

Journal home page: <http://ajarcde-safe-network.org> ISSN 2581-0405

Hydrolysis of Banana Stems with Sulfuric Acid Catalyst

Muhammad Dhafa Putra Alansyah, Caecilia Pujiastuti*, Sani, Suprihatin

Department of Chemical Engineering, Faculty of Engineering and Science, Universitas Pembangunan Nasional "Veteran" Jawa Timur, Indonesia

ARTICLE INFO

Article History:

Received: 17 June 2026

Final Revision: 01 July 2026

Accepted: 05 July 2026

Online Publication: 07 July 2026

KEYWORDS

banana stem, hydrolysis, glucose, delignification

CORRESPONDING AUTHOR

*E-mail: caecilia.tk@upnjatim.ac.id

ABSTRACT

Banana stems are agricultural waste with high lignocellulose content, making them a potential raw material for glucose production. This study aimed to determine the effect of sulfuric acid (H_2SO_4) concentration and hydrolysis time on the resulting glucose content. Prior to hydrolysis, delignification was performed using a 15% hydrogen peroxide (H_2O_2) solution. Hydrolysis was conducted at 100°C , varying H_2SO_4 concentrations (1%, 3%, 5%, 7%, and 9%) and hydrolysis times (10, 15, 20, 25, and 30 minutes). The hydrolysis products were characterized using Fourier Transform Infrared (FTIR) spectroscopy, while the hydrolysate was analyzed using a refractometer to determine total solids ($^\circ\text{Brix}$) as an estimate of sugar content. The results indicated that increasing both hydrolysis time and H_2SO_4 concentration generally led to higher glucose yields. The highest glucose content, 15.2%, was achieved at an H_2SO_4 concentration of 7% with a hydrolysis time of 20 minutes. Further increases in acid concentration or hydrolysis time did not result in higher estimated glucose levels, likely due to glucose degradation. The findings demonstrate that H_2SO_4 concentration and hydrolysis time play a crucial role in the conversion of cellulose to glucose, highlighting the potential of banana stems as an alternative raw material for glucose production.

Contribution to Sustainable Development Goals (SDGs):

SDG 2: Zero Hunger

SDG 9: Industry, Innovation, and Infrastructure

SDG 12: Responsible Consumption and Production

SDG 13: Climate Action

SDG 15: Life on Land

1. INTRODUCTION

1.1. Research Background

Indonesia is one of the countries that contributes a significant amount of waste. Waste is anything discarded from human or natural activities after its primary purpose has been achieved. Nearly 75% of the waste in Indonesia is organic. The primary source of organic waste is agricultural waste. Agricultural waste from banana pseudostems is estimated to exceed 640,000 stems from 800,000 trees [1]. Data from the Central Statistics Agency (BPS) shows that banana production in Indonesia increased in 2020 to 8.18 million tons, a 12.39% increase compared to the

previous year. If agricultural waste is not managed effectively, it can become a problem for the community [2].

Based on data from previous research according to [3] in their research on "Kinetic Study of Acid Hydrolysis of the Glucose Obtained from Banana Plant" found the effect of the type of raw material in the form of banana plant residue (Musa AAA Cavendish) on glucose yield with the variables used being leaves, main leaf stalks (rachis), and pseudostems. There is also the influence of variables in the form of sulfuric acid concentration used in the acid hydrolysis process, namely 3 - 10% v/v, and also the reaction time, namely 0 - 30 minutes. The best glucose yield was 13.02 g/L (1.3%) under the conditions used for the banana pseudostem at 100°C for 20 minutes with 5% v/v H_2SO_4 . However, in this study there was no delignification process that functions to remove as much lignin and hemicellulose as possible



This work is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License

Published under licence by SAFE-Network

while maintaining the cellulose content, in order to maximize the acid hydrolysis process to form glucose. Meanwhile, according to [4] in their research on The Effect of Hydrogen Peroxide Concentration and Acid Catalyst on Making Glucose from Cardboard, the effect of hydrogen peroxide concentration in the delignification process on glucose yield was obtained with the variables used being 0-4% v/v for hydrogen peroxide concentration and sulfuric acid concentration in the acid hydrolysis process being 1-5% v/v. The best glucose yield was 9.8% at 4% H₂O₂ and 4% H₂SO₄ concentration conditions and the specified conditions being a reaction temperature of 120 °C and a time of 60 minutes. While the lowest yield was 1.1% glucose at 0% H₂O₂ and 1% H₂SO₄ concentration conditions. Therefore, it can be concluded that delignification must precede acid hydrolysis to achieve the highest glucose yield.

