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# I-Fuel: Biodiesel innovation based on fish waste as an environmentally friendly alternative energy source

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## ABSTRACT

**Background:** Srowo Sidayu Village has marine product processing activities in the form of bonggolan food products that generate fish waste such as bones, skins, heads, gills, and offal. This waste has not been optimally utilized, despite containing triglycerides with potential for biodiesel production. This study aims to identify the most promising types of fish waste as raw materials for biodiesel. **Methods:** This study employs a Systematic Literature Review (SLR) by reviewing previous research articles and relevant scientific publications, which were then analyzed descriptively and comparatively. The study also categorized fish waste based on type and anatomical part (head, skin, innards, etc.) to determine which components have the highest fat content and theoretical biodiesel potential. Selection criteria were applied to ensure that only studies reporting measurable fat content and conversion data were included in the analysis. **Findings:** The results show that fish waste contains varied and relatively high fat levels, particularly in the head, skin, and innards of certain fish species. With an estimated biodiesel conversion efficiency of 90%, each kilogram of fish waste can potentially produce biodiesel proportional to its fat content. Snakehead heads demonstrate the greatest potential, with an estimated yield of approximately 574 grams of biodiesel per kilogram of waste. **Conclusion:** All bonggolan fish waste shows potential for biodiesel production, with snakehead waste being the most promising. However, further experimental studies are required to validate these theoretical estimations. **Novelty/Originality of this article:** This research synthesizes prior findings to identify fish waste types with the highest biodiesel potential and highlights the need for experimental verification of fat content, oil yield, and conversion efficiency.

**KEYWORDS:** biodiesel; environmentally friendly alternative energy; fish waste.

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## 1. Introduction

Srowo Sidayu Village is one of the villages in Sidayu District, Gresik Regency. This village is also often known as a fishing village. The majority of the livelihood of the people of Srowo village are fishermen and fish cracker sellers, so Srowo Sidayu Village is one of the largest cracker-producing villages in Sidayu (Hidayatullah, et al., 2020). In making crackers, only fish meat is needed, so cracker production in Srowo village creates a considerable fish waste problem. Every day, this process leaves around 200 to 300 kilograms of waste consisting of bones, skin, head, gills, and the entrails of fish. This figure even jumps significantly to around 400 kilograms per day at special times, such as during the month of Ramadan, Eid al-Fitr and New Year (Rasyida, et al., 2025). This fish waste includes the head, bones, gills, tail, and innards of fish. The waste is often dumped into the environment without management so that it can cause environmental problems such as soil pollution,

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water pollution, and unpleasant odors. The people of Srowo village also often dump their fish waste into the river or local water bodies without first treatment. Research by Melenia & Hidayah (2023) shows that liquid waste from fish canning plants contains pollutant parameters such as Biochemical oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS) that exceed the quality standard limit, so it has the potential to cause significant changes in the function of wastewater receiving water bodies. The wastewater quality standard is the maximum limit of pollutants that can be present in the waste that will be discharged into the water. The characteristics of fish processing industrial waste in the Tegal area shows that fish waste disposed of without prior treatment still contains a fairly high pollutant load (Jatiningtyas et al., 2020). The liquid waste produced has a pH value ranging from 7.61–8.08, TSS of 810–1,065 mg/L, BOD of 10–30 mg/L, COD of 44–90 mg/L, and ammonia (NH<sub>3</sub>) of around 0.04–0.10 mg/L. When compared to the standard of wastewater quality of the fishery product processing industry in Indonesia as stipulated in the Regulation of the Minister of Environment Number 5 of 2014, the TSS value in the waste exceeds the permissible threshold of 100 mg/L, while the parameters of pH, BOD, COD, and ammonia are still below or close to the set quality standard value. Nonetheless, the high concentration of suspended solids suggests that the disposal of fish waste without treatment still has the potential to degrade the quality of water bodies, especially through increased turbidity, sedimentation, and disturbance to the aquatic ecosystems around the disposal site. This is also in line with Julia (2025) research which also shows that fish waste discharged into water bodies without treatment can reduce the quality of river water and affect the capacity of pollution loads. If water quality decreases, this can disrupt aquatic ecosystems and aquatic organisms living in them if not addressed (Pamungkas, 2016).

