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Review Article

Biodiesel Production Process from *Reutealis trisperma*: Technology, Opportunities and Challenges

Proses Produksi Biodiesel dari Biji Reutealis trisperma : Teknologi, Peluang dan Tantangan

Gesha Desy Alisha[1]*

[1] Faculty of Forestry, Universitas Mulawarman, Samarinda, 75123, East Kalimantan, Indonesia

*email: geshada@fahutan.unmul.ac.id

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Abstract: *Reutealis trisperma* (sunan candlenuts) is a non-edible vegetable oil source that can be used as a feedstock for biodiesel production. The biodiesel production process from *Reutealis trisperma* seed oil involves several stages, including oil extraction, purification, as well as esterification and transesterification reactions using catalysts. This article aims to examine the technology of biodiesel production from *Reutealis trisperma* seeds, the challenges faced in industrial implementation, and its future development opportunities. Various oil extraction methods, such as mechanical pressing and solvent extraction are compared to determine the efficiency of crude oil conversion. Additionally, the use of heterogeneous and homogeneous catalysts in the transesterification process is analyzed to optimize biodiesel conversion. The results of the literature study conducted indicate that biodiesel from *Reutealis trisperma* has characteristics that comply with national and international biodiesel standards. However, there are several challenges in the production process, such as the availability of raw materials, the fatty acid content and composition of *Reutealis trisperma*, environmental impact, and sustainability aspects. The development of more environmentally friendly technology and the utilization of biomass waste-based catalysts present potential opportunities to enhance the sustainability of this biodiesel production.

Keywords: Reutealis trisperma, biodiesel, transesterification, catalyst

Abstrak: *Reutealis trisperma* (kemiri sunan) merupakan salah satu sumber minyak nabati non-edible yang berpotensi sebagai bahan baku biodiesel. Proses produksi biodiesel dari minyak biji *Reutealis trisperma* melibatkan beberapa tahapan seperti, ektraksi minyak, pemurnian, serta reaksi esterifikasi dan transesterifikasi menggunakan katalis. Artikel ini bertujuan untuk mengkaji teknologi produksi biodiesel dari biji *Reutealis trisperma*, tantangan yang dihadapi dalam implementasi di industri serta peluang pengembangannya dimasa depan. Berbagai metode ektraksi minyak seperti pengepresan mekanis dan ekstraksi menggunakan pelarut dibandingkan untuk mementukan efisiensi konversi minyak mentah. Selain itu, penggunaan katalis heterogen dan homogen dalam proses transesterifikasi dianalisis untuk meningkatkan konversi biodiesel yang optimal. Hasil studi literatur yang telah dilakukan menunjukkan bahwa biodiesel dari *Reutealis trisperma* memiliki karakteristik yang memenuhi standar biodiesel nasional dan internasional. Namun, terdapat beberapa tantangan dalam proses produksinya, seperti ketersediaan bahan baku, kandungan dan komposisi asam lemak pada *Reutealis trisperma*, dampak lingkungan, serta aspek lingkungan. Pengembangan teknologi yang lebih ramah lingkungan dan pemanfaatan katalis berbasis limbah biomassa menjadi peluang potensial untuk meningkatkan keberlanjutan produksi biodiesel ini.

Kata kunci: Reutealis trisperma, Biodiesel, transesterifikasi, katalis

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INTRODUCTION

Reutealis trisperma (sunan candlenuts) is one of the potential plants producing non-food vegetable oil that can be used as an alternative raw material for biodiesel (Anggraini, 2018). The high oil content in *Reutealis trisperma* seeds reaches 45-60%, and this plant does not compete with food (Murni et al., 2016; Bery et al., 2009). This makes *Reutealis trisperma* a promising choice to be used as a raw material for biodiesel.

Biodiesel or also known as Fatty acid methyl ester (FAME) is renewable, biodegradable, golden or dark brown in color with a high boiling point and low vapor pressure (Awogbemi et al., 2024). Biodiesel is produced through a transesterification process involving the reaction between vegetable oil/fat and alcohol, such as methanol or ethanol. This process usually uses homogeneous base catalysts such as KOH and NaOH to produce methyl esters (biodiesel products) and glycerol (by-products) (El-Naggar et al., 2024). In terms of biodiesel production using *Reutealis trisperma* raw materials, there are several factors that are the main challenges, namely oil extraction efficiency, catalyst selection, waste treatment, and cost control (Variyana et al., 2023; Farouk et al., 2024; Elsayed et al., 2024).