1.2. Literature Review

Banana stems are agricultural waste with significant potential as a biomass source due to their high content of cellulose, hemicellulose, and lignin. This high lignocellulose content allows them to be used as a raw material for glucose production. Therefore, banana stems have the potential to become an environmentally friendly, economically valuable, and sustainable raw material.

Table 1. initial components of banana stems

No	Item	rate
1	Selulose	40-50%
2	Hemiselulose	25-30%
3	Lignin	15-25%

Based on Table 1, banana stems are composed of the main lignocellulosic components, namely cellulose, hemicellulose, and lignin. Cellulose is the component with the highest amount, at around 40–50%, making it the main source of carbohydrates that can be hydrolyzed into glucose. Hemicellulose content ranges from 25–30%, which acts as a polysaccharide that makes up plant cell walls and can be converted into simple sugars. Meanwhile, lignin content is around 15–25%, providing strength and rigidity to the banana stem. The high cellulose and hemicellulose content indicates that banana stems have the potential as raw materials for the production of glucose, bioethanol, and various other bioconversion products, so they can be utilized as a source of biomass that is economically valuable and environmentally friendly [3].

1.2.1. Delignification

Delignification is the initial stage aimed at reducing the lignin content in lignocellulosic materials. This process damages the lignin structure and releases carbohydrate compounds after opening the lignocellulose structure to make the cellulose more accessible and dissolves the lignin content in the material, making the lignin easier to separate from the fibers. Delignification damages the lignin structure and releases carbohydrate compounds [5]. The use of sodium hydroxide in the delignification process can degrade the ether bonds that connect lignin to cellulose [6]. Generally, the convectional delignification method uses sodium chlorite (NaOCl) in an acidic environment. However, the use of sodium chlorite can cause environmental problems because chlorine compounds and their derivatives can produce other chlorinated compounds, leading to serious

environmental issues. H₂O₂ is a strong oxidizing compound and can therefore be used in bleaching and delignification processes [7]. The H₂O₂ catalyzed substructural lignin oxidation process begins with a single electron cleavage of the aromatic substrate donor ring, producing an aryl cation radical, which then undergoes various postenzymatic reactions. As a result, lignin is broken down into H₂O [5]. Hydrogen peroxide (H₂O₂) has a strong oxygen-releasing capacity and is readily soluble in air. The advantages of using H₂O₂ in the bleaching process include its greater environmental friendliness compared to chlorine-based chemicals [6].

1.2.2. Hydrolysis

Hydrolysis is a chemical reaction that breaks down molecules into two parts by adding water molecules (H₂O) with the aim of converting polysaccharides into simple monomers. Hydrolysis in the glucose production process is the stage in which polysaccharide compounds, such as cellulose or starch, are broken down into simple sugars, such as glucose, by breaking glycosidic bonds with the aid of water. This process can occur enzymatically with enzymes such as cellulase and β-glucosidase, or chemically with acids or bases. Factors such as catalyst type, concentration, temperature, reaction time, and the solid-to-liquid ratio influence the rate of conversion from cellulose to glucose and the possibility of byproduct formation. There are several types of hydrolysis, as follows: 1. Acid hydrolysis 2. Base hydrolysis 3. Enzyme hydrolysis [8]. In the acid hydrolysis method, lignocellulosic biomass is exposed to acid at a specific temperature and pressure, producing sugar monomers. Some commonly used acids for acid hydrolysis include sulfuric acid (H₂SO₄), perchloric acid, and HCl. The following is the reaction in acid hydrolysis:

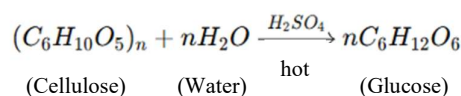


Fig. 1. Acid Hydrolysis Reaction

The advantage of using concentrated acid is that it can convert up to 90% of the sugar. However, the disadvantage is that it is quite expensive to operate because the equipment used must be acid-resistant and neutralization is required at the final stage. However, using dilute acid results in less sugar conversion than using concentrated acid, and the operating costs are lower [9]. Stated that plantains were hydrolyzed with H₂SO₄ at concentrations ranging from 2% to 12% for 60-120 minutes and at temperatures ranging from 90-110°C. The highest glucose concentration was 0.23 g/ml at 12% acid concentration and 90 minutes. Based on these results, it can be concluded that enzymatic hydrolysis produces higher glucose levels but requires more time, whereas acid hydrolysis requires less time and a lower concentration. So in this study, the acid hydrolysis method with H₂SO₄ was chosen [10].

1.3. Research Objective

The aim of this research is to produce glucose from banana stem (*Musa paradisiaca*) by hydrolysis process and to obtain the best conditions from the concentration and hydrolysis time variables studied in terms of high glucose concentration values.

2. MATERIALS AND METHODS

The primary material for this study was the banana pseudostem (*Musa paradisiaca*) obtained from Palang District, Tuban, East Java. The banana stems were washed, oven-dried at 70°C, then pulverized and sieved to a particle size of 40 mesh. The solvents used included distilled water (H₂O), hydrogen peroxide (H₂O₂), sulfuric acid (H₂SO₄), and sodium carbonate (Na₂CO₃). In the delignification stage, 10 grams of the material were weighed and mixed with 200 mL of 15% H₂O₂ at a solvent-to-solid ratio of 20 mL:1 g. The mixture was stirred at room temperature for 60 minutes at 300 rpm. Subsequently, the residue was filtered and washed until neutral pH was reached, then oven-dried at 70°C. The second process was acid hydrolysis using the cellulose residue, to which 200 mL of H₂SO₄ was added at varying concentrations (1%, 3%, 5%, 7%, and 9%) and an acid-to-solid ratio of 20 mL:1 g. The mixture was heated using a magnetic stirrer hot plate at 100°C for 10, 15, 20, 25, or 30 minutes at 300 rpm. The mixture was cooled and filtered to obtain the filtrate. The filtrate was neutralized using a 10% Na₂CO₃ solution and then filtered again. The hydrolysis filtrate was analyzed using a refractometer calibrated with distilled water prior to measurement to determine the total dissolved solids value (°Brix) as an estimate of glucose content. The hydrolysis product was subsequently characterized using Fourier Transform Infrared (FTIR) spectroscopy via the Diffuse Reflectance Spectroscopy method, with a resolution of 4 cm⁻¹ and a wavenumber range of 4000–400 cm⁻¹. All experiments were performed in triplicate, and the results obtained are presented as mean values.

3. RESULT AND DISCUSSION

The effects of hydrolysis time and sulfuric acid concentration on the total dissolved solids content (°Brix) resulting from the hydrolysis of banana stems were analyzed to determine the most effective process conditions. Hydrolysis times were varied (10, 15, 20, 25, or 30 minutes), while H₂SO₄ concentrations were varied (1%, 3%, 5%, 7%, and 9%). The glucose content produced in each treatment was measured and compared to determine the relationship between these variables and the efficiency of cellulose conversion to glucose. The results are presented in Figures 2, 3 and 4.

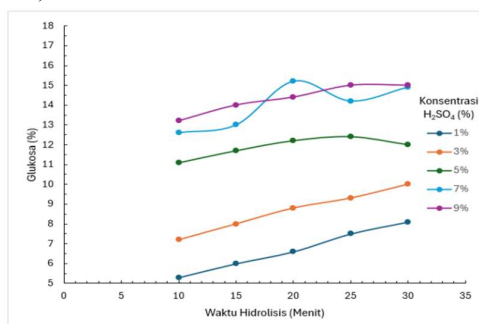


Fig. 2 Relationship between Hydrolysis Time (Minutes) and Glucose Content (%)

