

Seagas: Evaluating the Biodiesel Potential of Local Seaweed Species *Kappaphycus Alvarezii* and *Eucheuma* sp.

Ylaiza Fayne C. Delos Reyes, Cleford Jay D. Bacan, Kerby Boy Sultan, Trixie Mia P. Rebuta, Aaliyah Martine J. Estember, Allyza Pearl Baroy, Queen Margarette Ayaron, Eshymyl Frya Retes, Gee William G. Apura

Cor Jesu College Inc., Philippines

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ABSTRACT

The study evaluated the biodiesel quality of two local seaweed species, *Kappaphycus alvarezii* and *Eucheuma* sp., in terms of density, viscosity, flash point, and combustion efficiency. Biodiesel samples were produced and tested under an alternative laboratory setup, with measurements taken across three replicates. *K. alvarezii* biodiesel exhibited a density of 0.88 g/cm³, viscosity of 4.80 cSt, flash point of 131°C, and combustion efficiency of 98.40%, while *Eucheuma* sp. biodiesel showed a density of 0.88 g/cm³, viscosity of 5.02 cSt, flash point of 0.88°C, and combustion efficiency of 98.00%. Comparisons with commercial diesel, which had a density of 0.85 g/cm³, viscosity of 3.50 cSt, flash point of 60°C, and combustion efficiency of 99.00%, revealed statistically significant differences in all parameters ($p < 0.05$). The results indicate that both seaweed-derived biodiesels possess higher viscosity and flash points than commercial diesel, suggesting their potential suitability for biodiesel applications. However, combustion efficiency was slightly lower than that of commercial diesel. Overall, *K. alvarezii* and *Eucheuma* sp. Show promise as alternative biodiesel sources, meeting key biodiesel quality parameters.

Keywords: biodiesel, *Kappaphycus alvarezii*, *Eucheuma* sp., density, viscosity, flash point, combustion efficiency, alternative biodiesel, renewable energy

INTRODUCTION

The rising human population on Earth increases the usage of essentials, specifically energy. The more the population grows, the more energy consumption rises, and the bigger the chance it might drain energy resources. The huge amount of energy used particularly from non-renewable sources might put the planet's resources and environment under pressure. The utilization of non-renewable resources such as fossil fuels poses a major environmental threat, as burning them causes harmful effects to the environment due to its excessive greenhouse gas emissions, mainly carbon dioxide (CO₂) into the atmosphere. As a consequence, this adds up to global warming which leads to rising temperatures and extreme weather conditions. Together with the use of fossil fuels, it causes environmental imbalances like pollution and the destruction of natural habitats for animals. Hence, the demand to develop alternative ways to minimize our dependency on fossil fuels has become of great importance.

Fossil fuels have powered the world for centuries, but their devastating environmental impact is undeniable—driving climate change, polluting air and water, and accelerating ecological collapse. In 2023, China led global primary energy consumption at 170.7 exajoules, emphasizing its immense reliance on fossil fuels and the corresponding emissions that contribute to rising global temperatures (Statista, 2024). The United States, responsible for 4.7 billion metric tons of CO₂ emissions in 2020, continues to be a major force behind worsening global warming, intensifying hurricanes, wildfires, and heatwaves (Yi et al., 2023). Australia, the third-largest fossil fuel exporter in 2019, supplied 390 million tonnes of coal, 77.5 million tonnes of liquefied natural gas (LNG), and 400,000 barrels per day of crude oil and petroleum products—fueling the world's dependence on carbon-heavy energy sources and deepening the climate crisis (Gulliver, 2024). Meanwhile, Argentina's electricity production relied on fossil fuels for over 72% of its energy in 2020, further increasing

greenhouse gas emissions and environmental degradation (Voumik & Ridwan, 2023). These figures illustrate the ongoing global dependence on fossil fuels and the pressing necessity to transition toward cleaner energy sources to mitigate their environmental impact.

Asian countries have become major contributors to global carbon emissions, with nations like Saudi Arabia, Indonesia, and Russia playing significant roles in escalating environmental concerns. Despite efforts to curb emissions, these Asian nations remain among the world's largest carbon emitter, with varying commitments to renewable energy. While Russia enacted a law in 2021 to limit greenhouse gas emissions, Saudi Arabia has yet to implement substantial policies to reduce its carbon footprint or transition away from fossil fuels.

Strengthening and enforcing sustainable policies will be crucial in achieving meaningful reductions in emissions. To address future energy demands and reduce dependence on fossil fuels, biofuels present a promising alternative. There are four generations of biofuels, with third-generation biofuels—particularly those derived from seaweed—gaining attention due to their high carbohydrate content and carbon sequestration capabilities. Seaweed is a particularly viable biomass feedstock in Asia, where countries like China, Japan, Indonesia, and South Korea lead in its cultivation for various industrial applications. However, as noted by Pardilhó et al. (2021), seaweed composition varies depending on species, location, environmental conditions (such as light, temperature, nutrient content, and water salinity), and biotic interactions. Given these factors, optimizing seaweed cultivation for biofuel production could serve as a sustainable strategy for reducing carbon emissions while promoting renewable energy adoption in Asia.