Not only that, people also often feed their poultry with the fish waste. Giving fish waste that has not been adequately processed to poultry has the potential to cause various health problems and feed quality. Raw fish waste if not treated properly can accelerate the process of decay and microbial contaminants that are not suitable for the poultry digestive tract. The use of fish waste as an ingredient for animal feed needs to go through the stages of proper processing, processing, and handling, because unprocessed fish waste can contain contaminants and do not meet stable nutritional standards for livestock (Najoan, 2019). In addition, other research findings suggest that raw fish waste needs to be treated (e.g. through fermentation or silage) before being used as poultry feed, as such processes can lower the pH, reduce pathogenic microbes, and improve nutrient stability; Without this treatment, raw fish waste can promote the growth of unwanted microbes as well as harm poultry health if given directly (e.g. fermentation of silage which has been shown to lower pH improves feed safety) (Shabani, et al., 2018). Research by Abasubong et al. (2025) states that the provision of fish waste in poultry feed can have a negative impact depending on the quality, composition and proportions used. In large quantities, poor-quality or improperly processed feed can negatively affect livestock products, including causing undesirable taste in meat or eggs and impairing poultry health. Furthermore, unhygienic feed—such as improperly processed fish waste—can introduce pathogens, degrade water quality, and pose risks to human health through the food chain. In aquaculture systems, uneaten or low-quality feed contributes significantly to the release of nitrogen and phosphorus into aquatic environments, leading to water pollution and eutrophication (Kong et al., 2020; Barbosa et al., 2024; Milián-Sorribes et al., 2021).

On the other hand, the increasing demand for energy at the local level and dependence on the use of fossil fuels causes its availability to continue to decrease (Parinduri & Parinduri, 2020). The use of fossil fuels also causes adverse impacts on the environment, such as air pollution and climate change, thus encouraging the need for the development of renewable energy sources (Tjiwidjaja & Salima, 2023). Chemically, Biodiesel is a renewable fuel made from vegetable oil or animal fat through a transesterification chemical reaction, where the oil or fat is reacted with alcohol (Sukaryo, et al., 2021). Another definition of biodiesel is an alternative fuel derived from renewable sources such as vegetable oils and animal fats. Chemically, biodiesel is a mixture of methyl esters of long-chain fatty acids that

have almost the same physical properties as diesel, so they can be used as a substitute for fossil fuels in diesel engines (Mardawati, et al., 2019). The process of making biodiesel involves the conversion of triglycerides (and/or free fatty acids) into fatty acid methyl esters (FAME) through chemical reactions such as esterification and/or transesterification (Lemetige, et al., 2020). According to Devita (2015), biodiesel has several advantages, including that biodiesel has a high number of setane, so that the combustion process takes place faster and its thermodynamic efficiency increases. In addition, biodiesel is safer against the risk of fire during storage and distribution compared to diesel. This fuel is also naturally biodegradable, providing a better engine lubrication effect so that it can extend the life of the engine, and is able to significantly reduce black smoke emissions from diesel engine exhaust, making it more environmentally friendly. In addition, the use of biodiesel can also reduce greenhouse gas emissions (Tomo & Brunner, 2022).

In addition to having various advantages, the development of biodiesel is not immune to various technical challenges, such as the sustainable availability of raw materials, production costs, and the oxidative stability of biodiesel. The oxidative stability of biodiesel is greatly influenced by the composition of its constituent fatty acids, where the high content of unsaturated fatty acids tends to increase the susceptibility of biodiesel to oxidation processes during storage (Knothe, 2005; Tomo & Brunner, 2022). This condition requires the selection of the right raw materials and optimal production process management so that the quality of biodiesel is maintained. In this context, the use of lipid-containing waste, such as fish waste, is a promising alternative to raw materials due to its abundant availability and high triglyceride content. The use of fish waste as a raw material for biodiesel not only aims to produce renewable energy, but also as a more effective waste management effort. This approach is further in line with the concept of the circular economy, where waste is seen as a resource that can be reused to produce value-added products (Kirchherr et al., 2017).

In line with this, the triglyceride content contained in organic waste from fish processing has the potential to be converted into biodiesel through the transesterification process (Zhou et al., 2021). Triglycerides are the main components in fish oil, making fish waste a potential raw material for biodiesel production because its chemical structure is relatively easy to convert into methyl ester through transesterification reactions (Putra et al., 2021). Research conducted by Purwaningrum & Sukaryo (2019) showed that the fish oil yield obtained from 100 grams of fish waste reached 22.40%, which indicates that fish oil waste has significant potential as a biodiesel raw material. The use of fish oil waste not only contributes to reducing the burden of environmental pollution, but also opens up opportunities for the development of renewable energy based on local resources. With the abundant and sustainable availability of fish waste, Srowo Sidayu Village has great potential to be developed as a biodiesel production center based on fishery waste on a local scale.

