Bioethanol Production from Waste Banana Peels using Alkaline Textile Industry Wastewater for Delignification Process

Rashid Amin[1], Shama Sahar[1], Mutahir Khan[1], Inamullah Khan[1], Aitezaz Alam[1], Jamil Ahmad[1*]
[1]Department of Chemical Engineering, University of Engineering and Technology, Peshawar, Pakistan.
***Correspondence**: engrjamilahmad@uetpeshawar.edu.pk

Citation | Amin. R, Sahar. S, Khan. M, Khan. I, Alam. A, Ahmad. J, "Bioethanol Production from Waste Banana Peels using Alkaline Textile Industry Wastewater for Delignification Process", IJIST, Vol. 07 Issue. 02 pp 897-906, May 2025
Received | April 15, 2025 **Revised |** May 17, 2025 **Accepted |** May 19, 2025 **Published |** May 21, 2025.

Depletion of fossil fuel quantity and the higher dependence on it may cause serious problems in the future. Alternative energy sources are required to overcome potential problems. Bioethanol is one of the suitable alternatives to fulfill our energy requirements. Bioethanol can be produced from various sources, including organic waste such as fruit and vegetable waste, which has the potential to produce bioethanol. In this work, bioethanol was produced from banana peels using alkaline textile industry wastewater for the delignification process. The effect of H_2SO_4 strength, pH of the solution for fermentation, banana peels delignification, and grinding (size reduction) on ethanol production was analyzed. Experimental results show that increasing the sulfuric acid concentration from 2% to 5%, and then to 10%, led to an increase in the refractive index and hence, ethanol production, with maximum ethanol yield observed at 10% H_2SO_4. Increasing the pH of the solution of fermentation from 2 to 14 shows an increase in the refractive index, and maximum ethanol was obtained at pH 6. The delignification and grinding (size reduction of banana peels) also showed a positive effect on the production of ethanol.

Keywords: Bioethanol, Delignification, Fruit and Vegetable Wastes, Banana Peels, Textile Wastewater

Introduction:

Conventional fuel is limited in the Earth's crust, and today's world depends on fuels for moving vehicles, heating, and electricity [1]. The predicted amount of crude oil in 2020 was 90 million [2]. Latest research shows that it will exceed the above figure due to the high reliance on crude oil [3]. This high dependency on crude oil and associated fuels, including gasoline, results in the emission of greenhouse gases from the combustion of various fuels, which in turn affects the environment, such as droughts, floods, skin diseases, etc. To overcome the effects of climate change, an alternate fuel for gasoline is required to fulfill the need of energy requirements [4]. Latest research shows that ethanol is the best alternative to gasoline, and it can be used in a blended form of 75 % gasoline. 25 % ethanol named E-25. Brazil is the best example of using ethanol blended with gasoline. Gasoline, a significant chain hydrocarbon, produces more amorphous carbon from the incomplete burning of organic matter than ethanol [5]. The leading cause of air pollution is the emission of sulfur dioxide and carbon monoxide from vehicles, which can cause severe health issues, biotic and abiotic, global warming, and alarming climate change effects [6]. The price of gasoline is increasing day by day in this time of inflation, and it is bleak to pay carbon taxes. To tackle this problem, renewable energy sources may be used to produce ethanol as a fuel, which can overcome the effects of climate change and reduce global warming, pollution, and inflation [7]. The latest study shows that diesel engines emit a severe amount of black carbon and nitrogen oxides, which badly affect human health [8]. Bioethanol has remarkable physicochemical properties [9] and may be considered as a suitable energy source and gasoline blend [10]. Over the last two decades, soil pollution has increased, alarming the living beings, the environment, and the atmosphere. It may spread through human activities, i.e., industrialization, transportation, etc [11]. Organic pollutants cause soil pollution, and the emission of greenhouse gases from automobiles disturbs the pattern of rainfall and increases the temperature of the earth, which affects the climate and causes global warming [12]. Currently, the world population exceeds 8.2 billion, and the food demand has also increased, which causes land pollution in the form of organic food waste. The organic food waste is recycled as an alternate source of energy and a driver of nitrogen, which contributes to waste quality and greenhouse gas emissions. Food waste can be converted into renewable energy sources using the latest technology, reducing organic food waste pollution [13]. Production of bio-ethanol fuel from organic food waste reflects waste-to-fuel technology [14]. Ethanol was previously produced from other fruit and vegetable waste, such as Indian chestnut, sweet potato, jackfruit, and pineapple. However, these wastes produced a small amount of ethanol after a long process. Pineapple waste produced 0.090% (0.90 mg/ml) Ethanol, sweet potato waste produced 0.079% (0.79 mg/ml) ethanol, jackfruit waste produced 0.045% (0.45 mg/ml) ethanol, whereas Indian chestnut waste produced 0.045% (0.45 mg/ml) ethanol [15] Figure 1 shows that the maximum yield of Ethanol was obtained from banana peels. The product yield content in banana peels increased by 7.38 (v/v) in the first 24 hours of fermentation and then went down after 72% of fermentation. In contrast, other wastes, like cabbage and mixed wastes, decreased product yield from the first 24 hours, and papaya waste decreased yield after 48 hours [16].