In addition to technical challenges, the development of biodiesel from *Reutealis trisperma* also faces various other obstacles, such as the availability of raw materials, management of marginal land for cultivation, and regulations related to renewable energy policies (Pranowo et al., 2015; Agustian, 2015). However, technological advances provide opportunities to improve production efficiency and biodiesel quality. For example, innovations in the use of heterogeneous catalysts and biorefinery approaches can optimize the production process while reducing environmental impacts (Ashok et al., 2024).

This article aims to review the technological advancements in biodiesel production from *Reutealis trisperma* seeds, identify the key challenges in the production process, and explore future development opportunities. This review is expected to provide comprehensive insights into the development of the *Reutealis trisperma* biodiesel industry as part of sustainable energy solutions.

MATERIALS AND METHODS

This study uses a review method. This review method aims to identify, analyze, and synthesize literature that is appropriate for this article. This review process includes several stages such as topic determination, literature search strategy, literature selection, literature analysis and synthesis, and organizing the results. Data sources are obtained from indexed national and international journals, and research results that have been conducted.

RESULTS AND DISCUSSION

Reutealis trisperma (sunan candlenut) is the name given to the poisonous candlenut plant. This plant originates from Southeast Asia. (Supriyadi et al., 2021). Figure 1 shows the fruit, tree, fruit skin, seeds and kernels of *Reutealis trisperma* (Riayatsyah et al., 2021; Joelianingsih et al.,

2021). *Reutealis trisperma* has great potential to be used as biodiesel. *Reutealis trisperma*, which is toxic and not consumed, has one of the advantages because it does not need to compete with food needs (Supriyadi et al., 2018). The content of *Reutealis trisperma* consists of 10% palmitic acid, 9% stearic acid, 12% oleic acid, 19% linoleic acid, and 51% α-elostearic acid. The presence of a-elostearic acid indicates that *Reutealis trisperma* is a poisonous plant. (Supriyadi et al., 2021). In addition, the presence of this content explains that *Reutealis trisperma* can be converted into biodiesel (Elouafy et al., 2022).

The process of converting biodiesel from *Reutealis trisperma* seeds involves several stages, such as oil extraction, purification, esterification, and transesterification (Riayatsyah et al., 2021; Osman et al., 2023; Monika et al., 2023). Oil can be extracted using mechanical methods, such as pressing or using organic chemical solvents (n-hexane) (Liu et al., 2023). The next process is that the oil that has been obtained is purified through degumming and neutralization processes to remove impurities such as phospholipids and free fatty acids (FFA) (Adhami et al., 2019). The transesterification process is the main stage in converting oil into biodiesel. This reaction takes place with the addition of methanol and ethanol and base catalysts such as NaOH and KOH. The results of the *Reutealis trisperma* oil conversion product are methyl ester (biodiesel) and glycerol as a by-product (Joelianingsih, 2016).

Figure 1. (a,c) Fruit, (b) tree, (d) fruit skin, (e) skin, (f) kernels of *Reutealis trisperma* (Riayatsyah et al., 2021; Joelianingsih et al. 2021)