Although various studies have discussed the use of fish waste as a raw material for biodiesel, these studies are still generally partial and focused on specific types of waste. Therefore, a more comprehensive study is needed to evaluate the potential of various types of fish waste as raw materials for biodiesel, especially waste produced from the fish cracker industry in Srowo Sidayu Village. This study is expected to make a scientific contribution to the development of renewable energy, especially related to the use of fish waste as a raw material for biodiesel, as well as add academic references through systematic studies of fish oil characteristics, conversion processes, and biodiesel efficiency produced from various types of fish. In addition, this research is expected to provide information for the community, especially fish processing business actors in Srowo Sidayu Village, as well as encourage increased awareness of the importance of environmentally friendly waste management while increasing the economic value of fish processing by-products.

## 2. Methods

### 2.1 Research approach

This study uses the Systematic Literature Review (SLR) method to identify and systematically analyze scientific articles that discuss the potential of fish waste from various types of fish as raw materials for biodiesel. The Systematic Literature Review (SLR) method is a systematic, explicit, and replicable approach to identify, evaluate, and synthesize various relevant research and thought results. It is also to detail previous research and explore relevant findings in this field. The SLR approach allows us to identify key trends, patterns, and findings relevant to the research topic (García-Peñalvo, 2022). This method aims to collect, critically examine, and integrate findings from various previous studies in order to gain an in-depth understanding of the research topic or question being studied. The SLR method has a number of advantages, including being able to provide comprehensive scientific evidence, reduce researcher bias, and identify research gaps that can be used as a basis for future research. However, this method also has some limitations, such as requiring large time and resources, and difficulty synthesizing results if there are differences in methodology between the studies analyzed (Kamila & Waluya, 2023). The SLR method has been widely applied in various fields of science. For example, research that has been conducted by (Rohid, et al., 2022) uses the SLR method to review the use of capturing gas emissions into electrochemical-based electrical energy. Another study conducted by (Khilma, et al., 2022) also used the SLR method to review the correlation between the use of 3D learning media and the level of understanding of biological material.

### 2.2 Literature search strategy

This method was chosen to obtain a comprehensive synthesis based on published scientific evidence. Literature searches were conducted through Google Scholar and scientific journal portals using the keywords "biodiesel from fish waste, biodiesel from fish fat or oil, fishery waste as an alternative energy, and management of fish fat into biodiesel". The publication range used is the last ten years (2015–2025) to ensure that the data studied is up-to-date and in accordance with the development of biodiesel technology. According to Nadhifah & Hasan (2022), more recent literature tends to provide more current information.

### 2.3 Inclusion and exclusion criteria

The articles obtained were selected based on inclusion and exclusion criteria. In the data collection process, inclusion and exclusion criteria are applied to select relevant literature that is suitable for study in this study (Fauziyah, et al., 2024). Inclusion criteria include the suitability of the topic with the research objectives, the availability of full text, the publication period, and the relevance of the discussion to the use of fish waste as a biodiesel raw material. The exclusion criteria include articles that are irrelevant, not scientific, duplicate publications, or do not provide adequate data.

### 2.4 Article selection procedure

The data selection procedure in this study is carried out through several systematic stages. As shown in Figure 1. The first stage is the screening of titles and abstracts to assess the initial suitability between the research topic and the focus of the study, namely the processing of fish waste into biodiesel. Furthermore, a full text reading of the article that is considered relevant is carried out to ensure that the content of the research really supports the research objectives. After that, duplicate articles that have similar data or research results are eliminated so that there is no repetition of sources. The last stage is the recording and grouping of selected articles based on important information such as the author's name,

year of publication, research objectives, methods used, main results, and conclusions. This procedure aims to obtain valid, relevant, and high-quality data sources as the basis for analysis in this literature review. In addition, it also aims to ensure that the study process can be replicated by other researchers with similar procedures.