It is concluded that banana peels may be used as a raw material for biofuel production, as their product yield is the highest. Moreover, bananas are used throughout the whole year, while other fruits and vegetables are available only in a specific season. The raw material, which is mainly composed of cellulose and hemicellulose, can be converted into simple sugar by the hydrolysis process. However, it has a fibrous material called lignin, which hurts the production process. Therefore, to maximize the production, delignification is carried out, as lignin hinders the hydrolysis process [17].

In this research work, a novel approach to ethanol production from waste banana peels is presented. The significant global generation of organic waste, with over 30% being fruit and vegetable waste like the widely consumed banana (over 100 billion annually), and the environmental burden of high-pH textile wastewater from Pakistan's textile industry, this study introduces a unique solution for waste-to-energy transformation. Banana peels, rich in cellulose and hemicellulose but containing lignin that hinders the process of ethanol production, are subjected to alkaline delignification using textile wastewater (an alkaline byproduct of the textile bleaching process). This specific application of textile wastewater for lignin removal in banana peels for bioethanol production represents a novel waste-to-energy transformation (which was never used before for ethanol production). The results demonstrate a significantly higher ethanol yield compared to conventional processes, which highlights the potential of this advanced and environmentally friendly transformation.

This study's primary Aim was to investigate bioethanol production from waste banana peels using alkaline textile industry wastewater for the delignification process. Objectives:

To optimize the (H_2SO_4) concentration used in the hydrolysis process on the efficiency of sugar release and subsequent ethanol yield.

- To evaluate the influence of pH (ranging from 2 to 14) on the fermentation process and ethanol product yield.
- To analyze the role of delignification in enhancing the hydrolysis process by reducing lignin content in banana peels.
- To explore the novel use of alkaline textile industry wastewater as a sustainable medium for delignification, contributing to waste-to-energy solutions.

By addressing these objectives, the study sought to develop an efficient, eco-friendly method for bioethanol production while repurposing industrial and agricultural waste.

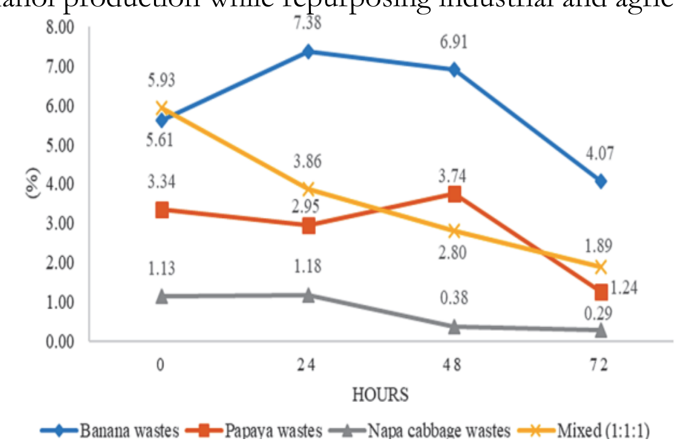

Figure 1. Bioethanol production with a combination of fruit and vegetable wastes

Materials and Methods:

Grinder:

A grinder is a machine used to crush and pulverize material into smaller pieces, shown in Figure 2. In the context of producing ethanol from banana peels, a grinder breaks down the banana peels into fine pulp to increase the surface area for the hydrolysis process, which breaks down the complex carbohydrates into simple sugar, which is then converted into ethanol in the fermentation process.

Specification of the Grinder:

- voltage: 220/240 V, 50Hz/60Hz
- Rotating speed: 28000 r/min
- Working time: 5 min
- Power factor: 1800W
- Grinding degree: 30~300
- Interval time: 10 min

Figure 2. Grinder for size reduction.