Biodiesel Production Technology from Reutealis trisperma Seeds

Biodiesel made from *Reutealis trisperma* seeds has several advantages, namely high oil content, non-edible, can grow on marginal land, and has sustainable and economic value. The oil content in *Reutealis trisperma* seeds ranges from 50-60%. This is quite high compared to other vegetable oil sources such as palm oil and jatropha (Rahmawati et al., 2021; Prabaningrum et al., 2020). However, the free fatty acid (FFA) content in *Reutealis trisperma* seeds is quite high at around 2.44% from the ideal 0.5% for biodiesel production. This can cause a saponification reaction, so an esterification process is needed. The esterification reaction is presented in Figure 2, which aims to reduce the free fatty acid content in the oil. Additionally, it can cause corrosion and scale on vehicle injector engines (Supriyadi et al., 2021). This process requires an acid catalyst to reduce the free fatty acid content in the oil. The acid catalyst commonly used to reduce free fatty acids is sulfuric acid (H2SO4) (Holilah et al., 2013; Riayatsyah et al., 2021). However, sulfuric acid-based catalysts have several disadvantages, such as being corrosive, difficult to separate from biodiesel products, and low catalyst reusability because they are homogeneous (Abbas and Ilyas, 2021). Therefore, to overcome the disadvantages of homogeneous acid catalysts, heterogeneous acid catalysts can be used which are easier to separate from biodiesel products, can be used repeatedly, and have a lower level of corrosivity (Okechukwu et al., 2022). Heterogeneous acid catalysts that are widely used are zeolites, acid functionalized mixed metal oxides, and activated carbon. Heterogeneous catalysts such as zeolites, silica, metal oxides, and activated carbon can be optimized by impregnation with acid solutions, such as sulfuric acid or hydrochloric acid to increase the acidity of the catalyst (Okechukwu et al., 2022; Aneu et al., 2022; Prado et al., 2018).

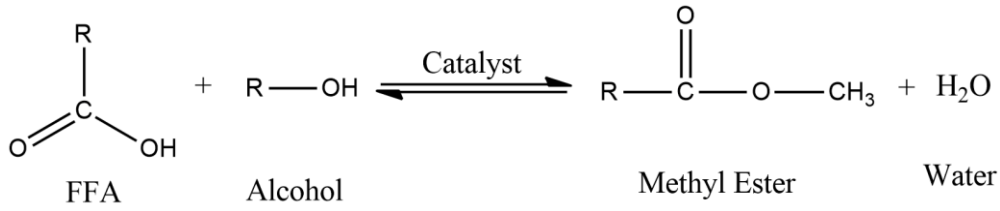

Figure 2. Esterification reaction

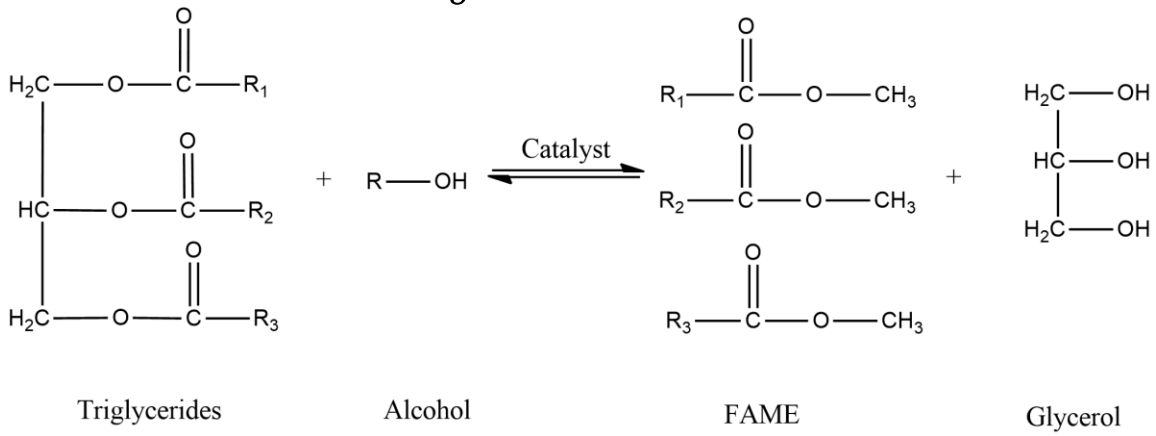

Figure 3. Transesterification Reaction

After the fatty acid content decreases, the next stage is to carry out the transesterification process of *Reutealis trisperma* seeds to produce biodiesel. Figure 3 shows the reaction in the transesterification process. The transesterification process is carried out using a base catalyst, where the most used catalysts are homogeneous catalysts such as NaOH and KOH (Purdy et al., 2024). The use of homogeneous base catalysts is preferred because of their lower cost. Nevertheless, a purification stage is needed to remove residual catalyst from the final product (Nawin et al., 2024; Gholami et al., 2025). Like the esterification process, this process can also use heterogeneous base catalysts for the conversion process. Heterogeneous base catalysts that are often used are calcium oxide (CaO), magnesium oxide (MgO), zinc oxide (ZnO), zeolite and activated carbon modified by base impregnation (Bello, 2024). Where, heterogeneous base catalysts are preferred because they can be reused, and have low levels of pollution (Gholami et al., 2025).

