De Souza Figueiredo, K. C. (2024). Bioethanol preparation and separation from pineapple peel upon combining fermentation and pervaporation through biochar-containing PDMS membranes. *Scientia Plena*, *20*(10), 1–9. https://doi.org/10.14808/sci.plena.2024.104201

Nunez-delgado, A. (n.d.). *Frontier Studies in Soil Science*.

Nzelibe, H. C., & Okafoagu, C. U. (2007). *Optimization of ethanol production from Garcinia kola (bitter kola) pulp agrowaste*. *6*(September), 2033–2037.

Obi, F. O., Ugwuishiwu, B. O., & Nwakaire, J. N. (2016). *AGRICULTURAL WASTE CONCEPT , GENERATION , UTILIZATION AND MANAGEMENT*. *35*(4), 957–964.

Østby, H. (2023). *Hemicellulolytic enzymes in lignocellulose processing*. *0*(January), 531–548.

Pendse, D. S., Deshmukh, M., & Pande, A. (2023). Heliyon Different pre-treatments and kinetic models for bioethanol production from lignocellulosic biomass : A review. *Heliyon*, *9*(6), e16604. https://doi.org/10.1016/j.heliyon.2023.e16604

Rao, M. M., Mohan, S., Prabhakara, B. T., Srinivasa, R., & Goddu, R. (2024). Discover Sustainability A comprehensive review on agricultural waste production and onsite management with circular economy opportunities. *Discover Sustainability*. https://doi.org/10.1007/s43621-024-00492-z

Remsion, A. A. O.-O. A. O. (2019). *PRODUCTION OF ETHANOL FROM PLANTAIN , PINEAPPLE AND BANANA WASTE BY*. *7*(7), 389–397.

Sánchez, M., Laca, A., Laca, A., & Díaz, M. (2021). *Value-Added Products from Fruit and Vegetable Wastes : A Review*. *2000376*, 1–21. https://doi.org/10.1002/clen.202000376

Sources, L., & Vasi, K. (2021). *Bioethanol Production by Enzymatic Hydrolysis from Different*.

Subramaniam, S., Sanyal, U., & Robert, R. (2022). *Molecular structural dataset of lignin macromolecule elucidating experimental structural compositions*. 1–13. https://doi.org/10.1038/s41597-022-01709-4

Tropea, A., Wilson, D., Torre, L. G. La, Curto, R. B. Lo, Saugman, P., Troy-davies, P., Dugo, G., & Waldron, K. W. (2014). *Bioethanol Production From Pineapple Wastes*. *3*(4), 60–70. https://doi.org/10.5539/jfr.v3n4p60

Upadhyay, A., Lama, J. P., & Tawata, S. (2010). *Utilization of Pineapple Waste : A Review*. *6*(2004).

Vanholme, R., Demedts, B., Morreel, K., Ralph, J., & Boerjan, W. (2010). *Lignin Biosynthesis and Structure 1*. *153*(July), 895–905. https://doi.org/10.1104/pp.110.155119

Victoria, M., Cabeza, C., Daniel, C., Ruedas, T., Cecilia, D., Ordoñez, R., Wilmer, J., & Llanos, P. (2024). *Characterization of pineapple peel (Ananas comosus) Perolera variety as a potential resource for bioethanol production comosus) variedad Perolera como recurso potencial para la producción de bioetanol Caracterização da casca de abacaxi (Ananas comosus) variedade Perolera como recurso potencial para produção de bioetanol*. *37*(3), 73–83. https://doi.org/10.18273/revion.v37n3-2024006

Wadhwa, M., Bakshi, M. P. S., & Makkar, H. P. S. (2015). *Wastes to worth : value added* *products from fruit and vegetable wastes*. *043*. https://doi.org/10.1079/PAVSNNR201510043

Yoshimi, Y., Tryfona, T., & Dupree, P. (2025). *Structure , Modification Pattern , and Conformation of Hemicellulose in Plant Biomass*. *7201301*. https://doi.org/10.5458/jag.7201301

Zoghlami, A., & Paës, G. (2019). *Lignocellulosic Biomass : Understanding Recalcitrance and Predicting Hydrolysis*. *7*(December). https://doi.org/10.3389/fchem.2019.00874

A M Agapkin , I A Makhotina, N. A. I. (2022). *The problem of agricultural waste and ways to solve it*. https://doi.org/10.1088/1755-1315/981/2/022009

Adiya, Z. I. S. G., Adamu, S. S., Ibrahim, M. A., Okoh, E. V. C., & Ibrahim, D. (2022). *Comparative Study of Bioethanol Produced from Different Agro- Industrial Biomass Residues*. *7*(2), 143–152.

