POTENTIAL OF PEDADA FRUIT AS A RENEWABLE ENERGY AND CLIMATE MITIGATION SOURCE IN INDONESIA: A REVIEW

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Abstract

Indonesia has one of the largest mangrove ecosystems in the world, which provides important ecological functions such as coastal protection, biodiversity support, and climate mitigation. Among various mangrove species, Sonneratia sp. (pedada fruit) has attracted attention due to its high carbohydrate content, making it a promising biomass source for renewable energy production. This study aims to evaluate the potential of pedada fruit as a raw material for bioethanol production and its contribution to climate change mitigation in Indonesia through a comprehensive literature review. This review analyzed approximately 50 scientific articles, conference proceedings, and research reports related to mangrove biomass utilization, bioethanol production processes, and the environmental benefits of mangrove ecosystems. The results showed that pedada fruit contains approximately 59% carbohydrates along with lignocellulosic components such as cellulose, lignin, and hemicellulose, which are suitable for conversion into bioethanol through pretreatment, hydrolysis, fermentation, and distillation processes, and can be applied in Indonesia with its large number of mangroves. Bioethanol production from mangrove fruit can follow second- to fourth-generation bioethanol technologies, depending on the processing approach used. In addition to providing renewable energy, utilizing mangrove fruit as a bioethanol feedstock can encourage community participation in mangrove conservation and restoration efforts. Therefore, mangrove fruit has significant potential as a sustainable, renewable energy source while also supporting climate mitigation strategies and coastal ecosystem management in Indonesia.

Keywords: *bioethanol, climate mitigation, mangrove, renewable energy, Sonneratia sp.*

Introduction

Indonesia is the largest archipelagic country in the world, with a sea area of more than 70% of the total area of Indonesia (Rencana Strategis Deputi Bidang Koordinasi Kedaulatan Maritim Dan Energi Tahun 2020-2024, 2020). Coastal areas in Indonesia are widely overgrown with mangrove plants. Mangroves function as wave breakers, prevent abrasion, produce food for living things, and in climate mitigation efforts (Dinilhuda et al., 2019) so that mangrove plants are very important plants to be planted in Indonesia. The absence of mangroves can cause a lack of natural protection for the coastline, so that coastal ecosystems become more easily damaged by human activities and extreme weather changes (Irfandi et al., 2025). Based on data from the Ministry of Forestry in 2025, the area of mangroves in Indonesia is 3,440,464 hectares for existing ones and 769,824 hectares for the area of potential mangrove habitat (Keputusan Menteri

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Kehutanan Republik Indonesia No 594 Tahun 2025 Tentang Peta Mangrove Nasional 2024, 2025). Mangroves in Indonesia have a lot of species diversity, including *Rhizopora* sp., *Avicenna* sp., *Sonneratia* sp., *Bruguire* sp., *Xylocarpus* sp., *Ceriops* sp., and *Exoecaria* sp. (Fitria & Dwiyanoto, 2021). These various types of mangroves contain carbohydrates (Fattah et al., 2025), so they can be used to make further products, one of which is bioethanol, a renewable energy source that can replace the use of fossil fuels.

With this background, a literature review was conducted to evaluate the potential of pedada fruit (*Sonneratia* sp.) to become bioethanol as renewable energy in Indonesia, with the hope of providing a comprehensive picture to strengthen the role of pedada fruit as bioethanol in the national energy transition.

Based on research conducted by (Huda, 2017), raw materials that are considered efficient and easy to process into bioethanol generally have a carbohydrate content of between 50-60% of the dry weight. Of the various types of mangroves that have a carbohydrate content of between 50-60% is Sonneratia sp. Sonneratia sp or better known as pedada fruit, is one type of mangrove fruit that has a carbohydrate content of between 50-60%. From research conducted by (Mila Prametha et al., 2025), the carbohydrate content in pedada fruit is around 59.09%, so it has the potential to produce bioenergy, especially bioethanol. In addition to the carbohydrate content, the content of lignin, cellulose, and hemicellulose can also be processed into bioethanol.