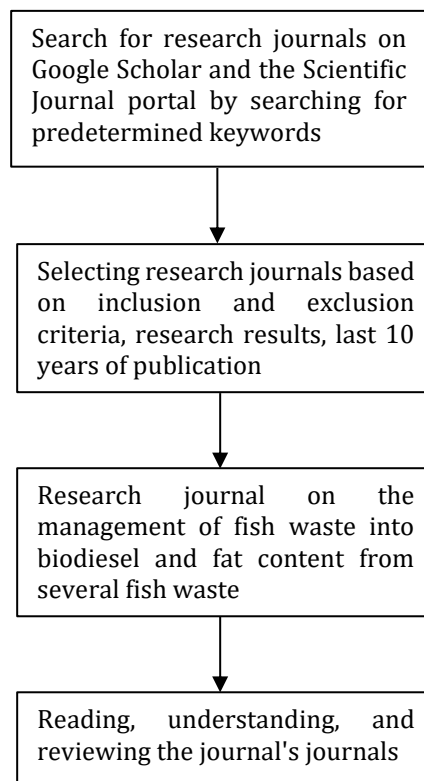


Fig. 1. Flow chart of the article selection process in systematic literature review

### 2.5 Data extraction and synthesis

The data extracted from each article includes the types of fish waste, fish body parts included in the waste, oil or lipid content of various types and parts of fish, the process of making biodiesel from fish waste, and the potential for its conversion into biodiesel. The data is compiled in a synthesis table to facilitate the process of analysis and comparison between studies. This approach enables a more systematic evaluation of findings and supports the identification of key patterns across the reviewed literature.

### 2.6 Data analysis

Data analysis is carried out through several stages, namely data reduction to filter relevant information, data grouping based on the type and proportion of fish waste, and categorization based on the content of fish oil or fat and its conversion potential. The data obtained were analyzed descriptively and comparatively using a thematic synthesis approach to identify patterns, similarities, and differences in findings between studies so that the results of the synthesis obtained were not only descriptive, but also reflected general patterns and scientific trends that developed in research related to the use of fish waste for biodiesel production. The analytical approach also considered the consistency of the technical indicators used in each study, in particular the parameters of lipid content and fish oil yield. The determination of the type of fish waste that has the highest potential as a biodiesel raw material is based on the indicators of lipid content, the body parts of the fish used, and the consistency of results reported in various studies. The variation in results between studies was analyzed by taking into account the difference in fish type, oil or lipid

content in certain parts of the fish, the method of oil extraction, and the context and conditions of the reported research. The analysis was carried out without additional experiments, but rather through a critical synthesis of key findings from the relevant literature. The results of the analysis are presented in the form of tables and diagrams to facilitate the interpretation and comparison of data, especially in describing the distribution of fish waste types as well as variations in oil content reported in various studies.

### 3. Results and Discussion

#### 3.1 Characteristics of analyzed articles

Based on the results of a systematic literature review of 20 articles that met the inclusion criteria, information was obtained about the types of fish waste that have the potential to be used as raw materials for biodiesel. The articles were published in the range of 2015-2025 and discuss the characteristics of fish oil from different types of fish waste and its parts as a raw material for biodiesel. The time range was chosen to obtain an overview of the latest research developments related to the use of fish waste as a raw material for biodiesel. According to Nadhifah & Hasan (2022), the younger the age of literature, the more up-to-date the information contained in it. The articles analyzed consisted of accredited national journals and reputable international journals, with the majority being experimental research articles and several literature review articles. The types of fish waste studied in the article include fish heads, fish offal, fish skin and other parts of marine fish that become waste. This variation shows that almost all parts of fish have the potential to be used as raw materials for biodiesel.

In general, the analyzed articles report the characteristics of fish oil from different parts of fishery waste with their types of fish as well as their potential conversion to biodiesel. Most of the articles use experimental research methods with a focus on the oil extraction process and the analysis of the characteristics of the resulting biodiesel such as yield and methyl ester content. Based on the research area, most of the studies came from countries with developing fisheries sectors, including Indonesia, which have large quantities of fish waste availability. One of them is a study by Harsono (2016), which examines the use of fish waste as a raw material for biodiesel in Indonesian territory with an energy efficiency approach for biodiesel production from fish waste. These findings are relevant to the focus of this research which examines the potential of fish waste in one of the villages in Indonesia as a raw material for biodiesel. The dominance of publications in the last decade shows the increasing attention of researchers to the use of fishery waste as a source of renewable energy. This is in line with the increasing sustainability issues and the need for non-food biodiesel raw materials.

