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ORIGINAL ARTICLE

Utilization of Ubi Gajah as a Non-Edible Cassava Feedstock for Bioethanol Fuel Production

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ABSTRACT - This study investigates the potential of Ubi Gajah, a non-edible cassava variety, as a sustainable feedstock for bioethanol production. Utilizing non-edible biomass is important for reducing competition with food resources while promoting renewable energy development. In this research, both the pulp and peels of Ubi Gajah were used as substrates for bioethanol production through acid hydrolysis followed by fermentation. Hydrolysis was conducted using sulfuric acid at concentrations of 5%, 10%, and 15% (v/v), after which the treated biomass was heated under pressure to enhance substrate breakdown and sugar release prior to fermentation for 48 hours. The results clearly showed that increasing acid concentration improved hydrolysis efficiency and ethanol production. The highest ethanol yield was obtained from Ubi Gajah pulp hydrolysed with 15% (v/v) sulfuric acid, producing 220.89 g/L of bioethanol, whereas the peels produced a lower maximum yield of 156.65 g/L under the same conditions. These findings indicate that Ubi Gajah pulp is a more effective substrate for bioethanol production than the peels. Fuel characterization based on ASTM standards confirmed that the produced bioethanol possesses properties suitable for transportation fuel applications. In addition, tests on bioethanol–diesel blends demonstrated favourable exhaust emission characteristics and acceptable diesel engine performance. Overall, the study highlights Ubi Gajah as a promising non-food biomass resource for sustainable bioethanol production and cleaner alternative fuel applications.

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INTRODUCTION

Energy stands as one of the primary core fundamental requirements for sustaining life [1-2]. However, fossil fuel reserves are now declining, while global energy demand and primary energy consumption continue to rise. In addition, combustion-related emissions further add to global warming [3-4]. Thus, People have been putting in effort to bring in renewable, greener energy, such as bioenergy and bioethanol, which have received attention from researchers and consumers [5-6]. Liquid biofuels present a more suitable option since they can serve as an alternative for petroleum based fuel to lower the reliance on raw petroleum and help lower environmental pollution, as petroleum typically has an oxygen content below 1%, Meanwhile, biofuels typically contain between 10% and 45% oxygen, resulting fuel combustion becoming more effective and lowering the hydrocarbons in exhaust gas emissions [7-8].

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Biofuels are generally biodegradable because they come from organic materials. Ethanol can be found in two main forms: fermented ethanol and synthetic ethanol. Synthetic ethanol is created by converting ethylene with steam in the presence of a catalyst. On the other hand, fermented ethanol is made from plant materials that contain starch or sugars, where the sugars are broken down through fermentation to form ethanol. A range of agricultural products can be used for this purpose, and Table 1 lists several common feedstocks that are typically used in ethanol production [9].

Fuel ethanol, a blend of gasoline and ethanol, is commonly used in many sectors, including transportation. The “gasohol” or E10 is the most widely used is mixture of ethanol-gasoline, a mixture of 90% gasoline with 10% ethanol. The mixture ethanol with gasoline results in more fuel usage due to the energy held in the mixture. This is due to the blend's energy content. Gasoline contains 3.3% more energy content per gallon than E10, Meanwhile, gasoline contains 24.7% more energy per gallon compared to E85 [10]. E-diesel (Ethanol-diesel blend), 0.2-5.0% (v/v) of additive and holds around 15% (v/v) of ethanol, which maintains the blend's balance and specific properties of fuel, for example the corrosion inhibition, lubricity and Cetane number. For example, additive is crucial because E-diesel mixture is unstable and will split over time. E-diesel fuels are still in the evaluation phase, and past results showed that Blended fuels containing biodiesel and bioethanol may contribute to lower levels of some exhaust emissions [5].

Table 1. Ethanol production feedstocks

Feedstock properties	Examples
Direct sugar sources	Sugarcane, Sugar beets, molasses, fruits
Starchy crops	Wheat, corn, cassava, barley, potato
Woody materials or Cellulosic	Straw, sawdust, poplars, corncob

This research is focused on gas emissions and diesel engine performance evaluation of fuels fuelled using bioethanol diesel blends (BDB) with varying amounts of ethanol. The bioethanol is being suggested to be produced through abundant resources obtainable from the raw material which is ‘Ubi Gajah’ in Malaysia through the acid hydrolysis process. The fuel properties were characterised in accordance with standards of ASTM.