Energy consumption in Indonesia increases annually, driven by the increasing number of industries, transportation, households, and agriculture. According to data from the Central Statistics Agency (BPS), energy consumption increased by 6.4% in 2023 compared to 2022. Fossil fuels account for approximately 90% of the country's primary energy source (Kementerian PPN/Bappenas, 2024). The use of fossil fuels can lead to greenhouse gas emissions, which can contribute to global warming, climate change, air pollution, and environmental damage (Anser et al., 2020; Breetz et al., 2025; Li, 2023; Steel et al., 2025; Zimon et al., 2023). Therefore, a transition to a sustainable energy system based on renewable energy is needed.

Bioethanol is a renewable energy source that can replace fossil fuels (Tobe et al., 2022). Bioethanol plays a crucial role in the global transition to sustainability, serving as a renewable fuel, particularly in the transportation sector, and reducing greenhouse gas emissions (Vacharanukrauh et al., 2025). Bioethanol is a renewable energy source derived from carbohydrate-containing raw materials through a fermentation process (Kahar et al., 2025).

Research Methodology

This study employed a comprehensive literature review method involving extensive and in-depth research on the potential of pedada fruit as a bioethanol feedstock. The information sources were extensive and varied, including research reports, conference proceedings, and relevant scientific articles. The research articles used as references in this study were taken from the last 10 years of data. The stages of the literature review method include: 1) collecting research literature related to bioethanol, 2) analyzing and synthesizing data, 3) interpreting data, and 4) concluding. The data in this study were collected from various secondary sources derived from research articles focusing on the same research topic.

Results and Discussion

Potential of Pedada Fruit

Pedada fruit (*Sonneratia* sp.) is a plant that lives in the mangrove ecosystem (Handayani et al., 2025). Pedada fruit can be converted into several energy products, as shown in Figure 1.

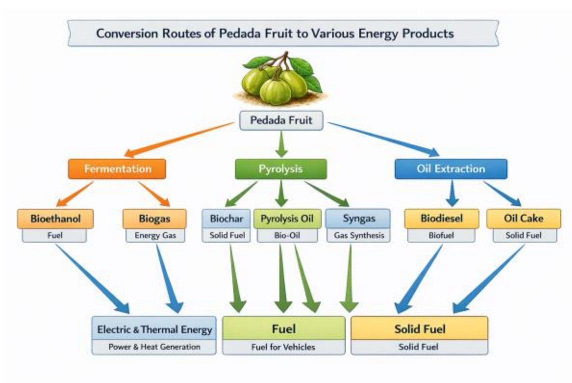

Figure 1. Various energy products produced by pedada fruit

Pedada fruit contains carbohydrates with a content of 59.09%, which has a function as an energy producer (Mila Prametha et al., 2025). In addition to containing carbohydrates, pedada fruit also contains 24.8995% cellulose, 5.0896% lignin, and 11.7486% hemicellulose (Ningrum et al., 2025). The content of carbohydrates, cellulose, lignin, and hemicellulose in pedada fruit can be converted into bioethanol (Beluhan et al., 2023; Damayanti et al., 2021; Darsono & Sumarti, 2014; Dwicahyana et al., 2025).

Development of Bioethanol Production Process

Currently, bioethanol production is divided into four generations based on the raw materials used in the process of producing bioethanol (Mohd Azhar et al., 2017; Tse, Wiens, & Reaney, 2021). In all generations, through the process of pre-treatment, hydrolysis, fermentation, and separation/purification (Vacharanukrauh et al., 2025). The pre-treatment process is very important in the process of making bioethanol in some raw materials because it affects the release of sugar in the fermentation process, which can affect the final result of bioethanol (Ben-Iwo et al., 2016; Tse, Wiens, Shen, et al., 2021).

The development of the bioethanol production process began with the first generation, which utilized raw materials with high starch content, such as corn and wheat seeds, and sugar sources like sugar cane, thereby causing competition between food and energy (Petroleum Supply Annual, 2024; Puri et al., 2012; Rebeiro, 2013). In the second generation, bioethanol is developed using raw materials that are not sourced as food ingredients, namely, using raw materials sourced from lignocellulose, which is abundant and sustainable (Zuliani et al., 2021). In the third generation, bioethanol is produced using microorganisms that synthesize fermentable carbohydrates, making the process possible through enzymatic hydrolysis and microbial fermentation (Dutta et al., 2014; Nishida et al., 2023). Fourth-generation bioethanol is the most advanced stage in bioethanol development, utilizing metabolic engineering and synthetic biology to increase fermentation efficiency (Assaf et al., 2024; Mignogna et al., 2024). In this fourth generation, several microorganisms are genetically engineered to utilize glucose and pentose sugars found in lignocellulosic biomass hydrolysates for bioethanol production.