Distillation column:

A distillation column (Figure 3) works on the fractional distillation principle. Here, ethanol is separated from the mixture, usually the ethanol-water mixture. Ethanol's boiling point is 78 °C, and that of water is 100 ℃. Due to the difference in the boiling points of the two components, separation is achieved.

Figure 3. Distillation column.

Components of a Distillation Column:

- Heater
- Condenser
- Distillation flask
- Receiving flask
- Stand

Refractive meter:

An instrument used to measure the refractive index of a liquid solution using the principle of refraction of light.

Working principle:

It works by passing light through a sample and measuring the angle of refraction, which changes with changes in the concentration of solute.

Methodology:

Sedimentation Of Textile Wastewater:

Textile industrial wastewater, which is used to produce bioethanol, was collected from the Dawood textile industry in Hayatabad, Peshawar, Pakistan. The sedimentation process was performed to remove all the suspended particles and heavy metals in textile industrial wastewater, and clear alkaline water was obtained.

Washing of raw material (Banana peels):

Banana peels contain dust particles and other impurities, which were removed by washing them with tap water.

Delignification:

In the delignification tank, lignin was removed by heating banana peels for 3 hours, in the presence of alkaline textile waste water, and a temperature of 70 ℃ was maintained. Here, lignin was reduced by 50%. After this, the size reduction of delignified material was carried out.

Washing:

In this step, the delignified banana peels, which had a blackish color due to black liquor produced during delignification, were washed again with tap water to proceed to the next step.

Acid hydrolysis:

Solution of H_2SO_4 was prepared with the concentrations of 2%, 5%, and 10%. The material after crushing was divided into three equal parts. Each part of the material was added in the 2% H_2SO_4, 5% H_2SO_4, and 10% H_2SO_4 respectively. In the Pre-treatment tank, the peels were treated and heated at 80 °C temperature for 10 minutes, as shown in Figure 4. The hydrolyzed solution was neutralized by the addition of NaOH to get the optimum pH of 6.

Figure 4. Pre-treatment of banana peels.

Neutralization:

In this step, the hydrolyzed solution, which was strongly acidic due to the addition of H_2SO_4 for complex bond breaking, was neutralized by the addition of NaOH to get a favorable condition for the fermentation.

Fermentation:

Saccharomyces cerevisiae (Baking Yeast) was added to the neutralized solution to break down the glucose molecules to get the desired product. The process took seven days, and an ethanol-water mixture was produced as a product, and CO_2 was produced as a by-product.

Distillation:

The ethanol-water mixture was separated by using a simple atmospheric distillation technique. The boiling point of ethanol is lower than water. Prepared ethanol had a refractive index of 1.36.

Refractive meter (testing):

After the distillation, the ethanol was tested by the refractive meter to check its purity by the refractive index.

Production of bioethanol can be shown in Figure 5.

Flow diagram of methodology:

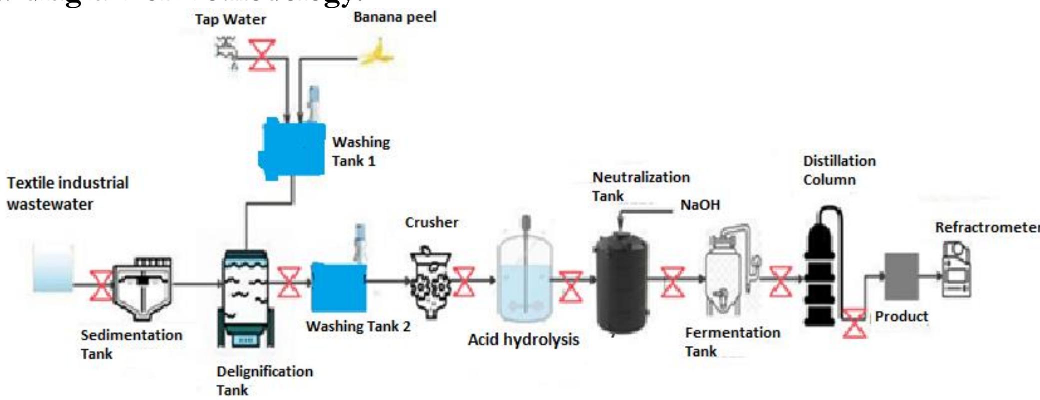

Figure 5. Flowsheet for the production of bio-ethanol.

Results and Discussion:

Effect of H_2SO_4 strength on ethanol production:

After fermentation, the refractive index of all three samples, i.e., using 2%, 5%, and 10% H_2SO_4, was found out and tabulated against the sulfuric acid strength as shown in Figure 6.