MATERIALS AND METHODS

Raw Ubi Gajah, grown under natural conditions, was collected from Sarawak. The inner pulp and outer peel from Ubi Gajah were divided manually. The samples were cut into small pieces and blended with a blender. Then, it was divided into equal portions and transferred to separate beakers for the next experiment. Chemicals from laboratory standards were used, H_2SO_4 (95–97%).

Acid Hydrolysis and Pre-Treatment

H_2SO_4 was added during pretreatment at concentrations of 5% v/v, 10% v/v, and 15% v/v to the prepared samples. After that, they were placed in the autoclave for three hours. After hydrolysis, the solutions were filtered with filter paper and a glass funnel. Then, a pocket refractometer is used to measure the glucose content.

Fermentation and Bioethanol Production

Instant yeast (*Saccharomyces cerevisiae*) was cultured in Yeast Extract-Peptone-Dextrose (YPD) medium utilizing 10 g of yeast extract, 20 g of peptone, 20 g of glucose and 1 l of water were mixed together [11]. The solution is being autoclaved for 2 hrs and refrigerated for further used. For restoring yeast function, rehydration process was done by adding measured amount of yeast into 10 ml of YPD medium. The rehydrated yeast mixture was then inoculated into measured amount of YPD medium for further incubation at room temperature on an orbital shaker for 20 hrs at 150 rpm. Fermentation was carried out by mixing YPD and hydrolysed solution at 1:2 ratio. Then the fermentation medium was thoroughly mixed employing an orbital shaker for 48 hrs with a rotational speed of 150 rpm at room temperature. Periodically, samples of the fermentation medium were withdrawn to measure the glucose an ethanol concentration utilizing pocket refractometers.

Bioethanol Fuel Properties Analysis

Fuel property testing for the produced bioethanol was carried out in accordance with the standards of ASTM.

Engine Performance and Gas Emission Analysis Test Using Bioethanol and Diesel Blends

Bioethanol–diesel fuel blends with certain volumes of ethanol added (5%, 10%, 15%, and 20 % v/v) were then prepared by using the diesel fuel and Bioethanol produced. Pure diesel and BDB were used to run the Techno-Mate (TNM-TDE-700) engine for performance testing. The engine was tested three times, with 20 ml of diesel, and each BDB was used in every test. At once, the acquired data were used to determine Fuel Consumption Rate, engine Torque output, Engine Power, Specific Fuel usage rate, Brake Horsepower, including indicated horsepower, with the engine tested at a load of 120 N, and the throttle was halfway open. The gases coming out of the exhaust, including NO_2, CO, SO_2, NO, and NO_x, were measured with a monitoring analyzer. About 3 ml of fuel was poured into an evaporating dish. One end of the paper went into the fuel, and the other end was lit. When the fuel started burning, the analyzer was pointed at the smoke. The results from the device were recorded. Figure 1 illustrates the substrate preparation from ubi gajah for bioethanol biofuel production.