Animesh, L. M., Sengar, S., & Neog, R. (2022). Pineapple processing waste (PPW): bioactive compounds , their extraction , and utilisation : a review. *Journal of Food Science and Technology*, *59*(11), 4152–4164. https://doi.org/10.1007/s13197-021-05271-6

Antunes-ricardo, M. (2023). *Solid-State Fermented Pineapple Peel : A Novel Food Ingredient with Antioxidant and Anti-Inflammatory Properties*.

Atul. U, Jeewan. P, L. and S. . T. (2003). *Utilization_of_Pineapple_Waste_A_Review (1)*.

Beckham, G. T. (2018). *A Brief Introduction to Lignin Structure*. *19*.

Broda, M., & Yelle, D. J. (2022). *Bioethanol Production from Lignocellulosic Biomass — Challenges and Solutions*.

Bušić, A., Morzak, G., Belskaya, H., & Šantek, I. (2018). *Bioethanol Production from Renewable Raw Materials and Its Separation and Purification : A Review*. *9818*, 0–3. https://doi.org/10.17113/ftb.56.03.18.5546

Caulfield, I. (1990). *THE STRUCTURES OF CELLULOSE*. *197*, 89–98.

Chalchisa, T., & Dereje, B. (2021). *From waste to food : utilization of pineapple peels for vinegar production*. *9*(1), 1–5. https://doi.org/10.15406/mojfpt.2021.09.00254

El-ramady, H., Brevik, E. C., Bayoumi, Y., Shalaby, T. A., El-mahrouk, M. E., Taha, N., Elbasiouny, H., Elbehiry, F., Amer, M., Abdalla, N., & Prokisch, J. (2022). *An Overview of Agro-Waste Management in Light of the Water-Energy-Waste Nexus*.

Frasca, S. (2024). *Lignocellulosic Biomass Components for Materials Applications*.

Hossain, A. B. M. S., & Fazliny, A. R. (2016). *Creation of alternative energy by bio- ethanol production from pineapple waste and the usage of its properties for engine*. *2016*(X).

Hu, L., Fang, X., Du, M., Luo, F., & Guo, S. (2020). *Hemicellulose-Based Polymers Processing and Application*. 2066–2079. https://doi.org/10.4236/ajps.2020.1112146

Idayanti, R. W., Arifin, M., Purbowati, E., & Purnomoadi, A. (2022). *Utilization of Pineapple Waste as a Roughage Source Diets for Ruminant : A Review*. *20*(Itaps 2021), 123–130.

Kumari, T., & Raghubanshi, A. S. (2023). *Waste management practices in the developing nations : challenges and opportunities*. 773–797.

Laine, C. (2005). *STRUCTURES OF HEMICELLULOSES AND PECTINS IN WOOD AND PULP*.

Mala, T., Piayura, S., & Itthivadhanapong, P. (2024). Characterization of dried pineapple (Ananas comosus L .) peel powder and its application as a novel functional food ingredient in cracker product. *Future Foods*, *9*(March), 100322. https://doi.org/10.1016/j.fufo.2024.100322

Mcnamara, J. T., Morgan, J. L. W., & Zimmer, J. (2016). *HHS Public Access*. 895–921. https://doi.org/10.1146/annurev-biochem-060614-033930.A

Nonato, S. de M., & De Souza Figueiredo, K. C. (2024). Bioethanol preparation and separation from pineapple peel upon combining fermentation and pervaporation through biochar-containing PDMS membranes. *Scientia Plena*, *20*(10), 1–9. https://doi.org/10.14808/sci.plena.2024.104201

Nunez-delgado, A. (n.d.). *Frontier Studies in Soil Science*.

Nzelibe, H. C., & Okafoagu, C. U. (2007). *Optimization of ethanol production from Garcinia kola (bitter kola) pulp agrowaste*. *6*(September), 2033–2037.

Obi, F. O., Ugwuishiwu, B. O., & Nwakaire, J. N. (2016). *AGRICULTURAL WASTE CONCEPT , GENERATION , UTILIZATION AND MANAGEMENT*. *35*(4), 957–964.

Østby, H. (2023). *Hemicellulolytic enzymes in lignocellulose processing*. *0*(January), 531–548.

Pendse, D. S., Deshmukh, M., & Pande, A. (2023). Heliyon Different pre-treatments and kinetic models for bioethanol production from lignocellulosic biomass : A review. *Heliyon*, *9*(6), e16604. https://doi.org/10.1016/j.heliyon.2023.e16604

Rao, M. M., Mohan, S., Prabhakara, B. T., Srinivasa, R., & Goddu, R. (2024). Discover Sustainability A comprehensive review on agricultural waste production and onsite management with circular economy opportunities. *Discover Sustainability*. https://doi.org/10.1007/s43621-024-00492-z

Remsion, A. A. O.-O. A. O. (2019). *PRODUCTION OF ETHANOL FROM PLANTAIN , PINEAPPLE AND BANANA WASTE BY*. *7*(7), 389–397.