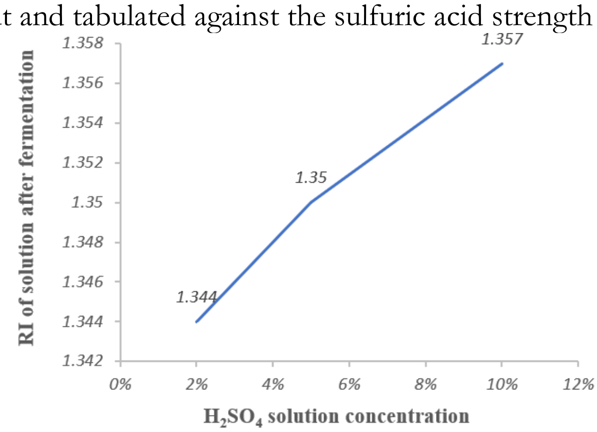

Figure 6. Refractive Index of ethanol water mixture vs H_2SO_4 solution concentration (pH = 6.0)

Table 1. RI and H_2SO_4 solution concentration

H_2SO_4 concentration	Refractive Index
10 %	1.357
5 %	1.350
2 %	1.344

The results revealed that the refractive index was increased as the strength of the acid increased and reached a value of 1.357, close to the refractive index of pure ethanol, i.e., 1.36, as shown in Figure 6. Thus, the optimum value of refractive index for the mixture was 1.357, which means that the ethanol percentage in the solution will be maximum when the refractive index of the solution is 1.357 or near this value. The refractive index of ethanol is 1.36, and that of water is 1.34. Therefore higher the refractive index, the higher will be the ethanol (Product) concentration. However, it should not be more than 1.36 nor less than 1.34. Table 1 represents the results of the refractive index and H_2SO_4 solution concentration.

Effect of solution pH on fermentation on ethanol production:

(Figure 7) represents the effect of pH of the solution prepared for fermentation on the refractive index of the ethanol-water mixture. As shown in the figure 7, at pH 6, an optimum value of refractive index, i.e., 1.357, was obtained close to the refractive index of ethanol (1.36) corresponding to the maximum amount of the product ethanol-water mixture. Table 2 represents the results of the refractive index and solution pH.

Table 2. RI and solution pH

PH	Refractive Index
01	1.346
06	1.357
14	1.367

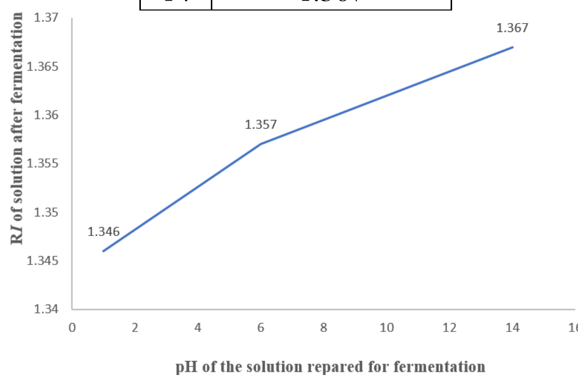

Figure 7. Refractive Index vs pH of prepared solution for fermentation (10% H_2SO_4)

Effect of banana peels delignification on the ethanol production:

Experiments were conducted without and with the delignification process, and the results were tabulated as shown in Table 3. It is shown that the refractive index was high when delignification was carried out. It is concluded that the delignification increases the product yield of ethanol.

Table 3. Comparison of ethanol production with and without delignification

Delignification	Refractive Index	pH	Concentration of H_2SO_4 (%)
Without	1.351	6.0	10
With	1.357	6.0	10

Effect of raw material size on ethanol production:

The ethanol product yield was also affected by the size of the raw material (banana peels) used as feed for the hydrolysis process. Experiments were carried out with and without grinding just before the hydrolysis process, and the results in Table 4 revealed that the experiment performed with size reduction had a higher refractive index and vice versa, which was translated as high ethanol production.

Table 4. Effect of grinding of raw material on the ethanol production

Grinding	Refractive Index	pH	Concentration of H_2SO_4 (%)
Without	1.348	6.0	10
With	1.357	6.0	10

The overall experimental results are tabulated in Table 5, which shows the effect of pH, strength of H_2SO_4, the effect of delignification process, and grinding on the refractive index and ethanol production.