Table 1 shows the results of biodiesel conversion from *Reutealis trisperma* seed oil with various catalysts. The conversion of *Reutealis trisperma* seed oil biodiesel reached 98.72%. This is much higher than the conversion of biodiesel from waste cooking oil (WCO) and crude palm oil (CPO). Where, the conversion results of biodiesel from used cooking oil are around 54.13% using the KF/SiO2 catalyst (Aneu et al., 2022). Meanwhile, the conversion results of biodiesel production from Crude Palm Oil (CPO) using the lipase enzyme are 61.67% (Rachmadona et al., 2023). So, biodiesel from *Reutealis trisperma* seeds needs to be further developed.

Table 1. Various catalysts used in the biodiesel production process from *Reutealis trisperma* seeds

Catalysts	Biodiesel Conversion Percentage	Biodiesel Standards	References
Acid catalyst (H_2SO_4) Base catalyst (KOH) (ultrasonication method)	95,29%	ASTM D6571 EN 14214	Riayatsyah et al. (2021)
Acid catalyst (HCl) Base catalyst (Ca/Zn)	98%	-	Rahmawati et al. (2021)
Acid catalyst (H_2SO_4) Base catalyst (KOH) (conventional method)	44,26%	International Biodiesel Standards	Prabaningrum, et al. (2020)
Acid catalyst (Lewatit K2640 sulfonate ion exchange resin) Base catalyst (KOH)	91,75%	-	Lim et al. (2020)
Acid catalyst (-) Base catalyst (NaOH)	87,96%	SNI 047182 EN 14214 ASTM D6751	Supriyadi et al. (2021)
Acid catalyst (H_2SO_4) Base catalyst (NaOH)	98,72%	ASTM D6751	Silitonga et al. (2017)
Acid catalyst (H_2SO_4) Base catalyst (KOH-impregnated eggshell)	94%	ASTM D6751	Kusmiyati et al. (2019)

Challenges of the Biodiesel Production Process from *Reutealis trisperma* Seeds: Biodiesel production from *Reutealis trisperma* suggests great potential as a renewable energy source. However, there are several challenges that must be considered in the production process.

Availability and Cultivation of *Reutealis trisperma*: *Reutealis trisperma* (sunan candlenut) has the potential as a raw material for biodiesel. This is due to its high oil content (Herman et al., 2023). This plant has not been widely cultivated commercially, so the availability of raw materials on a large scale is still limited. In addition, the time required to bear fruit reaches 5 to 6 years. Of course, this can hinder the development of the biodiesel industry using *Reutealis trisperma* as a raw material (Cholid and Santoso, 2020).

Oil Content and Free Fatty Acid Composition: The oil extracted from *Reutealis trisperma* has a high fatty acid content. This can inhibit the efficiency of the transesterification process. The high FFA content requires additional pretreatment such as carrying out the esterification process first (Riayatsyah et al., 2021). The high FFA content *in Reutealis trisperma* suggests using an acid catalyst first to reduce the FFA content (Yeow et al., 2024). Of course, this increases the cost and complexity of the biodiesel production process.

Biodiesel Purification Process and Quality Standards: After the transesterification process, the produced biodiesel undergoes a purification stage to remove residual catalysts, glycerol, and other contaminants (Iqbal et al., 2024). This process certainly also requires additional analytical technology and costs. Moreover, biodiesel must meet quality standards, such as SNI 7182:2015 (Indonesian National Standard), EN 14214 (European Union International Standard), and ASTM D6751 (United States International Standard) (Febriansyah, 2022). Where, these quality standards determine parameters such as viscosity, sentane number, and water content (Adebisi et al., 2020). To ensure that the biodiesel product produced is of the best quality and can be used globally, it must meet the predetermined quality standards.