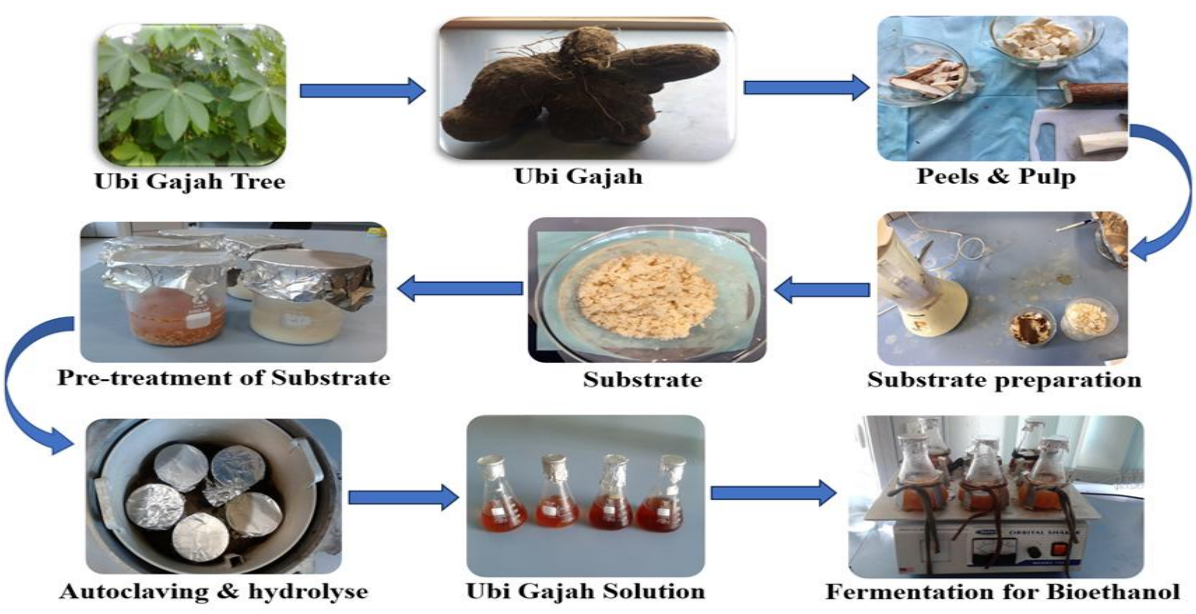

Figure 1. Substrate Preparation from Ubi Gajah for Biofuel Bioethanol Production

RESULTS AND DISCUSSION

Analysis of Ubi Gajah Pre-Treatment and Acid Hydrolysis

After 3 hours of hydrolysis, the autoclaved substrate solutions at all three concentrations developed a reddish-brown colour, as shown in Figure 2(a). The higher the acid concentration used during soaking, the darker the resulting solution appeared. The solutions produced after the hydrolyzed sample had a bad, strong smell, but the initial solutions were odourless. The solutions became clean after filtration, as shown in Figure 2(b).

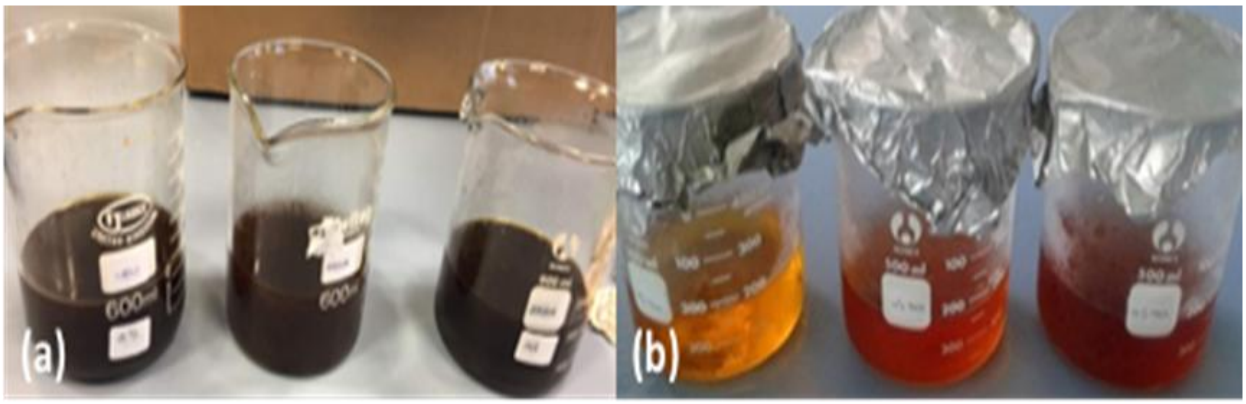

Figure 2. Ubi Gajah substrate solutions (a) before hydrolysis and (b) after hydrolysis and filtering with H_2SO_4 (5%, 10%, and 15% v/v).

Glucose Concentration in Hydrolysed Solutions

After hydrolysis, starch is converted into glucose, but the process produces a bitter-tasting degradation by-product. Despite this, it is widely accepted that even at high temperatures, dilute acid only converts cellulose to about 60–65% of the glucose it should theoretically produce. Table 2 shows the glucose concentration in each hydrolysed solution. It is clear that the stronger the acid concentration, the more glucose is made. The Ubi Gajah pulp will produce more glucose than the peels. Based on the results, it can be determined that the pulp of Ubi Gajah produces higher amounts of glucose levels because of its higher content of more fermentable sugar and starch than the peels, which consist of a high percentage of lignocellulose and a small amount of sugars. In addition, the amount of acid used during hydrolysis changed how much glucose came out.