The Philippines is one of the significant producers of CO₂ in the Asia-Pacific region, which affects both its economic and environmental growth due to the increasing levels of greenhouse gases (Sabado et al., 2022). The country's continuous economic development and industrialization have led to a growing demand for energy across various sectors, including utilities, industry, and transportation. As of 2022, energy consumption has been rising at a rate of 4% annually since 2020, leading to heightened concerns about sustainability and prompting the need for a shift toward renewable energy sources (Philippine Energy Research, 2022). A study conducted in Laguna found that blending biodiesel with fossil fuels resulted in a 42.27% reduction in greenhouse gas emissions. This suggests that biodiesel, particularly when derived from microalgae, can play a significant role in reducing carbon footprints and supporting more sustainable energy practices (Dizon et al., 2022).

In 2007, the Philippines passed the Biofuel Act, also known as Republic Act 9367, which requires the blending of 20% bioethanol and 10% biodiesel in all petroleum fuels by the year 2020. For the production of bioethanol, feedstocks like sugarcane and molasses are utilized, while coconut oil is primarily used for biodiesel manufacturing (Acda, 2022). Moreover, microalgae have shown great promise as a source of biodiesel production due to their high oil content, rapid growth rate, and potential environmental benefits (Nortez & Arguelles, 2023). This highlights the potential of microalgae-based biodiesel as a key solution to reducing emissions and enhancing energy security in the Philippines. According to Lacorte (2022), for Mindanao, which was recently ravaged by powerful typhoons and extreme weather that brought communities flash floods, landslides, and storm surges, switching to clean energy would be the best decision to take action. The engineers of Ateneo de Davao University encouraged workshop participants to consider renewable energy sources since it is cleaner, less expensive, and more abundant over time. The study was led by a desire to better understand renewable energy technology and make it more useful and affordable for the local community. Only 30% of Mindanao's energy comes from renewable sources, with the remaining 50% coming from coal and 20% from diesel and other fossil fuels, said Assistant Secretary Romeo Montenegro, Mindanao Development Authority deputy executive director.

Several studies have indicated that environmental conditions play a significant role in influencing lipid production in organisms. Jaworowska and Murtaza (2022) highlight that seaweeds, in particular, are a rich source of active lipids, within a high concentration of unsaturated fatty acids. These characteristics make seaweed a promising option for biofuel production. In a study conducted by Almarza et al. (2020) in Iloilo City, three seaweed species—*Dictyota dichotoma*, *Sargassum cristaeifolium*, and *Padina minor* were evaluated for their potential in biodiesel production. The findings revealed that *Padina minor* exhibited the highest lipid content and favorable fatty acid composition, making it the most promising alternative for biodiesel production.

among the three species. These studies emphasize the importance of selecting suitable seaweed species, like *Padina minor*, for biodiesel production, further supporting the potential of seaweeds as a renewable and eco-friendly source of biofuel.

Statement of the Problem

This study aims to assess the potential of selected seaweed species found in one of the islets in Davao del Sur as biodiesel. Furthermore, this study seeks to answer the following questions:

1. What is the average biodiesel quality of the *K. alvarezii* in terms of:
 - 1.1 density;
 - 1.2 viscosity;
 - 1.3 flash point; and
 - 1.4 combustion?
2. What is the average biodiesel quality of the *Eucheuma sp.* in terms of:
 - 2.1 density;
 - 2.2 viscosity;
 - 2.3 flash point; and
 - 2.4 combustion?
3. What is the average quality of commercial diesel in terms of:
 - 3.1 density;
 - 3.2 viscosity;
 - 3.3 flash point; and
 - 3.4 combustion?
4. Is there a significant difference in the biodiesel quality between the local seaweed species and the commercial diesel?

Significance of the Study

This study aims to assess the biodiesel potential of selected seaweed species found in Pasig Islet, Santa Cruz, Davao del Sur. The findings of this study may be advantageous to the following stakeholders and beneficiaries:

Department of Energy. The department may benefit from this study by promoting seaweed-based biodiesel that could help reduce the usage of imported fossil fuels.

Bureau of Fisheries and Aquatic Resources. The BFAR may benefit from this study by gaining valuable insights into the viability of local seaweed species for biodiesel production, potentially enhancing sustainable energy initiatives and supporting regional marine resource management.

Fuel Companies. This study provides fuel companies with insights into the viability of local seaweed species as a cost-effective and sustainable biodiesel source, promoting renewable energy adoption and reducing environmental impact.

Seaweed farmer. Seaweed farmers could benefit from this study by discovering if their seaweed is good for making biodiesel, which could lead to new business opportunities and better profits. It might also help them improve their farming practices for better results.

Future Researchers. This study may provide a future researcher who will examine the potential of seaweed for environmental products, biofuel, and sustainable food.

Scope and Limitations

This study was conducted in one of the researchers' houses in Digos City, within the academic year 2024-2025. The researchers utilized selected seaweed species from one of the islets in Davao del Sur province, namely, *Kappaphycus alvarezii* and *Eucheuma* sp. The selected seaweed species was tested to determine its potential as biodiesel. The selected seaweed species were chosen due to their abundance in the locality of Davao del Sur.

The study's main objective is to determine the biodiesel potential of seaweeds found in one of the islets within the province of Davao del Sur. The seaweed species that will be assessed are only *Kappaphycus alvarezii* and *Eucheuma* sp. Thus, seaweed species from neighboring islands and other types of seaweed will not be assessed. Additionally, the study will only assess the density, viscosity, flash point, and combustion of the biodiesel derived from seaweed. Moreover, the study will only cover a specific period, meaning the result will not be generalized to other times of the year or locations outside of Davao del Sur.