Sánchez, M., Laca, A., Laca, A., & Díaz, M. (2021). *Value-Added Products from Fruit and Vegetable Wastes : A Review*. *2000376*, 1–21. https://doi.org/10.1002/clen.202000376

Sources, L., & Vasi, K. (2021). *Bioethanol Production by Enzymatic Hydrolysis from Different*.

Subramaniam, S., Sanyal, U., & Robert, R. (2022). *Molecular structural dataset of lignin macromolecule elucidating experimental structural compositions*. 1–13. https://doi.org/10.1038/s41597-022-01709-4

Tropea, A., Wilson, D., Torre, L. G. La, Curto, R. B. Lo, Saugman, P., Troy-davies, P., Dugo, G., & Waldron, K. W. (2014). *Bioethanol Production From Pineapple Wastes*. *3*(4), 60–70. https://doi.org/10.5539/jfr.v3n4p60

Upadhyay, A., Lama, J. P., & Tawata, S. (2010). *Utilization of Pineapple Waste : A Review*. *6*(2004).

Vanholme, R., Demedts, B., Morreel, K., Ralph, J., & Boerjan, W. (2010). *Lignin Biosynthesis and Structure 1*. *153*(July), 895–905. https://doi.org/10.1104/pp.110.155119

Victoria, M., Cabeza, C., Daniel, C., Ruedas, T., Cecilia, D., Ordoñez, R., Wilmer, J., & Llanos, P. (2024). *Characterization of pineapple peel (Ananas comosus) Perolera variety as a* *potential resource for bioethanol production comosus) variedad Perolera como recurso potencial para la producción de bioetanol Caracterização da casca de abacaxi (Ananas comosus) variedade Perolera como recurso potencial para produção de bioetanol*. *37*(3), 73–83. https://doi.org/10.18273/revion.v37n3-2024006

Wadhwa, M., Bakshi, M. P. S., & Makkar, H. P. S. (2015). *Wastes to worth : value added products from fruit and vegetable wastes*. *043*. https://doi.org/10.1079/PAVSNNR201510043

Yoshimi, Y., Tryfona, T., & Dupree, P. (2025). *Structure , Modification Pattern , and Conformation of Hemicellulose in Plant Biomass*. *7201301*. https://doi.org/10.5458/jag.7201301

Zoghlami, A., & Paës, G. (2019). *Lignocellulosic Biomass : Understanding Recalcitrance and Predicting Hydrolysis*. *7*(December). https://doi.org/10.3389/fchem.2019.00874

A M Agapkin , I A Makhotina, N. A. I. (2022). *The problem of agricultural waste and ways to solve it*. https://doi.org/10.1088/1755-1315/981/2/022009

Adiya, Z. I. S. G., Adamu, S. S., Ibrahim, M. A., Okoh, E. V. C., & Ibrahim, D. (2022). *Comparative Study of Bioethanol Produced from Different Agro- Industrial Biomass Residues*. *7*(2), 143–152.

Animesh, L. M., Sengar, S., & Neog, R. (2022). Pineapple processing waste (PPW): bioactive compounds , their extraction , and utilisation : a review. *Journal of Food Science and Technology*, *59*(11), 4152–4164. https://doi.org/10.1007/s13197-021-05271-6

Antunes-ricardo, M. (2023). *Solid-State Fermented Pineapple Peel : A Novel Food Ingredient with Antioxidant and Anti-Inflammatory Properties*.

Atul. U, Jeewan. P, L. and S. . T. (2003). *Utilization_of_Pineapple_Waste_A_Review (1)*.

Beckham, G. T. (2018). *A Brief Introduction to Lignin Structure*. *19*.

Broda, M., & Yelle, D. J. (2022). *Bioethanol Production from Lignocellulosic Biomass — Challenges and Solutions*.

Bušić, A., Morzak, G., Belskaya, H., & Šantek, I. (2018). *Bioethanol Production from Renewable Raw Materials and Its Separation and Purification : A Review*. *9818*, 0–3. https://doi.org/10.17113/ftb.56.03.18.5546

Caulfield, I. (1990). *THE STRUCTURES OF CELLULOSE*. *197*, 89–98.

