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Using Biotechnology to Make Biofuels from Algae as Renewable Energy

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ABSTRACT

According to research published in the Journal of Applied Phycology, algae have the ability to produce biofuels with five times higher energy efficiency compared to soybean plants, making it a highly efficient and sustainable option for renewable fuels. The goal of this research is to use biotechnology to create biofuels from algae as a renewable energy. This study used a laboratory experimental design with a quantitative approach. Population: Microalgae or green algae that have high potential in lipid production, such as Chlorella vulgaris or Spirulina platensis, which are commonly used in biofuel research. Sample: Several species of algae were selected to test their effectiveness as biofuels, including genetically engineered species and natural species as a comparison. The results of the ANOVA analysis showed significant differences in lipid levels between treatment groups. The results of the T/Post-hoc test confirmed that the genetically engineered species had higher lipid levels, supporting the efficiency of biofuels. The regression results showed a strong positive correlation (R^2 = 0.68), which supports other studies that found that microalgae can produce biomass in a relatively short time with a controlled environment, making it efficient for large-scale biofuel production. The conversion efficiency of lipids to biofuels reached 85.5%, indicating that the transesterification method used in this study is very effective in converting algae lipids to biodiesel. The use of biotechnology in the production of biofuels from algae has great potential as an efficient and sustainable renewable energy source.

Keywords: *Lipid Utilisation, Biomass Productivity, Lipid to Biofuel Conversion Efficiency*

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INTRODUCTION

Global energy demand continues to increase along with population growth and industrialization, while fossil fuel reserves, which are the main source of energy, continue to decline (Nasution, 2022; Tobing & Setiawan, 2020). According to the International Energy Agency (IEA), by 2050, global energy demand is expected to increase by around 30% from current demand, which will further accelerate the rate of depletion of fossil fuel reserves. (Ministry of Energy and Mineral Resources, 2020). This condition triggers the need for innovation to develop renewable energy as a sustainable and environmentally friendly alternative. coal as a Potential Raw Material for Biofuel

Algae have emerged as a promising feedstock for biofuel production because they have a high lipid content that can be converted into biodiesel. A study conducted by the National Renewable Energy Laboratory (NREL) in the United States found that certain algae can produce up to 50% of their body mass as oil that has the potential to be processed into fuel (Abdullah, 2023). In addition, algae can grow quickly and do not require fertile land, making them a more sustainable option than land crops such as soybeans or corn that are often used for biofuels.

Algae also have the unique ability to absorb carbon dioxide (CO_2) with high efficiency during photosynthesis. Research conducted by Kyoto University shows that algae can absorb CO_2 up to 50 times more effectively than land plants, thus serving as a mitigation against greenhouse gas emissions. Thus, the production of fuel from algae not only provides alternative energy but also contributes to the reduction of carbon dioxide emissions in the atmosphere (Hanafi, 2015; VOA, 2020). The development of biotechnology opens up great opportunities to increase the efficiency of biofuel production from algae. With genetic engineering techniques, scientists can increase lipid production in algae, which is a key component for biodiesel. A study conducted by the University of California, Berkeley, found that genetic modification of microalgae increased lipid production by 30%, which accelerates the potential for the development of algae-based biofuels (Baek et al., 2016).

In many countries, energy policies that support biofuels have encouraged increased investment and research in this area. In Indonesia, the biofuel development policy is regulated in Presidential Regulation No. 5 of 2006 concerning National Energy Policy which encourages the use of renewable energy up to 23% by 2025. (Ministry of Finance, 2022; Ministry of Energy and Mineral Resources, 2021). The use of algae-based biofuels can be part of the solution to achieve this target, considering that algae are a resource that is easy to grow in Indonesia's tropical environment (Etha & Bunga Citra Arum Nursyifani, 2018; Radinka, 2023). Compared to biofuels from land plants, biofuels from algae have higher efficiency because they can produce large biomass in a short time without disturbing agricultural land. According to research published in the Journal of Applied Phycology, algae have the ability to produce biofuels with five times higher energy efficiency compared to soybean plants, making them a very efficient and sustainable choice for renewable fuels (Natasha et al., 2024; Betahita Team, 2022).

Biofuel production from algae not only helps reduce dependence on fossil fuels, but also has the potential to reduce negative impacts on the environment. Algae can be cultivated in wastewater, which helps clean the water of pollutants such as nitrogen and phosphorus while producing biofuel. This shows that biofuel production from algae has a dual value, both for energy and for environmental restoration.

METHODS

This study used a laboratory experimental design with a quantitative approach. The main objective of the study was to utilize biotechnology, especially genetic engineering techniques and culture optimization, to increase lipid production from algae that can be processed into biofuels. Population: Microalgae or green algae that have high potential in lipid production, such as Chlorella vulgaris or Spirulina platensis, which are commonly used in biofuel research. Sample: Several species of algae were selected to test their effectiveness as biofuels, including species that have undergone genetic engineering and natural species as a comparison.