Definition of Terms

The following terms were defined to help with understanding the various components of this study.

Biodiesel. According to Mahapatra et al. (2021), This refers to a renewable fuel derived from biological sources such as vegetable oils or animal fats, used as an alternative to petroleum diesel in engines.

Combustion. The process of burning the biodiesel produced from seaweed species to evaluate its energy release and emissions characteristics under controlled conditions (Kohse-Höinghaus, 2023).

Density. A measurement of the mass per unit volume of the biodiesel derived from *Kappaphycus alvarezii* and *Eucheuma* sp. is used to assess its compatibility with biodiesel standards (Mujtaba et al., 2021).

Flashpoint. According to Santos et al. (2019), It is defined as the lowest temperature at which the vapor of a biodiesel sample can ignite in the air, indicating its safety and volatility during storage and handling.

Seaweed. A marine macroalgae species selected for its lipid content and biomass potential specifically *Kappaphycus alvarezii*, a red seaweed species known for its high carbohydrate and carrageenan content, and *Eucheuma* sp., a genus of red seaweed characterized by its robust growth and commercial significance in carrageenan production, which is analyzed for its capacity to produce biodiesel through extraction and transesterification.

Viscosity. The measure of a biodiesel's resistance to flow, which is assessed by determining the time required for a specific volume of the sample to pass through a syringe (Farouk et al., 2024).

METHODS

Research Design

In this study, a true experimental design was utilized. This method addresses unforeseen external variables –those not anticipated in the study design–that have the potential to influence the response variable (Costello, 2023). This design is appropriate as it allows for a straightforward comparison of biodiesel yields and quality

measures—such as density, viscosity, flash point, and combustion—across different seaweed species, specifically *K. alvarezii* and *Eucheuma* sp. without involving complex blocking or grouping factors. By comparing the results of several groups under controlled conditions, the researchers can easily discover any effects that appear on the changed variable. Furthermore, this design is well regarded for providing strong evidence that supports the existence of relationships among variables.

To understand the experiment clearly, two (2) different species of seaweed were collected. Both *K. alvarezii* and *Eucheuma* sp. were assessed by their average density, viscosity, flash point, and combustion as the researchers compared them to biodiesel yields. This approach will help the researchers better grasp if there is a significant difference in the fuel efficiency of biodiesel derived from seaweed compared to the conventional types of biodiesel.

Sampling Technique

The researchers employed complete random sampling in this study. Noor et al. (2022) define random sampling as the process of selecting random samples without identifying any of their features, which in this case are the variables of the seaweed species *Eucheuma* sp. and *K. alvarezii*.

Furthermore, given that it eliminates the need for critical analysis of the seaweed samples, random sampling is a time and money-efficient sampling method. It enables researchers to efficiently gather data without being limited by the difficulties and constraints of several tests and procedures. In situations where time and resources run short, this can be advantageous. Moreover, this study aims to evaluate the seaweed species *Eucheuma* sp. and *K. alvarezii*'s capacity to produce biodiesel. Given that the random sampling method is effective, economically viable, and feasible for the researchers to conduct the study, it is the most appropriate approach to use for this study.

Data Gathering Procedure

In the process of gathering data for the study, the researchers needed to follow specific procedures to acquire information.

Collection of the Seaweed Species

1. The two (2) seaweed species were collected at Lawis, Barangay Bato, Santa Cruz, Davao del Sur. The seaweed species was hand-picked by a local seaweed farmer via snorkeling.
2. The seaweeds were placed inside a one-gallon Ziplock bag filled with seawater and were transported to one of the researcher's houses inside an ice box. It was then stored inside a freezer.

Pre-treatment of the Seaweed Species

1. After collecting and determining the seaweed species, the seaweeds were washed with tap water to remove attached debris, coral parts, stones, and epiphytes.
2. After washing the seaweed, it was sun-dried to reduce moisture content, making it easier to extract lipids.
3. The washed seaweed was ground into smaller particles using a blender to increase the surface area for extraction.

Lipid Extraction and Transesterification

The following steps were adapted from the study of Gülüm and Bilgin (2015).

1. Ethanol was used to extract lipids from the seaweed. The ground seaweed was then mixed with the solvent.

2. The extracted lipids were then reacted with ethanol in the presence of a catalyst, sodium hydroxide. This reaction will be done at around 60-70°C for 1-2 hours.
3. After the transesterification process, the mixture will contain biodiesel, glycerol, and residual catalyst. These components were separated using a separation technique.

TESTING METHODS FOR BIODIESEL

The following equipment and time requirements needed for biodiesel quality testing were adapted from the study of Ateeq (2015).

1. In measuring the viscosity of the biodiesel derived from seaweed, a syringe flow test technique was utilized with 10 mL of each sample
2. The density of the extract was determined using a precision balance with 0.01 g accuracy with 10 mL of each sample.
3. An open flame test was performed to measure the flash point of the biodiesel with 5 mL of each sample
4. Lastly, the combustibility of the transesterified seaweed was tested using the flame height and burn time technique with 5 mL of each sample.

Measures

To measure biodiesel quality, the researchers assessed key parameters such as density, viscosity, flash point, and combustion efficiency. Density was determined using a hydrometer, following ASTM D1298 standards.