Table 5. Overall experimental results

Exp No.	Delignification	Grinding	pH	Concentration of H_2SO_4	Refractive Index
1	Yes	Yes	6	2	1.344
2	Yes	Yes	6	5	1.350
3	Yes	Yes	6	10	1.357
4	Yes	Yes	14	10	1.365
5	Yes	Yes	1	10	1.346
6	Yes	No	6	10	1.352
7	No	Yes	6	10	1.351

Discussion:

Comparison of this study with previous research.

Table 6. Comparison of Ethanol Production from Various Feedstocks

Study	Feedstock	Key Conditions	Yield/Output	Key Findings
Current Experiment	Banana peels	pH 14, 10% H_2SO_4, delignified, ground	1.365 (Refractive Index)	Highest RI achieved; pH 14 result unusual
[16]	Mixed fruit waste	Natural yeast, pH 5.5-6.0, 72h fermentation	4.5% v/v ethanol	An effective natural fermentation process
[14]	Cassava/banana waste	10% H_2SO_4, ground, pH 6.0	450 mL from 3kg of waste	Demonstrated grinding benefits
[10]	Pure ethanol	N/A (reference standard)	1.361 RI (20°C)	Industry purity benchmark
[9]	Sugarcane (Brazil)	Industrial scale production	5,000 L/ha/year	Large-scale economic viability

Table 7. Ethanol Production Comparison by Refractive Index (RI)

Study	Feedstock	Key Conditions	Refractive Index (RI)	Equivalent Ethanol Purity	Key Findings
Current Experiment	Banana peels	pH 14, 10% H_2SO_4, delignified, ground	1.365	~96% ethanol	Potential measurement artifact at pH 14
[16]	Mixed fruit waste	Natural yeast, pH 5.5-6.0	1.358	~92% ethanol	Typical for fermented bioethanol
[14]	Cassava waste	10% H_2SO_4, ground, pH 6.0	1.352	~88% ethanol	Lower RI suggests impurities
[10]	Pure ethanol	Reference standard (20°C)	1.361	100% ethanol	Anhydrous benchmark
[9]	Sugarcane ethanol	Industrial distillation	1.360-1.363	—	—

Conclusions and Recommendations:

Bioethanol was produced from banana peels using textile industry wastewater and the delignification process. The effect of H_2SO_4 strength, pH of solution to fermentation, banana peels delignification, and grinding (size reduction) on the refractive index of bio-ethanol was analyzed. It was concluded that maximum ethanol was produced at 10% H_2SO_4 and pH 6. Additionally, the process of delignification and grinding had a positive effect on the production of ethanol.

Author's Contribution: Rashid Amin and Shama Sahar: Performed experimental work and wrote the first draft of the manuscript. Mutahir Khan: Helped in data collection. Inamullah Khan: Helped in Experimentation. Aitezaz Alam: Helped in writing - the review and editing. Jamil Ahmad: Did overall supervision and manuscript finalization.

Conflict of interest: The authors have declared no conflict of interest.

References:

[1] S. M. A.E. Atabani, A.S. Silitonga, Irfan Anjum Badruddin, T.M.I. Mahlia, H.H. Masjuki, "A comprehensive review on biodiesel as an alternative energy resource and its characteristics," *Renew. Sustain. Energy Rev.*, vol. 16, no. 4, pp. 2070–2093, 2012, doi: https://doi.org/10.1016/j.rser.2012.01.003.

[2] J. D. Edwards, "Crude oil and alternate energy production forecasts for the twenty-first century: The end of the hydrocarbon era," *Am. Assoc. Pet. Geol. Bull.*, 1997, [Online]. Available: https://pubs.geoscienceworld.org/aapg/aapgbull/article-abstract/81/8/1292/39464/Crude-Oil-and-Alternate-Energy-Production

[3] B. K. hattacharya, S., & Sachdev, "Can renewable energy reduce the demand for crude oil: An analysis?," *Int. J. Multidiscip. Res. Growth Eval.*, pp. 94–98, 2021, [Online]. Available: https://www.researchgate.net/publication/356453094_Can_renewable_energy_reduce_the_demand_for_crude_oil_An_analysis

[4] R. Y. Aliyu Galadi ALHASSAN, Richard Balthi MSHELIA, "REVIEW OF THE USE OF BIOETHANOL AS ALTERNATIVE FUEL FOR INTERNAL COMBUSTION ENGINES," *ACTA Tech. CORVINIENSIS – Bull. Eng.*, 2021, [Online]. Available: https://acta.fih.upt.ro/pdf/2021-2/ACTA-2021-2-25.pdf