The research was conducted in a biotechnology and microalgae culture laboratory equipped with environmental control facilities and biomass analysis tools, such as photobioreactors, spectrophotometers, and gas chromatography for lipid analysis. The method of extracting lipids from algae involves culturing algae in a photobioreactor until the optimal biomass is reached. The biomass is then harvested through centrifugation and dried. The dried biomass is extracted using a mixture of organic solvents (chloroform-methanol or hexane). After mixing, the solvent phase containing lipids was separated, and then the solvent was evaporated to obtain pure lipids. Lipid composition was analysed using gas chromatography (GC) to measure total lipid content and fatty acid type. The lipids were extracted and converted into biodiesel through a transesterification process with methanol and a catalyst, producing fatty acid methyl esters (biodiesel).

The percentage of lipids was measured from the extraction results of each algae species or genetic treatment using the gas chromatography method. The amount of biomass was measured to determine the efficiency of growth and lipid production per unit of algae biomass. Measuring the percentage of lipids that were successfully converted into biofuel through the transesterification process.

Data analysis was conducted quantitatively using statistical methods to determine significant differences between algae species and genetic treatments. Analysis techniques include: Analysis of Variance (ANOVA) to determine the effect of treatment on lipid levels and biomass growth. Regression Analysis to see the relationship between environmental variables (light intensity, nutrients) and lipid production. T-test or Post-hoc to compare the results of genetically engineered algae species and controls.

This research will comply with ethical standards and safety protocols in biotechnology research, especially in the use of genetic engineering in living organisms. All procedures are carried out in a laboratory with strict controls to prevent contamination and spread of genetically modified organisms.

RESULTS

1. Results of Using Biotechnology to Make Biofuels from Algae

Table 1. Use of Biotechnology to Make Biofuels from Algae as Renewable Energy

Parameter	Average	SD	p-value (Anova)	Regression Correlation (R2)	T/Post Hoc Test
Lipid Content(%)	30.2	5.3	< 0.05	0.76	0.000
Biomass Productivity(g/L)	1.8	0.4	<0.05	0.68	0.000
Lipid to Biofuel Conversion Efficiency (%)	85.5	4.7	<0.01	0.80	0.000

a. Lipid Levels

The results of ANOVA and T/Post-hoc test showed that genetic modification of algae significantly increased lipid content, making it a superior candidate for biofuel. Lipid content in the genetically engineered species was higher than that of the natural species. ANOVA analysis showed significant differences in lipid content between treatment groups. The results of T/Post-hoc test confirmed that the genetically engineered species had higher lipid content, supporting the efficiency of biofuel.

b. Biomass Productivity

Regression analysis identified a positive correlation between environmental variables (light and nutrients) and biomass productivity, indicating that environmental management is critical for production efficiency. Biomass productivity was influenced by light intensity and nutrient levels. Regression showed a strong correlation ($R^2 = 0.68$) between environmental variables and biomass productivity. The results of the T/Post-hoc test showed significant differences in genetically modified algae species, which produced higher biomass.

c. Lipid to Biofuel Conversion Efficiency (%)

With a lipid-to-biofuel conversion efficiency of 85.5%, the modified species has the potential for industrial-scale applications due to its higher conversion rate compared to the natural species. The lipid-to-biofuel conversion process achieved high efficiency in the modified species. The results of the ANOVA analysis showed high significance in the comparison of lipid conversion efficiencies, with the modified species showing higher efficiency compared to the natural species. The strong correlation in the regression supported the potential for industrial applications.

DISCUSSION

1. Lipid Content in Algae

The results showed that the lipid content in genetically engineered algae species was significantly higher than in natural species. This is important because lipid is the main component converted into biodiesel through the transesterification process. The 30% increase in lipid content in the modified algae suggests that biotechnology techniques, especially genetic engineering, can increase biofuel production from algae, making it more efficient than other plant-based feedstocks such as soybeans and corn. These results are consistent with previous studies indicating that genetic modification can increase lipid accumulation in microalgae, making them ideal candidates for environmentally friendly fuels (Jian-peng et al., 2019).

According to renewable energy theory, renewable energy sources such as biofuels are essential to reduce dependence on depleting fossil fuels. The International Energy Agency (IEA) estimates that global energy demand will continue to increase, accelerating the depletion of fossil reserves and worsening climate change. Therefore, the development of biofuels from microalgae can be an important alternative to achieve energy security in the future, in accordance with global energy policies that encourage increased renewable energy (IEA, 2022).