#### 3.2 Distribution of potential types of fish waste as biodiesel raw materials

The synthesis results showed that the types of fish waste that are most often reported as potential raw materials for biodiesel include skins, bones, gills, heads, and offal residues from cracker processing. The distribution of different parts of fish waste from different fish types as reported in the literature is presented in Figure 2. Based on the data extracted from the selected articles, the oil content in fish waste shows a significant variation. Fish skin waste is the most widely reported type of waste, followed by the head, bones and offal of fish left over from processing. This suggests that parts of fish rich in soft tissue and fat are more widely used in biodiesel research than hard parts such as bones.

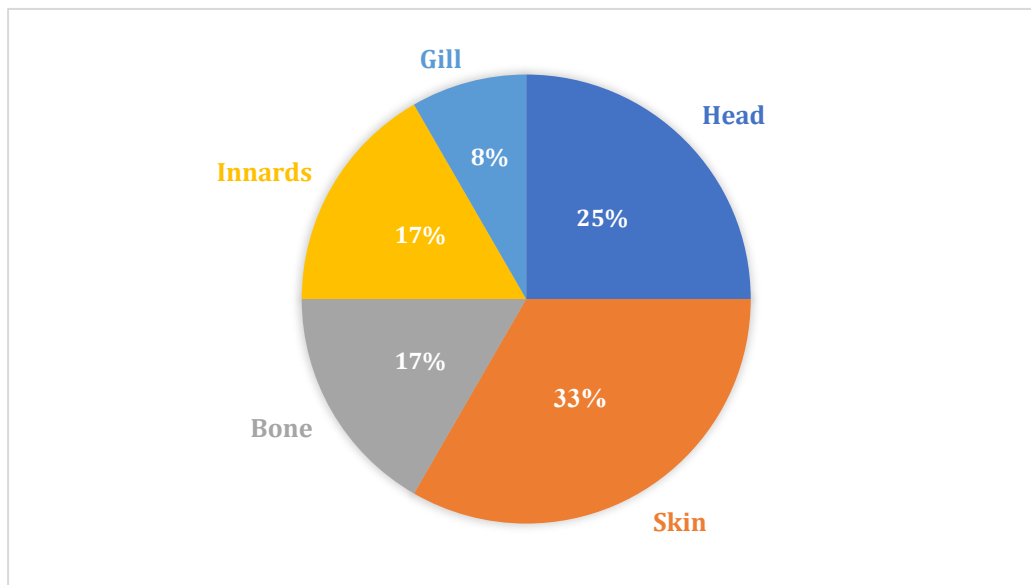


Fig. 2. Article distribution diagram

A number of national studies show that the availability of lipids or oils in fish waste is the main factor in the selection of waste types as raw materials for biodiesel. A study on the utilization of catfish waste reports that oil extracted from catfish offal can be processed through a transesterification process to produce methyl ester as the main component of biodiesel (Azizah et al., 2024). In addition, research on the characteristic test of biodiesel based on fish offal waste shows that biodiesel can be produced through certain stages of production, which indicates that the oil content in the waste is significant enough to be used as a raw material for biodiesel (Purwaningrum & Sukaryo, 2018). This finding is strengthened by the proceedings report which states that catfish offal waste has a high fat content, so it has great potential to be converted into biodiesel with methyl ester as the main product (Azizah & Wardana, 2022).

### 3.3 Fish waste oil content based on review results

Based on the data extracted from the selected articles, the oil content in fish waste shows significant variations between types of fish and between parts of the fish's body. Fish waste generally contains fat or oil with relatively high triglyceride levels, so it has great potential to be converted into methyl ester through the transesterification process and used as value-added biodiesel (Lestari, 2017). This variation in oil content shows that the potential for fish waste as a raw material for biodiesel is not uniform, but is greatly influenced by the biological characteristics of the fish and the body parts used. Several studies report noticeable differences in fat levels in different parts of fish waste. Haryati et al. (2022) stated that the skin of the lobster contains a fat content of 5.01%, while the bones of the lobster only contain fat of 0.32–0.52% (Anggraeni et al., 2019). In other types of fish, tuna skin is reported to have a fat content of 0.53% (Hizbullah et al., 2020), while mackerel skin shows a higher fat content, which is  $8.41 \pm 0.71\%$  (Gunawan et al., 2018). In addition, milkfish skin contains 4.76% fat (Perceka et al., 2011), while kurisi fish gills have a fat content of 1.94% (Jumiati et al., 2021).