To determine the density of biodiesel using the weighing method, first, the researchers weigh an empty container and record its mass. Next, the researchers added exactly 10 mL of biodiesel and weighed the container again. After that, the empty container's weight was subtracted from the total weight to obtain the mass of the biodiesel. The density was then calculated using the formula as shown in figure 1. Based on ASTM D6751 standard, an acceptable biodiesel density ranges from 860 to 900 kg/m³. If the density falls within this range, the biodiesel meets the standard for proper combustion and engine performance. A density below 860 kg/m³ suggests the fuel may have low energy content, affecting efficiency. Conversely, a density above 900 kg/m³ indicates the fuel may be too thick, leading to injector clogging and incomplete combustion. Table 1 shows the table of interpretation for biodiesel's density.

$$\text{Density} = \frac{\text{Mass of the Sample}}{\text{Volume of the Sample}}$$

Table 1. Table of Interpretation of Diesel Quality based on Density

To determine the viscosity of biodiesel using the syringe flow technique, 10 mL of biodiesel derived from each seaweed species and commercial diesel was placed in a syringe, and the time it took for the liquid to flow out was recorded. The viscosity was then estimated using the formula $v = K \times t$, where K is a calibration constant based on reference fluids, and t is the measured flow time. The calculated viscosity was compared to the ASTM D6751 standard, which specifies an acceptable range of 1.9 - 6.0 mm²/s. If the viscosity falls within this range, the biodiesel is suitable for use. A viscosity below 1.9 mm²/s indicates that the biodiesel is too thin, potentially leading to poor lubrication and engine wear, while a viscosity above 6.0 mm²/s suggests that the fuel is too thick, which can cause injector clogging and incomplete combustion. Figure 2 shows the calculation of the biodiesel's viscosity while table 2 shows the interpretation of biodiesel's viscosity.

$$v = K \times t$$

Where K = calibration constant based on reference fluids

t = measured flow time

Table 2. Table of Interpretation of Biodiesel Quality based on Viscosity

To determine the flash point of biodiesel using the open flame test, the sample is heated in a container while a small flame is introduced at regular temperature intervals. The temperature at which the biodiesel momentarily ignites is recorded as the flash point. According to ASTM D6751, the minimum flash point for biodiesel is 130°C to ensure safety in storage and transportation. If the flash point is $\geq 130^\circ\text{C}$, the biodiesel is safe and meets ASTM standards. A flash point between 100–129°C suggests a borderline result, meaning the fuel may pose a higher fire risk. If the flash point is below 100°C, the biodiesel fails the standard, indicating high volatility and potential fire hazards. This test is essential for ensuring the biodiesel's safety before commercial use. Figure 3 shows the calculation of the biodiesel's flash point while table 3 shows the table of interpretation for the flash point.

$$FP = T_{flash}$$

Where FP = Flash Point ($^\circ\text{C}$)

T_{Flash} = Temperature at which a flash is observed

Table 3. Table of Interpretation of Biodiesel Quality based on Flash Point

To determine biodiesel combustion performance, a fixed volume of biodiesel is ignited, and both flame height and burn time are recorded. The combustion index (CI) is then calculated using the formula $CI = H/T$, where H is the flame height and T is the burn time. Based on ASTM standards, an optimal CI value ranges from 0.15 to 0.30 cm/s, ensuring proper combustion and efficient energy release. A lower $CI < 0.15$ cm/s suggests slow burning, which may lead to carbon buildup and incomplete combustion. Meanwhile, a higher $CI > 0.30$ cm/s indicates rapid burning, potentially causing engine knocking and increased heat production. This method provides a simple yet effective way to evaluate biodiesel's suitability for use as a fuel. Figure 4 shows the calculation of the biodiesel's combustion efficiency while table 4 shows the table of interpretation for the combustion.

$$CI = \frac{H}{T}$$

Where CI = combustion index (cm/s)

H = average flame height (cm)

T = average burn time (s)

Table 4. Table of Interpretation of Biodiesel Quality based on Combustion Efficiency

Data Analysis

In this study, the data were analyzed through quantitative statistics to determine the qualifications of the two seaweeds for biodiesel production. Descriptive Statistics were used together with the Mean and Standard Deviation which helped to describe and explain the data by providing summaries about the samples and the measures of the data. The mean was used to assess the overall impact of the effectiveness of the two groups, while the standard deviation provided the assessment of the spread of data and the variability within each condition. A high standard variation indicated that the seaweeds were closer to the standard quality of biodiesel and a low deviation suggested that the seaweed were not relatively close to the standard quality of biodiesel. The study also utilized the Analysis of Variance (ANOVA) where the researchers utilized this to determine the significant differences among the selected seaweed species for biodiesel production, including commercial diesel. By calculating the F-statistic and associated p-value, ANOVA evaluated whether the variation between the group means was greater than the variation within the groups.

RESULTS AND DISCUSSION

This chapter deals with the presentation, analysis, and interpretation of data. The first part describes the biodiesel quality of *Kappaphycus alvarezii* and *Eucheuma* sp. in terms of density, viscosity, flash point, and combustion efficiency. The second part presents a comparison of the biodiesel quality of the two seaweed species with commercial diesel, along with statistical analyses to determine significant differences among the fuel samples.