Bioethanol Production with Raw Materials from Pedada Fruit

Pedada fruit is a type of mangrove that contains carbohydrates, cellulose, lignin, and hemicellulose. Pedada fruit can be used as raw material for bioethanol. The process of producing bioethanol can follow the process in the second, third, or fourth generation if seen from the content contained in the pedada fruit.

Initial Treatment

In the manufacture of bioethanol, pretreatment is very crucial. This pretreatment aims to change the physical and chemical structure of biomass so that the sugars in it are more easily converted into bioethanol (Humera Farheen et al., 2026; Khairiah & Ridwan, 2021; Shukla et al., 2023). This treatment process includes cleaning and drying to remove dirt and reduce the water content in the raw material so that the raw material is ready to be processed in the fermentation stage (Dayatmo & HS, 2015; Jasman & Ahmad, 2021; Jönsson & Martín, 2016).

Fermentation Process

The content parameters in pedada fruit are a very important part of determining the fermentation route that will be carried out. The content of pedada fruit can be seen in Table 1.

Table 1. Pedada fruit content (Ningrum et al., 2025)

Pedada Fruit Content	Amount (%)
Water content	10.8399
Ash content	5.8708
Lipid content	0.6123
Protein content	8.1004
Carbohydrate content	59.0948

Table 1 shows that pedada fruit (*Sonneratia* sp.) has a low protein content but a high carbohydrate content. This high carbohydrate content makes it suitable as a raw material for bioethanol because carbohydrates can be fermented directly into bioethanol (Amalia & Rezeki Muria, n.d.; Andana et al., 2020; Sadimo et al., 2016). Fermentation of carbohydrates into bioethanol can use several microorganisms, including Saccharomyces cerevisiae, Zymomonas mobilis, Trichoderma viride, and several types of indigenous yeast (Gustina et al., 2022; Mohd Azhar et al., 2017; Praveen & Brogi, 2025). This fermentation process is carried out to convert the reducing sugar content obtained from carbohydrates in pedada fruit into bioethanol.

Distillation Process

The distillation process is one of the techniques used in bioethanol purification (Onuki et al., 2008). The distillation process is carried out by heating a liquid mixture, where the components with the lower boiling points will evaporate first, concentrate in the vapor phase, and then condense back into a liquid (Setiawan, 2018; Stewart, 2024). This distillation method is the most common method used to increase the alcohol content of fermentation products in the production of bioethanol (Lay et al., 2010; Sehwantoro et al., 2021).

Mangrove Plants as a Form of Climate Mitigation Effort in Indonesia

Mangroves in Indonesia play a vital role in climate mitigation. Mangroves have the capacity to absorb 3-5 times more carbon than tropical forests and can protect coastal areas from abrasion, tsunamis, and sea level rise (Fitria & Dwiyanoto, 2021; Soleman Imburi et al., 2024; Wihartono, 2025). The use of mangrove fruit as bioethanol can increase community motivation to plant and care for mangroves (Abubakar et al., 2023; Anggraeni Luthfiyatul Afifah et al., 2025; Farhaeni, 2016; Mulyani et al., 2018).

Conclusions

Based on the nutritional content of pedada fruit (Sonneratia sp.), it can be concluded that pedada fruit has potential as a raw material for bioethanol, a renewable energy source. This content allows pedada fruit to be processed into bioethanol through several stages, including pre-treatment, hydrolysis, fermentation, and distillation. Based on a literature review, bioethanol production from pedada fruit can be integrated with second-, third-, or even fourth-generation bioethanol technologies.

In addition to its potential as a bioenergy source, the utilization of pedada fruit for bioethanol production can contribute to climate change mitigation and sustainable coastal management. By providing economic value to mangrove resources, this approach may encourage local communities to participate in mangrove conservation and restoration efforts. Therefore, the development of pedada-based bioethanol can support Indonesia's transition toward renewable energy while simultaneously strengthening ecosystem protection and community-based environmental management.

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