Relatively high fat content is generally found in the part of fish waste that is dominated by soft tissues and fat storage tissues, such as offal and fish heads. Fish offal for months is reported to contain 17.80% fat (Aldian & Bija, 2023). In cod fish, the fat content of the head and bones reached 35.98% and 26.21%, respectively (Apituley et al., 2020). Milkfish head contains 3.48% fat (Almuis et al., 2024). The highest fat content was reported in snakehead, especially in the head at 63.8% and the offal at 19.9% (Umage, 2020). These findings show that fish body parts rich in soft tissue and lipids have a greater potential to be utilized as

biodiesel raw materials than hard parts such as bones. In addition to being influenced by the type and proportion of fish, the variation in oil content reported in various studies is also related to the difference in the extraction method used. Some studies applied solvent extraction methods, while other studies used direct heating or a combination of physical and chemical methods. Differences in extraction conditions, such as the type of solvent, temperature, extraction time, and the ratio of ingredients to solvents, also contribute to variations in the oil content obtained. Thus, the difference in lipid content values between studies does not indicate inconsistency in results, but rather reflects differences in the methodological approach used. The variation in the content of fish waste oil is summarized in Table 1.

Table 1. Fat Content of different parts and types of fish

Types of fish	Waste section	Fat content (%)	Biodiesel production potential
Whale	Skin	5.01	Medium
Whale	Bones	0.32-0.52	Low
Tuna	Skin	0.53	Low
Mackerel	Skin	8.41	Medium
Moonfish	Innards	17.80	Hight
Milkfish	Skin	4.76	Medium
Bream	Gills	1.94	Low
Cob	Head	35.98	Hight
Cob	Bones	26.21	Hight
Milkfish	Head	3.48	Low
Snakehead	Head	63.8	Very high
Snakehead	Innards	19.9	Hight

Overall, the results of the synthesis showed that snakehead head waste had the highest fat content, reaching 63.8%, followed by cod fish head at 35.98% and cod fish bones at 26.21%. The high fat content in these parts shows great potential to produce higher biodiesel yields than other fish body parts. On the other hand, low-fat waste such as ledge skin, milkfish skin, and kurisi gills is relatively less efficient when used as the main raw material for biodiesel, but can still be used as a blended material or through an integrated waste treatment approach.

### 3.4 Factors affecting variations in fish waste oil content

The difference in oil content variation is influenced by several factors, including the type of fish species, the method of oil extraction, and the condition of the raw materials. The fat content of fish is greatly influenced by biological factors such as the age of the fish, nutritional conditions, species type, and body parts of the fish. These biological variations cause differences in the total lipid and fatty acid profiles in the resulting waste (Anu Prasanna, et al., 2023). From the aspect of fish type, snakehead shows the highest potential because it contains balanced saturated and unsaturated fatty acids so that it can produce biodiesel with good physicochemical quality and viscosity in accordance with SNI and ASTM standards (Pratama et al., 2011; Rosyadi et al., 2020). The quality of biodiesel produced from various raw materials, including fish waste oil, must meet the requirements set out in SNI 7182:2015, including the parameters of viscosity, density, acid number, and iodine number (BSN, 2015).

In addition, the extraction method used in each study also affects the acquisition of oil. Some studies report that solvent-based extraction methods produce higher oil yields than mechanical methods. These findings are in line with the theory that the efficiency of lipid extraction is greatly influenced by the techniques and process conditions used (Lee, et al., 2017). The main process in the manufacture of biodiesel is transesterification. Transesterification is a chemical reaction between fats (triglycerides) and alcohols that produce alkyl esters and glycerol as byproducts. The basic principle of transesterification is the substitution of alcohol for fatty acids to form esters. Since this reaction is reversible,

excess amounts of alcohol are required for the equilibrium of the reaction to shift towards the ester product (Zuhra, et al., 2015). According to Hadrah et al. (2018), the transesterification reaction in the biodiesel manufacturing process takes place through three successive reaction stages. In the first stage, triglycerides (TG) react with methanol ( $\text{CH}_3\text{OH}$ ) producing diglycerides (DG) and methyl esters ( $\text{R}_1\text{COOCH}_3$ ). Furthermore, diglycerides react with methanol to form monoglycerides (MG) and methyl esters ( $\text{R}_2\text{COOCH}_3$ ). In the final stage, monoglycerides react with methanol producing glycerol (GL) and methyl ester ( $\text{R}_3\text{COOCH}_3$ ) as the end products of biodiesel. This series of reactions shows that the conversion of triglycerides to methyl esters takes place gradually until glycerol is formed as the main by-product.