Biodiesel Quality of *K. alvarezii*

The study investigated the biodiesel quality of the local seaweed *K. alvarezii* in terms of density, viscosity, flash point, and combustion efficiency. The researchers assessed the biodiesel quality of *K. alvarezii* in an alternative laboratory setup. The process began with the collection of the two (2) seaweed species, *K. alvarezii* and *Eucheuma* sp., followed by lipid extraction using ethanol to obtain the necessary oils for biodiesel production. The extracted lipids underwent transesterification, where a catalyst, sodium hydroxide, facilitated the conversion of lipids into biodiesel. After, purification of the biodiesel was done to remove residual byproducts. Lastly, the density, viscosity, flash point, and combustion efficiency of the biodiesel were determined. Each test was performed in three (3) replicates to ensure consistency and reliability of the result. Hence, the researchers obtained the following results.

Table 5. Biodiesel Quality of *Kappaphycus alvarezii*

	Replicate			Mean	SD	Interpretation
	R1	R2	R3			
Density (in g/cm ³)	0.87	0.88	0.89	0.88	0.01	Acceptable
Viscosity (in cSt)	4.75	4.85	4.8	4.80	0.05	High
Flash Point (in °C)	130	132	131	131.00	1.00	Safe
Combustion Efficiency (in percentage)	98.5	98.3	98.4	98.40	0.10	Excellent

Table 1 presents the biodiesel quality of *K. alvarezii*. In terms of diesel density, *K. alvarezii* has an average of 0.88 g/cm³ which indicates that the density is acceptable and falls within the diesel standard, ensuring proper combustion and engine performance. For viscosity, the table showed that *K. alvarezii* biodiesel has an average viscosity of 4.80 cSt, which means that it is high and can be used in low-speed diesel engines, and may be too thick for standard engines. Moreover, the flash point of the biodiesel derived from *K. alvarezii* has an average of 131.00 °C, which means that it is safe and is suitable for industrial and marine applications with reduced volatility. Lastly, the *K. alvarezii*-derived biodiesel has an average of 98.40% combustion, which indicates that its combustion efficiency is excellent and it is near-complete combustion, minimal emissions, optimal engine performance.

Furthermore, the biodiesel from *K. alvarezii* shows that it has excellent fuel properties, matches to the ASTM D6751 standard and highlights its potential good alternative to the customary diesel. The results for its density, viscosity, and its flashpoint can be supported by the studies of Abomohra et al. (2018) and Jaworowska and Murtaza (2022), where it states that rich lipid content and unsaturated fatty acids in seaweeds contributes to the promising biodiesel characteristics. It also aligns with the study of Illijas et al. (2023), where they elucidate the characteristics of the fatty acid composition of *K. alvarezii* and it showed that it contains significant amounts of fatty acids. This is also connected to the investigation of Mendes et al. (2024) on fatty acid methyl ester analysis of *K. alvarezii* where they found two saturated fatty acids and one monounsaturated fatty acid which concludes that these fatty acids found in *K. alvarezii* are ideal for transesterification to produce high-quality biodiesel with good combustion properties. These studies reflect the efficacy of *K. alvarezii* as shown in the results.

Biodiesel Quality of Eucheuma sp.

The study investigated the biodiesel quality of the local seaweed *Eucheuma Sp.*, in terms of density, viscosity, flash point, and combustion efficiency. The researchers assessed the biodiesel quality of *Eucheuma Sp.* in an alternative laboratory setup. The process started with seaweed harvesting of two species, *K. alvarezii* and *Eucheuma sp.*, and then proceeded to lipid extraction with ethanol in order to recover the oils to be used as biodiesel inputs. The resultant lipids were then transesterified through the use of sodium hydroxide as catalyst, wherein the lipids were converted to biodiesel. The biodiesel was then further purified to get rid of lingering byproducts. Lastly, the density, viscosity, flashpoint, and combustion efficiency of biodiesel were evaluated. All tests were performed in triplicate to guarantee the accuracy and consistency of the findings. Therefore, the researchers achieved the following results. Hence, the researchers obtained the following results.

Table 6. Biodiesel Quality of *Eucheuma Sp.*

	Replicate			Mean	SD	Interpretation
	R1	R2	R3			
Density (in g/cm ³)	0.88	0.89	0.88	0.88	0.01	Acceptable
Viscosity (in cSt)	4.92	5.1	5.05	5.02	0.09	Very High
Flash Point (in °C)	125	127	126	126.00	1.00	Safe
Combustion Efficiency (in percentage)	98.2	97.8	98	98.00	0.20	Excellent

Table 2 presents the biodiesel quality of *Eucheuma sp.* In terms of diesel density of *Eucheuma Sp.*, it has an average of 0.88 g/cm³ which indicates that it is acceptable and it falls within the diesel standard, ensuring proper combustion and engine performance. For viscosity, the table showed that *Eucheuma Sp.* biodiesel has an average viscosity of 5.02 cSt, which means that it is very high and it exceeds the standard, which may result in poor fuel injection, filter clogging, and engine deposits. Moreover, its flash point has an average of 126.00 °C, which shows that it is safe and is suitable for industrial and marine applications with reduced volatility. Lastly, for combustion efficiency, it has an average of 98.00 %, which indicates that it is excellent and it is near-complete combustion, minimal emissions, optimal engine performance.

Moreover, the results match the study of Mohadesi et al. (2021), biodiesel made from alternative feedstocks such as seaweeds, shows excellent combustion efficiency which serves its purpose in reducing carbon footprint of transportation and industrial sectors.

Diesel Quality of Commercial Diesel

The study investigated the diesel quality of the positive control in terms of density, viscosity, flash point, and combustion efficiency for comparison with the biodiesel. Hence, the researchers obtained the following results.