Abundance of *Reutealis trisperma* Oil in Indonesia: Reutealis trisperma is a new raw material that can be used as a source of raw material for making biodiesel. This plant can produce 300-500 kg of dry seeds per tree per year with an oil yield of 50-56% (Herizal and Anwar C., 2015). In addition, according to other studies, the productivity of dry seeds of Reutealis trisperma at the age of >8 years can reach 100-150 kg/tree/year. Where, the rate of dry seed production reaches 10-15 tons/ha/year. The production results are equivalent to 8 tons of crude oil/ha/year or around 7 tons of biodiesel/ha/year (Herman et al., 2023)

Environmental Impact and Sustainability: The development of biodiesel from *Reutealis trisperma* has the potential to reduce dependence on fossil fuels and reduce carbon emissions (Rahmawati et al., 2021). However, several sustainability factors must be considered, such as land use, water and energy consumption in the production process (Hamidov and Helming, 2020). In addition, the utilization of waste from seed extraction, the use of homogeneous catalysts that have an impact on the environment also need to be considered. Thus, the biodiesel production process is more environmentally friendly.

Economic Aspects: *Reutealis trisperma* has great potential as a raw material for biodiesel, but there are various challenges, one of which is from the economic aspect. Currently, the *Reutealis trisperma*-based biodiesel industry is still in the development stage, so it has not reached a large production scale (Riayatsyah et al., 2021). This plant-based biodiesel industry requires special infrastructure for production, distribution and storage that has not been widely developed (Azad et al., 2024). Some biodiesel production businesses are still small-scale, so the production cost per liter is higher than biodiesel from palm oil which is produced on a large scale (Simbolon and Aisyah, 2013). The efficiency of converting oil into biodiesel from *Reutealis trisperma* still needs to be improved to compete with other biodiesel sources. This can be done by using the ultrasonication method or catalysts that can produce biodiesel products approaching 99% (Lim et al., 2020; Riayatsyah et al., 2021).

Opportunities for Developing Biodiesel from *Reutealis trisperma* Seeds: Along with the increasing demand for renewable energy and global efforts to reduce greenhouse gas emissions, biodiesel from *Reutealis trisperma* has great prospects for further development. Some of the key opportunities that can be explored to improve the production and sustainability of biodiesel from *Reutealis trisperma* seed oil in the future include:

Development of *Reutealis trisperma* cultivation system: *Reutealis trisperma* is still not widely cultivated commercially. To increase the availability of raw materials, the development of a more efficient and sustainable cultivation system must be carried out in several stages, such as integration with agroforestry systems, utilization of marginal land, and improvement of breeding techniques (Cholid and Santoso, 2020). *Reutealis trisperma* can be planted together with other plants to increase ecological and economic benefits. In addition, *Reutealis trisperma* is also able to grow on less fertile land so that it does not compete with food crops (Santoso et al., 2019). Another thing that can be done is to select superior varieties with higher oil content and resistance to extreme environmental conditions.

Optimization of Oil Extraction Technology: More efficient oil extraction techniques can increase yields and reduce production costs. Potentially developed technologies include ultrasonic-based extraction and the use of enzymes in extraction. Ultrasonic-based extraction can increase extraction efficiency and reduce solvent consumption (Geow et al., 2020). Furthermore, this extraction method increases oil yield by optimizing the release of oil from raw material cells. (Marhamati et al., 2020). The use of enzymes in extraction can also be used by combining it with the Aqueous enzymatic extraction (AEE). AEE uses enzymes for oilseed extraction so that it can decompose macromolecular complexes such as lipoproteins, lipopolysaccharides, and cell walls in oilseeds. AEE has great potential because it can extract oil and protein simultaneously without causing damage (Gao et al., 2024).

CONCLUSIONS

Biodiesel from *Reutealis trisperma* seeds suggest great potential as a sustainable renewable energy source. The production process includes oil extraction technology,

esterification, transesterification, and purification of biodiesel products. The main advantage of biodiesel from *Reutealis trisperma* is that it has a high oil content and does not compete with food ingredients. This makes it an attractive alternative in the biodiesel industry. However, there are various challenges in its development including low plant productivity, the need for more environmentally friendly technology, and production cost efficiency that still needs to be improved. Moreover, sustainability aspects such as the availability of raw materials, environmental impacts, and policy and regulatory support are important factors in the successful commercialization of this biodiesel. It is hoped that in the future, research and technological innovation efforts must continue to be carried out to increase oil yields, optimize production processes, and effective waste management strategies.

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