Chalchisa, T., & Dereje, B. (2021). *From waste to food : utilization of pineapple peels for vinegar production*. *9*(1), 1–5. https://doi.org/10.15406/mojfpt.2021.09.00254

El-ramady, H., Brevik, E. C., Bayoumi, Y., Shalaby, T. A., El-mahrouk, M. E., Taha, N., Elbasiouny, H., Elbehiry, F., Amer, M., Abdalla, N., & Prokisch, J. (2022). *An Overview of Agro-Waste Management in Light of the Water-Energy-Waste Nexus*.

Frasca, S. (2024). *Lignocellulosic Biomass Components for Materials Applications*.

Hossain, A. B. M. S., & Fazliny, A. R. (2016). *Creation of alternative energy by bio- ethanol production from pineapple waste and the usage of its properties for engine*. *2016*(X).

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Kumari, T., & Raghubanshi, A. S. (2023). *Waste management practices in the developing nations : challenges and opportunities*. 773–797.

Laine, C. (2005). *STRUCTURES OF HEMICELLULOSES AND PECTINS IN WOOD AND PULP*.

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Mcnamara, J. T., Morgan, J. L. W., & Zimmer, J. (2016). *HHS Public Access*. 895–921. https://doi.org/10.1146/annurev-biochem-060614-033930.A

Nonato, S. de M., & De Souza Figueiredo, K. C. (2024). Bioethanol preparation and separation from pineapple peel upon combining fermentation and pervaporation through biochar-containing PDMS membranes. *Scientia Plena*, *20*(10), 1–9. https://doi.org/10.14808/sci.plena.2024.104201

Nunez-delgado, A. (n.d.). *Frontier Studies in Soil Science*.

Nzelibe, H. C., & Okafoagu, C. U. (2007). *Optimization of ethanol production from Garcinia kola (bitter kola) pulp agrowaste*. *6*(September), 2033–2037.

Obi, F. O., Ugwuishiwu, B. O., & Nwakaire, J. N. (2016). *AGRICULTURAL WASTE CONCEPT , GENERATION , UTILIZATION AND MANAGEMENT*. *35*(4), 957–964.

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Pendse, D. S., Deshmukh, M., & Pande, A. (2023). Heliyon Different pre-treatments and kinetic models for bioethanol production from lignocellulosic biomass : A review. *Heliyon*, *9*(6), e16604. https://doi.org/10.1016/j.heliyon.2023.e16604

Rao, M. M., Mohan, S., Prabhakara, B. T., Srinivasa, R., & Goddu, R. (2024). Discover Sustainability A comprehensive review on agricultural waste production and onsite management with circular economy opportunities. *Discover Sustainability*. https://doi.org/10.1007/s43621-024-00492-z

Remsion, A. A. O.-O. A. O. (2019). *PRODUCTION OF ETHANOL FROM PLANTAIN , PINEAPPLE AND BANANA WASTE BY*. *7*(7), 389–397.

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Sources, L., & Vasi, K. (2021). *Bioethanol Production by Enzymatic Hydrolysis from Different*.

Subramaniam, S., Sanyal, U., & Robert, R. (2022). *Molecular structural dataset of lignin macromolecule elucidating experimental structural compositions*. 1–13. https://doi.org/10.1038/s41597-022-01709-4

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Upadhyay, A., Lama, J. P., & Tawata, S. (2010). *Utilization of Pineapple Waste : A Review*. *6*(2004).

Vanholme, R., Demedts, B., Morreel, K., Ralph, J., & Boerjan, W. (2010). *Lignin Biosynthesis and Structure 1*. *153*(July), 895–905. https://doi.org/10.1104/pp.110.155119

Victoria, M., Cabeza, C., Daniel, C., Ruedas, T., Cecilia, D., Ordoñez, R., Wilmer, J., & Llanos, P. (2024). *Characterization of pineapple peel (Ananas comosus) Perolera variety as a potential resource for bioethanol production comosus) variedad Perolera como recurso potencial para la producción de bioetanol Caracterização da casca de abacaxi (Ananas comosus) variedade Perolera como recurso potencial para produção de bioetanol*. *37*(3), 73–83. https://doi.org/10.18273/revion.v37n3-2024006

Wadhwa, M., Bakshi, M. P. S., & Makkar, H. P. S. (2015). *Wastes to worth : value added products from fruit and vegetable wastes*. *043*. https://doi.org/10.1079/PAVSNNR201510043

Yoshimi, Y., Tryfona, T., & Dupree, P. (2025). *Structure , Modification Pattern , and Conformation of Hemicellulose in Plant Biomass*. *7201301*. https://doi.org/10.5458/jag.7201301

Zoghlami, A., & Paës, G. (2019). *Lignocellulosic Biomass : Understanding Recalcitrance and Predicting Hydrolysis*. *7*(December). https://doi.org/10.3389/fchem.2019.00874