Table 7. Diesel Quality of Commercial Diesel

	Replicate			Mean	SD	Interpretation
	R1	R2	R3			
Density (in g/cm ³)	0.85	0.86	0.85	0.85	0.01	Acceptable
Viscosity (in cSt)	3.5	3.6	3.4	3.50	0.10	Acceptable
Flash Point (in °C)	60	61	59	60.00	1.00	Safe
Combustion Efficiency (in percentage)	99	98.9	99.1	99.00	0.10	Excellent

Table 3 presents the quality of commercial diesel. In terms of density, commercial diesel has an average of 0.85 g/cm³ which indicates that it is acceptable and it falls within the diesel standard, ensuring proper combustion and engine performance. For viscosity, the table showed that commercial diesel has an average

viscosity of 3.50 cSt, which means that it is acceptable and meets standard diesel engine requirements for proper atomization and combustion. Moreover, the flash point of the commercial diesel has an average of 99.00, which indicates that it is safe and suitable for industrial and marine applications with reduced volatility. Lastly, its combustion efficiency has an average of 99.00 %, which means that it is excellent and it is near-complete combustion, minimal emissions, optimal engine performance.

Additionally, a study by Kim et al. (2020) says that the combustion performance of a conventional rail diesel engine was investigated by measuring the exhaust gas with respect to the number of injector holes, fuel type, and the use of exhaust gas recirculation (EGR), to provide a detailed reduction of environmental pollutants. Moreover, the components of the fuel's composition determine its physical and ignition properties, and their variations affect engine performance. In this study, n-heptane, n-dodecane, tetralin, and decalin were chosen as typical additives to blend with commercial diesel according to the China VI standard (Heavy Duty Diesel Vehicle Pollutant Emission Limits and Measurement Methods) in 20% and 50% volume fractions, respectively. The physical properties of the fuel blends, such as viscosity, density, cetane number (CN), and distillation range, were measured first. Then, the commercial diesel's lower heat value was measured, and blended fuels were calculated accordingly (Wei et al., 2022).

Significance of the Difference in the Biodiesel Quality of *K. alvarezii*, *Eucheuma Sp.*, and Commercial Diesel

Table 4 shows the results of a one-way analysis of variance to determine the significance of the difference in the biodiesel quality of different species seaweed seaweed-derived biodiesel and the positive control diesel. It can be observed that the F value is 4.704 with 3 and 8 degrees of freedom. The p-value is 0.036 which is less than 0.05. This further means that there is a need to reject the null hypothesis. This indicates that the three experimental groups significantly differ from the positive control in terms of their tensile strength.

Table 8. Significance of the Difference in the Biodiesel Quality of *K. alvarezii*, *Eucheuma Sp.*, and Commercial Diesel

	F	p	Decision	Interpretation
Density	14.600	0.005	Reject H_o	Significant
Viscosity	288.200	0.000	Reject H_o	Significant
Flash Point	4711.000	0.000	Reject H_o	Significant
Combustion Efficiency	38.000	0.000	Reject H_o	Significant

To determine which among the four setups significantly differ from the other, post hoc analysis was conducted particularly the pair-wise comparisons of sample means via the Tukey HSD test. The Tukey's honestly significant difference test (Tukey's HSD) tests differences among sample means for significance. The Tukey's HSD tests all pairwise differences while controlling the probability of making one or more Type I errors. Tukey's HSD test is one of several tests designed for this purpose and fully controls this Type I error rate (Salkind, 2010).

Table 9. Post Hoc Comparisons using the Tukey HSD Test

	Mean Difference	p	Decision	Interpretation
Density				
Between Kappaphycus alvarezii and Eucheuma Sp.	-0.0033	0.851	Fail to Reject H_o	No Significant Difference

Between Kappaphycus alvarezii and Commercial Diesel	0.0267	0.011	Reject H_o	Significant Difference
Between Eucheuma Sp. and Commercial Diesel	0.0300	0.006	Reject H_o	Significant Difference
Viscosity				
Between Kappaphycus alvarezii and Eucheuma Sp.	-0.2233	0.040	Reject H_o	Significant Difference
Between Kappaphycus alvarezii and Commercial Diesel	1.3000	0.000	Reject H_o	Significant Difference
Between Eucheuma Sp. and Commercial Diesel	1.5233	0.000	Reject H_o	Significant Difference
Flash Point				
Between Kappaphycus alvarezii and Eucheuma Sp.	5.0000	0.002	Reject H_o	Significant Difference
Between Kappaphycus alvarezii and Commercial Diesel	71.0000	0.000	Reject H_o	Significant Difference
Between Eucheuma Sp. and Commercial Diesel	66.0000	0.000	Reject H_o	Significant Difference
Combustion Point				
Between Kappaphycus alvarezii and Eucheuma Sp.	0.4000	0.031	Reject H_o	Significant Difference
Between Kappaphycus alvarezii and Commercial Diesel	-0.6000	0.005	Reject H_o	Significant Difference
Between Eucheuma Sp. and Commercial Diesel	-1.0000	0.000	Reject H_o	Significant Difference

Table 5 presents the post hoc analysis of biodiesel qualities reveals significant differences in most measured factors. For density, there was no significant difference between *K. alvarezii* and *Eucheuma sp.* ($p = 0.851$). However, significant differences were observed between *K. alvarezii* and commercial diesel ($p = 0.011$), as well as between *Eucheuma sp.* and commercial diesel ($p = 0.006$), indicating that both local seaweed biodiesels had significantly higher densities compared to commercial diesel. In terms of viscosity, significant differences were found between all pairs. The comparisons between *K. alvarezii* and *Eucheuma sp.* ($p = 0.040$), *K. alvarezii* and commercial diesel ($p = 0.000$), and *Eucheuma sp.* and commercial diesel ($p = 0.000$) all showed significantly higher viscosities for the local seaweeds biodiesel.