Glucose levels tended to increase with increasing hydrolysis time across various sulfuric acid concentrations. At 10 minutes of hydrolysis, the glucose levels produced were still relatively low, ranging from 5.3 to 13.2%. As the hydrolysis time increased to 30 minutes, glucose levels tended to increase in almost all acid

concentrations. This phenomenon indicates that hydrolysis time influences glucose formation from banana stem cellulose. The longer the contact time between the raw material and the acid solution, the greater the chance of cleavage of the glycosidic bonds in the cellulose chain into glucose molecules [11]. An increase in °Brix values indicates that a longer hydrolysis time results in the cleavage of more glycosidic bonds in cellulose, thereby producing dissolved sugars. However, measurements using a refractometer reflect only total dissolved solids; consequently, the results represent an estimate of sugar content rather than the specific glucose concentration.

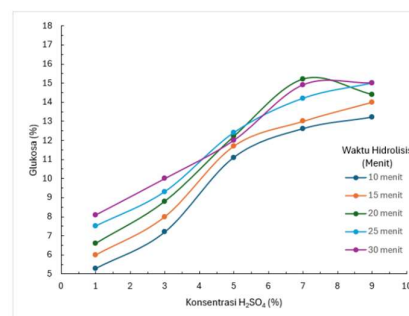


Fig. 3 Relationship between Acid Concentration (%) and Glucose Level (%)

The graph above shows that increasing acid concentration is generally followed by an increase in the glucose content produced. At a sulfuric acid concentration of 1%, the glucose content remains relatively low, ranging from 5.3–8.1%. As the acid concentration increases to 3% and 5%, the glucose content also increases, reaching 7.2–12.4%. A more significant increase is observed at concentrations of 7% and 9%, with the highest glucose content of 15.2% at 7% concentration after a hydrolysis time of 20 minutes. At H₂SO₄ concentrations above 7% or with longer hydrolysis times, the increase in °Brix values is no longer significant. This is attributed to the degradation of glucose into other compounds, such as hydroxymethylfurfural (HMF), resulting from excessively acidic hydrolysis conditions or prolonged reaction times. This indicates that the sulfuric acid concentration influences the effectiveness of the cellulose hydrolysis process into glucose. The higher the acid concentration used, the greater the number of H⁺ ions in the solution, this increasing the acid's ability to break the glycosidic bonds in the cellulose chain [12].

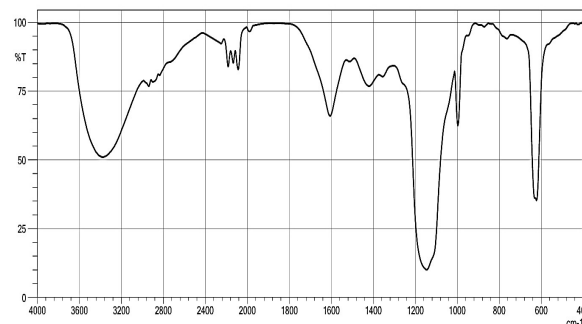


Fig. 4 FTIR Spectrum of Hydrolyzed Banana Stem Product

FTIR analysis was conducted to identify functional groups in the banana stem hydrolysis product following the delignification process. The FTIR spectrum displays a broad absorption band in

the 3300–3400 cm^{-1} region, indicating the presence of hydroxyl (O-H) groups. The high intensity of this band suggests a significant content of hydroxyl groups in the hydrolysis product, resulting from the cleavage of cellulose chains into simpler sugars. Meanwhile, the band at approximately 2920 cm^{-1} corresponds to aliphatic C-H vibrations. Strong absorption bands in the 1150–1030 cm^{-1} region are characteristic of C-O-C and C-O bonds, indicating the formation of carbohydrate compounds such as glucose derived from cellulose hydrolysis. Furthermore, the reduced intensity of the band in the 1520–1600 cm^{-1} region indicates a structural change in lignin following H_2O_2 delignification, thereby rendering the cellulose more accessible to the H_2SO_4 catalyst during hydrolysis. These FTIR results support the conclusion that delignification enhances cellulose accessibility to hydrolysis, although the analysis provides only qualitative evidence and cannot yet be used to quantify the percentage of lignin removal.