The transesterification process is influenced by various operational factors. According to Arpiwi (2015), the reaction time plays an important role in determining the amount of product produced, where before reaching equilibrium conditions, increasing reaction time will increase the formation of methyl esters. In addition, the ratio of molar alcohol to oil also greatly determines the conversion of esters obtained. The higher the amount of alcohol used, the greater the conversion of triglycerides to methyl esters, with a molar ratio of alcohol to vegetable oil commonly used on an industrial scale of 6:1 to achieve a methyl ester yield of more than 98% by weight. Another factor that affects is the type of catalyst, which functions to speed up the reaction by lowering the activation energy without changing the equilibrium of the reaction, thus allowing the process to take place at relatively low temperatures, namely below  $250^\circ\text{C}$ . The catalyst that is commonly used is an alkaline catalyst such as KOH.

The temperature of the reaction also affects the rate and efficiency of transesterification, where the reaction is generally carried out in the range of  $30$ – $65^\circ\text{C}$ , close to the boiling point of alcohol. Increasing temperature can accelerate the movement of molecules, decrease the viscosity of the mixture, and increase the frequency of collisions between reacting molecules. Stirring also plays a role in increasing the reaction rate by improving the contact between the oil and alcohol phases. After the reaction takes place, the deposition time becomes an important factor in the separation process of biodiesel and glycerol, because too long deposition can increase the number of acids due to oxidation. In addition, the water content in raw materials needs to be controlled, as the high moisture content can trigger saponification reactions that produce soap, increase viscosity, and inhibit the separation of biodiesel. The type of alcohol used in the transesterification process is generally methanol, because it has high reactivity, stability, and is easier to separate from glycerol than ethanol. In some processes, the addition of cosolvent is also done to unite the phases of oil and alcohol so that the reaction can take place faster and result in a higher methyl ester conversion.

In addition to the type of fish and extraction method, the variation in the oil content of fish waste is also influenced by the part of the fish body used as raw material. Research by Riza (2017) reported differences in the percentage of fish oil in different parts of catfish waste. This proves that the lipid content differs between parts of the fish's body that become waste, such as the head, stomach, skin, and offal which affects the total oil that can be obtained from waste. The condition of freshness and storage of raw materials also affects the quality and composition of the oil. The process of oxidation and the formation of degradation products can occur during storage, which has an impact on the stability of fatty acids and the value of oil peroxide. Studies on lemuru fish showed that the fatty acid profile changed and the peroxide number increased during cold storage, which illustrates the effect of storage conditions on oil stability (Andikawati, et al., 2020).

### *3.5 Limitations and implications of findings in biodiesel development*

This research has several methodological limitations that need to be considered in interpreting the research results. First, this study uses a literature study method so that all data analyzed are sourced from secondary data. Dependence on secondary sources causes research results to be greatly influenced by the quality, completeness, and validity of

previous research that is used as a reference. Therefore, the findings obtained do not fully reflect the empirical conditions in the field. In addition, the limitation of the number and year range of literature publications studied is also an obstacle in this study. The literature used is limited to articles that are available in full text and relevant to the research topic, so there is a possibility that another research is not accommodated. In addition, variations in methods, contexts, and research locations in each literature source cause differences in findings that require careful interpretation. However, these limitations do not reduce the essence of this study, because the literature selection process has been carried out systematically and data analysis has been carried out critically to obtain a comprehensive picture in accordance with the research objectives.

Despite these limitations, the findings of this study remain consistent with and reinforce previous research in the field. The results of this review reinforce the findings of previous research that stated that fish waste has high potential to be developed as a raw material for biodiesel. These findings are in line with previous research showing that fish waste contains lipids that can be converted into biodiesel with characteristics that meet fuel quality standards (Anu Prasanna et al., 2023). This study confirms that the high availability of lipids in certain types of fish and body parts is a key factor in the selection of biodiesel raw materials based on fishery waste. In contrast to previous studies that generally focused on one type or part of fish waste, this article presents a more comprehensive classification of different types of fish waste and its parts based on its biodiesel potential, thus providing a more comprehensive perspective. The main implication of this finding is the opening of opportunities for the use of fish waste as an alternative biodiesel raw material that is non-food. From an environmental aspect, the use of fish waste for biodiesel production has the potential to reduce pollution caused by the disposal of fisheries waste that is not properly managed. The conversion of waste to renewable energy also supports the implementation of the circular economy concept, namely by increasing the added value of waste while reducing negative impacts on the aquatic environment.