For flash point, all pairwise comparisons were significant, with *K. alvarezii* and *Eucheuma sp.* showing a significant difference ($p = 0.002$), as well as *K. alvarezii* and commercial diesel ($p = 0.000$), and *Eucheuma sp.* and commercial diesel ($p = 0.000$). Both local seaweed biodiesel exhibited significantly higher flash points compared to commercial diesel. Similarly, combustion point comparisons yielded significant differences between all groups. The comparisons between *K. alvarezii* and *Eucheuma sp.* ($p = 0.031$), *K. alvarezii* and commercial diesel ($p = 0.005$), and *Eucheuma sp.* and commercial diesel ($p = 0.000$) all indicated higher combustion points for both algae-based biodiesel. These results highlight the significant differences in key properties of biodiesel from *K. alvarezii* and *Eucheuma sp.* compared to commercial diesel, suggesting the potential for these algae-based biodiesel as alternative fuel sources.

The result agrees with the statement of Abomohra et al. (2018) and Jaworowska and Murtaza (2022), which highlight that seaweeds, particularly those rich in lipids and unsaturated fatty acids, exhibit promising biodiesel

characteristics. The findings also align with the study of Illijas et al. (2023), which identified *Kappaphycus alvarezii* as having significant fatty acid content suitable for biodiesel production. Additionally, the results support the study of Mendes et al. (2024), which found that *K. alvarezii* contains saturated and monounsaturated fatty acids that are ideal for transesterification, leading to high-quality biodiesel with efficient combustion properties.

Conversely, the results contradict the findings of Mohadesi et al. (2021), which suggested that biodiesel from alternative feedstocks may have lower combustion efficiency compared to commercial diesel. In this study, both *K. alvarezii* and *Eucheuma sp.* exhibited combustion efficiencies close to that of commercial diesel, indicating that seaweed-derived biodiesel can be a viable alternative fuel source.

SPSS RESULTS

One-way

Descriptives									
		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Density	Kappaphycus alvarezii	3	.8800	.01000	.00577	.8552	.9048	.87	.89
	Eucheuma Sp.	3	.8833	.00577	.00333	.8690	.8977	.88	.89
	Commercial Diesel	3	.8533	.00577	.00333	.8390	.8677	.85	.86
	Total	9	.8722	.01563	.00521	.8602	.8842	.85	.89
Viscosity	Kappaphycus alvarezii	3	4.8000	.05000	.02887	4.6758	4.9242	4.75	4.85
	Eucheuma Sp.	3	5.0233	.09292	.05364	4.7925	5.2541	4.92	5.10
	Commercial Diesel	3	3.5000	.10000	.05774	3.2516	3.7484	3.40	3.60
	Total	9	4.4411	.71613	.23871	3.8906	4.9916	3.40	5.10
Flash Point	Kappaphycus alvarezii	3	131.0000	1.00000	.57735	128.5159	133.4841	130.00	132.00
	Eucheuma Sp.	3	126.0000	1.00000	.57735	123.5159	128.4841	125.00	127.00
	Commercial	3	60.0000	1.00000	.57735	57.5159	62.4841	59.00	61.00

	Diesel								
	Total	9	105.6667	34.32929	11.44310	79.2788	132.0545	59.00	132.00
Combustion Efficiency	Kappahycus alvarezi	3	98.4000	.10000	.05774	98.1516	98.6484	98.30	98.50
	Eucheuma Sp.	3	98.0000	.20000	.11547	97.5032	98.4968	97.80	98.20
	Commercial Diesel	3	99.0000	.10000	.05774	98.7516	99.2484	98.90	99.10
	Total	9	98.4667	.45277	.15092	98.1186	98.8147	97.80	99.10

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Density	Between Groups	.002	2	.001	14.600	.005
	Within Groups	.000	6	.000		
	Total	.002	8			
Viscosity	Between Groups	4.060	2	2.030	288.200	.000
	Within Groups	.042	6	.007		
	Total	4.103	8			
Flash Point	Between Groups	9422.000	2	4711.000	4711.000	.000
	Within Groups	6.000	6	1.000		
	Total	9428.000	8			
Combustion Efficiency	Between Groups	1.520	2	.760	38.000	.000
	Within Groups	.120	6	.020		
	Total	1.640	8			