[5] Travis Joseph Kessler, "PREDICTIVE MODELING AND STATISTICAL EVALUATION OF CHEMICAL PROPERTIES RELEVANT TO THE COMBUSTION OF ALTERNATIVE FUELS AND FUEL BLENDS," *Univ. Massachusetts Lowel*, 2023, [Online]. Available: https://www.proquest.com/openview/746a3bade208c9a3f97aaa9d20893cfb/1?cbl=18750&diss=y&pq-origsite=gscholar

[6] I. Manisalidis, E. Stavropoulou, A. Stavropoulos, and E. Bezirtzoglou, "Environmental and Health Impacts of Air Pollution: A Review," *Front. Public Heal.*, vol. 8, 2020, doi: 10.3389/fpubh.2020.00014.

[7] I. Hernandez Carballo and M. R. Sisco, "Examining the effects of gasoline prices on public support for climate policies," *Nat. Energy 2024 92*, vol. 9, no. 2, pp. 219–227, Jan. 2024, doi: 10.1038/s41560-024-01449-2.

[8] C. H. Yaoxian Huang, Nadine Unger, Kandice Harper, "Global Climate and Human Health Effects of the Gasoline and Diesel Vehicle Fleets," *GEO Heal.*, 2020, [Online]. Available: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2019GH000240

[9] A. Szklo, R. Schaeffer, and F. Delgado, "Can one say ethanol is a real threat to gasoline?," *Energy Policy*, vol. 35, no. 11, pp. 5411–5421, 2007, [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S0301421507003114?via%3Dihub

[10] M. C. Paolo Iodice, "Ethanol/Gasoline Blends as Alternative Fuel in Last Generation Spark-Ignition Engines: A Review on CO and HC Engine Out Emissions," *Energies*, vol. 14, no. 3, p. 4034, 2021, doi: https://doi.org/10.3390/en14134034.

[11] B. Koul and P. Taak, "Soil Pollution: Causes and Consequences," *Biotechnol. Strateg. Eff. Remediat. Polluted Soils*, pp. 1–37, 2018, doi: 10.1007/978-981-13-2420-8_1.

[12] B. J. D. Olajumoke Oke Fayinminn, Faith A. Onitayo, Francis Adegbola Ogunkunle, "Chapter 11 - Soil pollution and climate change Author links open overlay panel," *Environ. Pollut. Public Heal.*, pp. 289–302, 2024, [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/B9780323959674000143?via%3Dihub

[13] J. G. Bruna Grizzetti, Ugo Pretato, Luis Lassaletta, Gilles Billen, "The contribution of food waste to global and European nitrogen pollution," *Environ. Sci. Policy*, vol. 33, pp. 186–195, 2013, [Online]. Available:

https://www.sciencedirect.com/science/article/abs/pii/S1462901113001251?via%3Dihub

[14] X. Yuan and M. Jin, "Fuel Ethanol Production from Lignocellulosic Wastes via Bioconversion," pp. 387–416, 2025, doi: 10.1007/978-981-96-1222-2_11.

[15] P. Chaudhary, Y., Durve-Gupta, A., Birla, B. K., Kalyan, C., & Gosavi, "Impact Factor: RJIF 5.44 www.biosciencejournals.com Volume 6; Issue 5," *ResearchGate*, 2018, [Online]. Available: https://www.researchgate.net/publication/330882823_Impact_Factor_RJIF_544_wwwbiosciencejournalscom_Volume_6_Issue_5

[16] E. L. Gemilang Lara UTAMA , Wahyu Kristian SUGANDI, "Dilution Ratio of Tacca leontopetaloides in the Production of Bioethanol with the Inoculation of Indigenous Yeasts Consortium," *J. Japan Inst. Energy*, vol. 97, no. 9, pp. 270–273, 2018, [Online]. Available: https://www.jstage.jst.go.jp/article/jie/97/9/97_270/_article

[17] B. L. Harry Rizka Permatasari, Fakhili Gulo, "PENGARUH KONSENTRASI H2SO4 DAN NaOH TERHADAP DELIGNIFIKASI SERBUK BAMBU (GIGANTOCHLOA APUS)," *Progr. Stud. Pendidik. Kim. FKIP Univ. Sriwij.*, [Online]. Available: https://core.ac.uk/download/pdf/267822919.pdf

Copyright © by authors and 50Sea. This work is licensed under Creative Commons Attribution 4.0 International License.