Table 2. Glucose Concentration Following Acid Hydrolysis

Hydrolysed Solutions	Glucose Concentration (g/L)		
	5% v/v H_2SO_4	10% v/v H_2SO_4	15% v/v H_2SO_4
Peels of Ubi Gajah	110.28	168.30	212.80
Pulp of Ubi Gajah	175.00	236.00	262.00

Bioethanol Production Analysis

During the fermentation process, yeast absorbs and changes glucose into ethanol. Apart from that, it produces CO_2. Bubbles appear when the sample is fermenting, however, the experiment here, no bubbles were observed because they were mixed using an orbital shaker. From Figures 3(a) and 3(b), the glucose in the samples showed a drop in glucose concentration, this means fermentation was happening, but after 18 hours it started to slow down.

The graphs in Figures 4(a) and 4(b) show bioethanol production based on sugar consumption. After 48 hours, there was still glucose left in every sample, although the bioethanol produced was already at its maximum. The maximum ethanol yield was achieved from Ubi Gajah pulp hydrolysed with 15% (v/v) sulfuric acid, resulting in 220.89 g/L of bioethanol. In contrast, the peels produced a lower maximum yield of 156.65 g/L under the same hydrolysis conditions.After 24 hours, bioethanol stopped increasing. Yeast must have suitable conditions to survive. Too much sugar after hydrolysis puts osmotic pressure on the yeast and affects its growth, which might lead to a longer lag phase at the beginning of fermentation. On the contrary, ethanol acts as another inhibitor that slows down the yeast when it becomes too concentrated, it damages the yeast's cell membrane [12, 13]. Hence, a typical Normal yeast can usually only maintain activity at about 12%–15% ethanol.

This explains why the process slowed down after 24 hours. No more glucose turns into ethanol once the ethanol level gets too high concentration surpasses the yeast's ethanol tolerance. Both glucose and bioethanol concentrations remained constant, although they were fermented for a longer time. Even so, in this experiment, the osmotic effect was hard to see because fermentation was so fast on the first day.

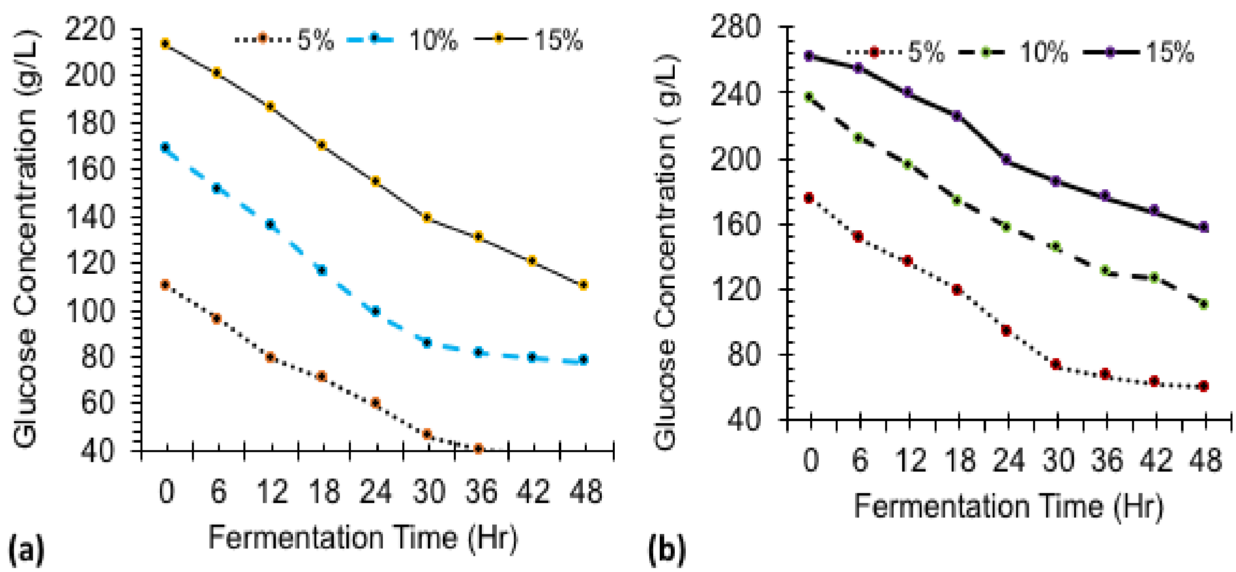

Figure 3. Consumption of Glucose Fermenting Ubi Gajah (a) peels and pulp (b) with H_2SO_4 (5%, 10%, and 15%). Values are the means of the results of duplicate experiments which differed by less than 10 %.