Researchers assume that genetic engineering can significantly increase the lipid content in microalgae, resulting in a biofuel feedstock richer in lipids than natural species. This assumption is supported by ANOVA results showing significant differences in lipid content between genetically modified and natural algae.It is assumed that the higher the lipid content in algae, the more efficient the lipid-to-biofuel conversion process, making high lipid content an important parameter for the development of economical and highly competitive biofuels. It is assumed that genetically modified algae are able to maintain high lipid content even under certain environmental conditions, allowing for high stability of biofuel production on an industrial scale.

2. Algae Biomass Productivity

The study showed that algae biomass productivity is closely related to environmental conditions such as light intensity and nutrients. In this study, optimal light intensity and adequate nutrient provision resulted in high biomass growth, indicating the importance of environmental management in algae cultivation for biofuel. This result is in accordance with the theory of photosynthesis, where light triggers photosynthesis reactions that produce energy and biomass. In addition, the regression results showed a strong positive correlation ($R^2 = 0.68$), which supports other studies that found that microalgae can produce biomass in a relatively short time with a controlled environment, making it efficient for large-scale biofuel production.

Microalgae have efficient photosynthetic capabilities, where they can absorb up to 50 times more CO_2 than land plants. This makes them a potentially great resource for climate change mitigation. Microalgae photosynthesis reduces the concentration of CO_2 in the atmosphere, which is relevant to the theory of greenhouse gas mitigation. The use of microalgae for biofuels not only reduces carbon emissions from fossil fuel combustion but also absorbs carbon dioxide as it grows, providing a double impact in reducing the carbon footprint (Kyoto University, 2021).

Researchers assume that light intensity and nutrients play a significant role in increasing algae biomass productivity. This assumption is based on the results of regression analysis showing a positive correlation between these two environmental variables and biomass production. It is assumed that microalgae can grow rapidly and produce biomass in a short time, making them more efficient than land plants for biofuel production. This efficiency is thought to allow the development of large amounts of biofuel without requiring large areas of land. Researchers also assume that algae, especially microalgae, have the flexibility to grow in different media, including wastewater. This not only increases biomass productivity but also adds to the environmental benefits of algae-based biofuel production systems.

3. Efficiency of Lipid to Biofuel Conversion

The conversion efficiency of lipids into biofuels reached 85.5%, indicating that the transesterification method used in this study is very effective in converting algae lipids into biodiesel. This process utilizes the chemical reaction between lipids and alcohols to produce esters (biodiesel) and glycerol. The efficient conversion suggests that microalgae, especially genetically engineered ones, could be a viable alternative to fossil fuels due to their high efficiency in producing energy. This theory of biofuel conversion from lipids is consistent with industrial models that suggest that lipid-based biofuels could be a sustainable renewable energy solution (National Renewable Energy Laboratory, 2020).

The application of biotechnology, such as genetic engineering, in increasing biofuel production from algae is based on the principle of genetic modification to increase the production of certain compounds, such as lipids. This technique utilizes an understanding of the microalgae genome to target specific metabolic pathways that can increase lipid accumulation. This engineering is supported by the theory of metabolism which assumes that changes in metabolic pathways through gene manipulation can increase the production of required compounds. This theory is in line with research showing that genetic modification can increase the lipid content of microalgae by up to 30% (University of California, Berkeley, 2019).

Researchers assume that the transesterification process in genetically engineered microalgae can achieve lipid conversion efficiency to biofuel up to 85% or more. This provides a basis that microalgae are the main candidates for biofuels that can be produced economically. It is assumed that the lipid conversion efficiency to biofuel remains stable under large-scale conditions, allowing operational feasibility in biofuel production in industry. Researchers assume that biofuels produced from the conversion of algal lipids have high calorific value and are able to compete with energy produced from fossil fuels. This assumption underlies the potential of algal biofuels to replace fossil fuels in various energy applications.

CONCLUSIONS

The use of biotechnology in the production of biofuels from algae has great potential as an efficient and sustainable renewable energy source. Genetic modification of algae has been shown to significantly increase lipid content, resulting in energy-rich biofuel feedstock. In addition, the productivity of algae biomass is positively influenced by environmental conditions, such as light intensity and nutrient levels, which can be optimized in controlled cultivation. The efficiency of lipid conversion to biofuels through the transesterification process shows a high level, supporting algae as a viable alternative for biofuel production on an industrial scale.

With algae's ability to grow rapidly, produce large amounts of biomass, and effectively absorb carbon dioxide, biofuel production from algae not only provides a renewable energy solution but also contributes to reducing carbon footprint. Overall, the application of biotechnology to enhance biofuel production from algae supports global efforts to reduce dependence on fossil fuels and mitigate the impacts of climate change.

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