4. CONCLUSION

Research indicates that banana stems (*Musa paradisiaca*) have the potential to serve as a lignocellulosic feedstock for sugar production via acid-catalyzed hydrolysis (using sulfuric acid) following a hydrogen peroxide delignification step. The optimal conditions identified in this study involved a 7% H_2SO_4 concentration, a hydrolysis duration of 20 minutes, and a temperature of 100°C, yielding a total dissolved solids value of 15.2 °Brix as an estimate of sugar content. Increasing the acid concentration or hydrolysis time beyond these parameters did not significantly increase °Brix values; this is likely attributable to the degradation of sugars into other compounds during hydrolysis. FTIR analysis revealed changes in functional groups indicating increased cellulose accessibility following delignification, although the method could not quantitatively determine the extent of lignin removal. As this study relied on refractometry to estimate sugar content, future research should employ more specific analytical methods such as DNS or HPLC and incorporate feedstock characterization and conversion efficiency data to ensure greater accuracy and comparability with other studies.

REFERENCE

- [1] Karyati, S. Herawati. L. 2013, 'Pengaruh Penambahann Limbah Pelepeh Pisang Sebagai Komponen Daur Ulang Kertas', Sanitasi, Jurnal Kesehatan Lingkungan, Vol. 5, No. 1, hh. 8-15.
- [2] Badan Pusat Statistik 2021, Data Produksi Pisang, Jakarta, BPS
- [3] Abril-González, M., Vele-Salto, A., & Pinos-Vélez, V. 2023, 'Kinetic Study of Acid Hydrolysis of the Glucose Obtained from Banana Plant', ChemEngineering, 7(2), 39.
- [4] Ajna, P. A., Masynur, Moh. B. S., & Siswanto 2023, 'Pengaruh Konsentrasi Hidrogen Peroksida dan Katalis Asam pada Pembuatan Glukosa dari Kardus', Prosiding Seminar Nasional Teknik Kimia Soeardjo Brotohardjono XIX, 60–65.
- [5] Siswanto, 2022, 'Pengaruh Konsentrasi Hidrogen Peroksida Dan Katalis Asam Pada Pembuatan Glukosa Dari Kardus', Jurnal Seminar Nasional Teknik Kimia Soeardjo Brotohardjono XIX, p-ISSN 1978-0427 e-ISSN 2776-5696, hh 60-65.
- [6] Amirillah N, dkk, 2020, 'Studi Efektivitas Metode Ekstraksi Selulosa dari Agricultural Waste', Jurnal Seminar Nasional Penelitian LPPM UMJ E ISSN:2745-6080.
- [7] Jufrinaldi, 2018, 'Isolasi Selulosa Dari Bagas Tebu Melalui Pemanasan Radiasi Gelombang Mikro', Jurnal Ilmiah Teknik Kimia, UNPAM, Vol. 2, No. 2, hh. 37-46.
- [8] Amândio, M. S. T., Rocha, J. M. S., & Xavier, A. M. R. B. 2023, 'Enzymatic Hydrolysis Strategies for Cellulosic Sugars Production to Obtain Bioethanol from Eucalyptus globulus Bark', Fermentation, 9(3), 241.
- [9] Azizah Y, 2022, 'Hidrolisis Ampas Tebu (Baggase) Menggunakan HCl Menjadi Cellulosa Powder', Jurnal Inovasi Ramah Lingkungan (JIRL) Vol. 3, No. 3, hh. 11-15.
- [10] Rosalina M.P., 2022, 'Pengaruh Waktu Hidrolisis Dan Konsentrasi Larutan Asam Pada Hidrolisis Kulit Pisang Tanduk', Jurnal Prosiding Diseminasi FTI, hh 1-8.
- [11] Safitri, A.D. et al. 2022, 'Glukosa Cair Dari Proses Hidrolisis Ubi Jalar Kuning', Chemical Engineering Journal Storage (CEJS), 2(4), p. 81. doi:10.29103/cejs.v2i4.7729.
- [12] Safitri, R. et al. 2018, 'Pengaruh Konsentrasi Asam Sulfat dalam Proses Hidrolisis Selulosa', Prosiding Industrial Research Workshop and National Seminar, 9, pp. 438–442.
- [13]