Technically, the results of the synthesis show that the fatty acid composition in fish waste oil, in particular the balance between saturated and unsaturated fatty acids, has a major effect on the quality of the biodiesel produced. The relatively balanced content of saturated and unsaturated fatty acids in snakehead waste oil indicates suitability to be converted into biodiesel with physicochemical properties that meet quality standards. This is in line with the opinion of Knothe (2005) who states that the physicochemical properties of biodiesel are greatly influenced by the fatty acid composition of the raw material, especially the level of saturation and length of its fatty acid chain. Pandiangan research (2022) shows that the total saturated fatty acids in snakehead waste oil are 40.438% and the total unsaturated fatty acids are 59.562%, consisting of MUFA of 16.298% and PUFA of 43.272%. The results of the analysis of the physico-chemical characteristics of the biodiesel produced are still within the required standard limits, thus strengthening the potential of fish waste as a raw material for biodiesel.

From a methodological perspective, this study shows that the Systematic Literature Review (SLR) approach is effectively used to map the potential of fish waste as a raw material for biodiesel comprehensively. The use of thematic synthesis allows the identification of general patterns and differences in results between studies despite variations in methods, types of fish, and waste parts analyzed. This approach provides a comprehensive picture that is difficult to obtain through single experimental research. However, the results of the study also show the need to standardize the reporting methods of lipid content and biodiesel yield in subsequent studies so that comparisons between studies can be carried out more accurately. Thus, these findings not only contribute to the substance aspects of fish waste-based biodiesel, but also provide methodological implications for similar research in the field of renewable energy.

However, the use of fish waste as a raw material for biodiesel also faces a number of challenges, especially related to high levels of free fatty acids, water content, and the presence of oxidized compounds that can inhibit the transesterification process. Therefore, the right pretreatment stage is needed before the main process of biodiesel production is

carried out so that the conversion of methyl ester can take place optimally (Nabgan et al., 2022; Shaah et al., 2021). From an economic perspective, fish waste has advantages due to its abundant availability and relatively low economic value. This condition opens up opportunities for the development of small- to medium-scale biodiesel, especially in fishery center areas, so that it can support the development of renewable energy based on local resources. Thus, this article positions itself as a synthesis study that provides a comprehensive overview of the potential of fish waste as a raw material for biodiesel, both from technical, environmental, and economic aspects. The findings in this study are expected to be the basis for further research and consideration in the formulation of fisheries waste utilization policies to support the development of renewable energy and the implementation of the circular economy concept.

#### **4. Conclusions**

This research is a literature that discusses the potential of various types and parts of fish waste made from crackers in Srowo village as a raw material for biodiesel. Through a systematic literature review approach, this study identified that fish waste, especially skin, bones, gills, head, and offal residues from processing, has significant potential as a sustainable alternative oil source due to the high triglyceride content in these parts. This shows that fishery waste is not only bad for the environment because it is disposed of without treatment, but can also have a good impact by being processed as a renewable energy source with high use value.

The main contribution of this study lies in the integrated mapping between the types of fish waste, the fish part of the fish waste, the intensity of studies in the literature, and the characteristics of oil content relevant to biodiesel production. This synthesis provides a comprehensive overview of research trends and reveals study gaps, especially related to the limitations of studies that systematically compare the potential between types of waste. Thus, this research enriches the state of the art in the development of biodiesel based on fishery waste and can serve as a conceptual foundation for further experimental research as well as decision-making in waste management and sustainable energy development.

Each fish waste has the potential to produce high biodiesel according to the fat content contained in the raw material. The results of the study show that all types and parts of fish have the potential to be used as biodiesel with an estimated biodiesel conversion of 90% with fish waste that has the greatest potential to be used as a raw material for biodiesel is snakehead heads with an estimated of around 574.2 grams of biodiesel. However, further experimental research is needed to prove this and optimize efficient extraction and transferification.

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#### **Author Contribution**

Conceptualization, N. Z and Z. A. R.; Methodology, N. Z and Z. A. R; Data Curation, N. Z. and Z. A. R; Formal Analysis, N. Z.; Writing – Original Draft Preparation, N. Z.; Writing – Review and Editing, Z. A. R. and D. N.; Supervision, D. N. All authors have read and approved the final manuscript.

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No new data were created in this study. All data used are derived from published articles included in the literature review.

## Conflicts of Interest

The authors declare no conflict of interest.

## Declaration of Generative AI Use

During the preparation of this work, the authors used ChatGPT to assist in improving language clarity, sentence structure, and academic writing. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

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