Post Hoc Tests

Multiple Comparisons

Tukey HSD

Dependent Variable	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound

Density	Kappaphycus alvarezii	Eucheuma Sp.	- .0033 3	.00 609	.851	-.0220	.0153
		Commercial Diesel	.0266 7*	.00 609	.011	.0080	.0453
	Eucheuma Sp.	Kappaphycus alvarezii	.0033 3	.00 609	.851	-.0153	.0220
		Commercial Diesel	.0300 0*	.00 609	.006	.0113	.0487
	Commercial Diesel	Kappaphycus alvarezii	- .0266 7*	.00 609	.011	-.0453	-.0080
		Eucheuma Sp.	- .0300 0*	.00 609	.006	-.0487	-.0113
Viscosity	Kappaphycus alvarezii	Eucheuma Sp.	- .2233 3*	.06 853	.040	-.4336	-.0131
		Commercial Diesel	1.300 00*	.06 853	.000	1.0897	1.5103
	Eucheuma Sp.	Kappaphycus alvarezii	.2233 3*	.06 853	.040	.0131	.4336
		Commercial Diesel	1.523 33*	.06 853	.000	1.3131	1.7336
	Commercial Diesel	Kappaphycus alvarezii	- 1.300 00*	.06 853	.000	-1.5103	-1.0897
		Eucheuma Sp.	- 1.523 33*	.06 853	.000	-1.7336	-1.3131
Flash Point	Kappaphycus alvarezii	Eucheuma Sp.	5.000 00*	.81 650	.002	2.4948	7.5052
		Commercial Diesel	71.00 000*	.81 650	.000	68.4948	73.5052
	Eucheuma Sp.	Kappaphycus alvarezii	- 5.000 00*	.81 650	.002	-7.5052	-2.4948
		Commercial Diesel	66.00 000*	.81 650	.000	63.4948	68.5052
	Commercial Diesel	Kappaphycus alvarezii	- 71.00 000*	.81 650	.000	-73.5052	-68.4948
		Eucheuma Sp.	- 66.00 000*	.81 650	.000	-68.5052	-63.4948
Combustion Efficiency	Kappaphycus alvarezii	Eucheuma Sp.	.4000 0*	.11 547	.031	.0457	.7543
		Commercial	-	.11	.005	-.9543	-.2457

		Diesel	.6000 0*	547			
	Eucheuma Sp.	Kappaphycus alvarezii	- .4000 0*	.11 547	.031	-.7543	-.0457
		Commercial Diesel	- 1.000 00*	.11 547	.000	-1.3543	-.6457
	Commercial Diesel	Kappaphycus alvarezii	.6000 0*	.11 547	.005	.2457	.9543
		Eucheuma Sp.	1.000 00*	.11 547	.000	.6457	1.3543
*. The mean difference is significant at the 0.05 level.							

Summary

This study aimed to evaluate the potential of seaweed-derived biodiesel as an alternative biofuel by analyzing its viscosity, density, flash point, and combustion characteristics. The research involved a step-by-step process, including seaweed, cultivation, lipid extraction, transesterification, and purification, followed by experimental testing of the biodiesel's properties.

Descriptive analysis and experimental methods were used to assess the fuel quality. Results indicated that the biodiesel met key standards but also highlighted areas requiring further refinement, particularly in viscosity and combustion efficiency. The study provides valuable insights into the feasibility of seaweed-based biodiesel production and its potential applications as a sustainable energy source. These findings emphasize the importance of continued research and development in alternative biofuels to promote environmental sustainability.

CONCLUSION

After a thorough investigation of seaweed-derived biodiesel, the following conclusions are drawn:

1. Seaweed-derived biodiesel is a viable alternative fuel source. The study shows that biodiesel produced from seaweed has promising fuel properties, making it a potential renewable energy option.
2. The biodiesel meets key fuel standards. The viscosity, density, and flash point of the biodiesel fall within acceptable ranges, indicating its potential for use in diesel engines.
3. Combustion characteristics require further optimization. While the biodiesel burns efficiently, improvements in ignition quality and energy output are needed to enhance performance.
4. Seaweed is a sustainable biofuel feedstock. Unlike traditional crops, seaweed does not require freshwater or arable land, making it an environmentally friendly alternative for biodiesel production.
5. Seaweed is a sustainable biofuel feedstock, but its lipid content varies. The lipid and fatty acid content should be documented throughout the year, as environmental conditions across different seasons may affect lipid accumulation. To add to this, other external factors should be considered and studied to attain optimal cultivation technology for higher lipid yield from seaweed.

RECOMMENDATION

1. For the Department of Energy, the DOE should support further research and development on seaweed-derived biodiesel by providing funding, technical assistance, and policy support for its large-scale

production. Establishing pilot projects and conducting feasibility studies will help assess its commercial viability and integration into the country's renewable energy (———).

2. The Bureau of Fisheries and Aquatic Resources (BFAR) should encourage sustainable seaweed farming practices by offering training programs and financial assistance to farmers. Strengthening the seaweed industry will not only boost local economies but also ensure a stable supply of raw materials for biodiesel production. Additionally, BFAR should collaborate with energy researchers to assess the environmental impact of large-scale seaweed cultivation.
3. Fuel companies should invest in the research and development of biofuels, particularly seaweed-based biodiesel, to diversify their energy sources and reduce dependence on fossil fuels. Partnerships with academic institutions and government agencies can facilitate (——) testing and production scaling while ensuring the fuel meets industry standards for efficiency and emissions.
4. Seaweed farmers should be provided with access to technology and resources that enable them to participate in biodiesel production. Government and private sector initiatives should help integrate seaweed farming into the renewable energy supply chain by ensuring fair market opportunities and sustainable farming practices.
5. Further researchers should explore the potential of other seaweed species for biodiesel production, focusing on lipid content, growth efficiency, and sustainability. Additionally, researchers should investigate other biodiesel quality tests beyond viscosity, density, combustion, and flashpoint to comprehensively assess its performance and regulatory compliance. Long-term studies on the environmental and economic impacts of seaweed-based biodiesel should also be conducted to support its large-scale implementation.

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