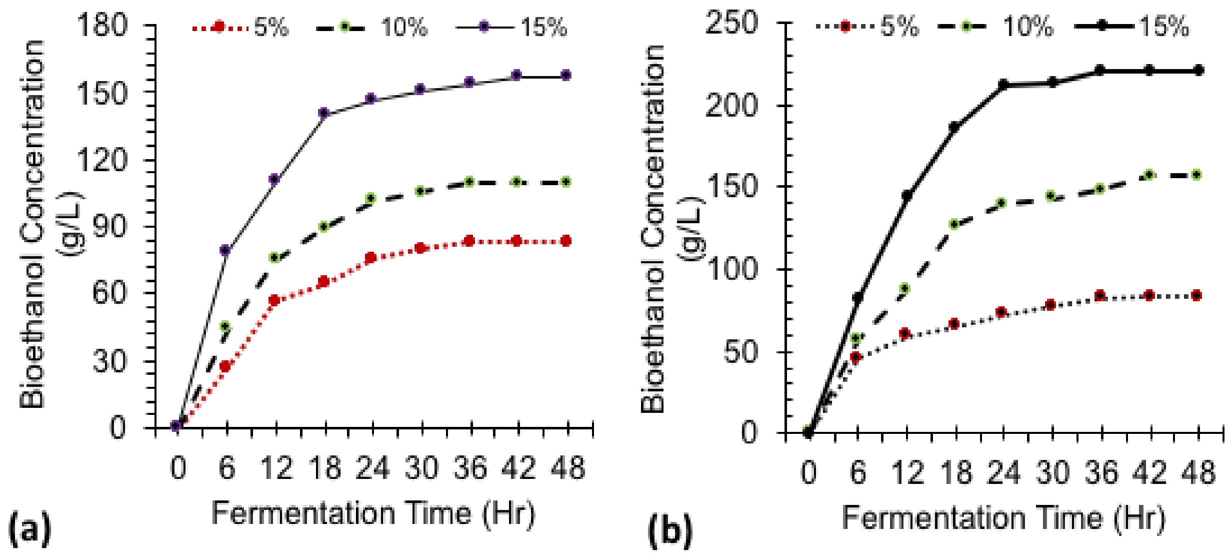

Figure 4. Bioethanol production during the Fermenting Ubi Gajah (a) peels and pulp (b) with H_2SO_4 (5%, 10%, and 15%). Values are the means of the results of duplicate experiments which differed by less than 10 %.

Density

Table 3 shows the density of the sample of Ubi Gajah peels and pulp. The peel sample is denser than the pulp sample, but each sample has a different temperature. Ethanol density changes easily with temperature and pressure. Changing these conditions will change ethanol's volume, and this causes the density to change. Furthermore, the density changes depending on how much alcohol and water it contains. In addition, even though both samples have the same amount of ethanol, their densities can still be different.

Table 3. Measured Properties of Ubi Gajah Peel and Pulp Samples

Bioethanol sample	Density (g/cm^3)	Temperature (°C)
Ubi Gajah peels	0.9941	28.1
Ubi Gajah Pulp	0.9926	26.3

The density of pure ethanol is 0.789 g/cm^3 at a temperature of 20°C. According to the data from [14], the peel sample's density indicates it has about 4% ethanol by volume, meanwhile, the pulp sample has about 6% ethanol by volume [14]. The samples were diluted so that they contained 10% ethanol. Moreover, the measured ethanol does not match the ethanol calculated from the densities. The difference probably happened because the pocket refractometer is not very accurate when measuring ethanol [15].

Gas Emissions

Table 4 shows the results from the gas emission test. The results show E-diesel blends release less NOx and SO_2. NOx means the total of NO and NO_2. More ethanol in the blend means less NOx is released. Because ethanol contains more oxygen, it can sometimes cause more NOx to form. Besides that, the gas temperature in the engine is what mainly causes NOx to form. The table shows that more ethanol in the blend means a lower fuel temperature. Ethanol cools the combustion, and this lower temperature helps reduce NOx emissions [16]. More ethanol in the blend caused more CO to be released. Diesel produced less CO than the ethanol blends. The blends did not reduce CO except at a few engine loads. Adding ethanol reduces the gas temperature and prevents CO from oxidizing properly, causing CO emissions to rise when the engine load is low. Since the test burned the fuel directly, the engine load was not clear and was treated as free or low load, which caused CO emissions to rise. Previous studies support and confirm these results [17-19].

Table 4. Gas Emissions from the Combustion of E-diesel Fuel Blend

Fuel	FT (^oC)	Types of Gas Emitted (ppm)				
		CO	NO	NO_2	NO_X	SO_2
Diesel	110	40	1	0.4	1.04	3
5% BDB	107.8	45	1	0.3	1.03	1
10% BDB	89.4	51	1	0.2	1.02	1
15% BDB	79.7	62	1	0.2	1.02	1
20% BDB	79	73	1	0	1	0

Diesel Engine Performance

Table 5 shows the factors that affect a diesel engine's performance. For every test condition, the fuel flow rate was measured to find out how much fuel the engine consumed. Diesel blends are less efficient than E-diesel (BDB) in terms of mechanical efficiency. Adding the ethanol-diesel increased Mechanical efficiency as more ethanol was added to the diesel fuel. Despite that, ethanol-diesel blends lower the power of the diesel engine without modification. This will lead to an increase in the specific fuel consumption [18]. Therefore, when the ethanol content is high, the fuel consumption will be higher. As ethanol is added to diesel, brake horsepower will be reduced when the volume of ethanol added [17-18], [19-20].

Table 5. Performance Properties of Diesel Engine

Engine Performance Indicator	Diesel	5% BDB	10% BDB	15% BDB	20% BDB
Torque (Nm)	36	36	36	36	36
Fuel Consumption Rate (ml/s)	0.1009	0.104	0.1067	0.1079	0.1089
Engine Power (kW)	0.585	0.5527	0.5053	0.4894	0.4739
Specific Fuel Consumption (ml/kW)	34.188	36.186	39.5804	40.8664	42.203
Brake Horsepower (kW)	4.2675	4.113	4.047	4.0282	4.0093
Horsepower (kW)	57.80	57.80	57.80	57.80	57.80
Mechanical Efficiency (%)	92.6268	92.8841	92.9983	93.0308	93.0635

CONCLUSION

The results of this study demonstrate that *Ubi Gajah*, a non-edible cassava variety, possesses strong potential as a sustainable feedstock for bioethanol production. Acid hydrolysis effectively converted the starch present in Ubi Gajah into fermentable sugars, producing sufficient glucose to support efficient ethanol fermentation. The findings indicate that increasing sulphuric acid concentration significantly improves glucose yield, as stronger acid conditions enhance the breakdown of starch molecules into simple sugars. Consequently, higher glucose availability resulted in increased ethanol production. The highest ethanol yield was obtained from Ubi Gajah pulp hydrolysed with 15% (v/v) sulfuric acid, producing 220.89 g/L of bioethanol. In comparison, the peels generated a lower maximum yield of 156.65 g/L under the same hydrolysis conditions. The study also highlights the importance of yeast strain selection, as ethanol yield is strongly influenced by yeast tolerance to increasing alcohol concentrations. Despite these promising outcomes, several factors require further investigation to improve process efficiency and commercial feasibility. Future work should focus on optimizing hydrolysis conditions, including acid concentration, temperature, and reaction time, to maximize glucose yield while minimizing degradation by-products. Additionally, the evaluation of more robust or engineered yeast strains with higher ethanol tolerance could further enhance fermentation efficiency. Process integration studies involving simultaneous saccharification and fermentation (SSF) or alternative pretreatment methods may also improve overall bioethanol productivity. Finally, techno-economic analysis and engine performance studies using optimized bioethanol blends are necessary to assess large-scale feasibility and practical applications. With continued optimization and scale-up studies, Ubi Gajah could become a viable non-food biomass resource for sustainable bioethanol production.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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