Exploring Biodiesel Potential from Black Soldier Fly Larvae with Base Catalysts

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Abstract. Biodiesel, a sustainable and renewable diesel fuel alternative, has traditionally relied on vegetable oil, but it presents challenges such as high production costs, extensive land requirements, and prolonged harvest times. This study investigates Black Soldier Fly Larvae (BSFL) as a promising alternative. BSFL offers distinct advantages, including a higher oil content, a smaller land footprint, shorter harvest periods (17-22 days), and organic waste reduction capabilities. BSFL-derived oil was extracted and converted into biodiesel using KOH and CaO as catalysts, yielding 92.71% w/w and 90.64% w/w, respectively. Biodiesel produced with KOH exhibited an ester content of 97.89%, a density of 851.69 kg/m3, a viscosity of 3.24 cSt, a heating value of 38.71 MJ/kg, and a carbon residue of 0.014%. CaOproduced biodiesel had an ester content of 64.52%, a density of 883.85 kg/m3, a viscosity of 18.15 cSt, a heating value of 38.12 MJ/kg, and zero carbon residue. BSFL, serving a dual role in waste reduction and biodiesel production, holds promise as a biodiesel source, reducing reliance on fossil fuels towards a sustainable future.

Keywords: Biodiesel, Black Soldier Fly Larvae (BSFL) Biodiesel Characteristics, Esterification, Transesterification

1 Introduction

Currently, fossil energy dominates energy sources in Indonesia, reaching 95%. Petroleum is a type of fossil energy that is used as the main component of fuel production [1]. Petroleum production can be augmented by 2-3% to fulfill the market demand [2]. However, the demand is not comparable to petroleum production which decreased by 7.87% in 2021 [3]. Fossilderived fuels can elevate greenhouse gas emissions which cause the climate instability, resulting higher

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global temperatures and rise in sea levels [4]. Based on this, alternative raw materials are needed which are readily accessible and environmentally friendly.

Biodiesel presents itself as a alternative fuels as an renewable energy source such as nontoxicity, high biodegradability, low sulphur and aromatics content [5]. Production of biodiesel can be produced using both vegetable and animal oils. Recently, 95% of biodiesel production dominates as a raw material. However, Its starting to be diminishing due to a significant 80% of production are only allocated to raw materials [6].

The oil from Black Soldier Fly Larvae (BSFL) can be utilized as an animal oil source to replace vegetable oil in biodiesel production. The development process of BSFL tends to be simple and cost-effective, and it is capable of reducing organic waste. Biodiesel production process using BSFL oil as a raw material, a catalyst is employed to assist in the processing. Biodiesel is produced through two processes, esterification and transesterification. However, it can also be produced by direct transesterification. The difference between the two processes is the type of catalyst used, esterification uses an acid catalyst while transesterification uses a base catalyst [5]. Research that has been carried out using the esterification process by adding 1% m/v H2SO4 catalyst and transesterification 2.5% m/v CaO catalyst produces a biodiesel yield of 93.08% [6]. The catalyst's impact on biodiesel production is evaluated with reference to the Decision of the Director General of New Renewable Energy and Energy Conservation Ministry of Energy and Mineral Resources Number 189/2019.

2 Materials and Methods

2.1 Lipid Extraction from Black Soldier Fly Larvae (BSFL)

The extraction of Black Soldier Fly Larvae (BSFL) is carried out to obtain crude oil that can be used to produce biodiesel. The prepupal stage of BSFL is deactivated at a temperature of 105˚C for 2 days using oven. The dried BSFL is then finely ground into powder. BSFL powder was placed on filter paper and liquid-liquid extraction was carried out using n-hexane solution in a soxhlet system at a temperature of 65°C for 2 hours. N-hexane has alike polarity as BSFL oil, therefor resulting higher yield during the extraction process [7]. After the extraction, BSFL oil and the solution are segregated using rotary evaporator.

2.2 Acid-catalyzed esterification

The crude oil from BSFL contains Free Fatty Acid (FFA), which can disrupt the methyl ester formation process [8]. Acid-catalyzed esterification is used to convert FFA as a pre-treatment process for biodiesel production. 3% (w/w) H_2SO_4 is dissolved in methanol in round bottom flask, with a methanol-to-oil ratio of 6:1. H_2SO_4 catalyst, dissolved in methanol, is mixed with the extracted oil. The mixture of oil and solution is stirred using a magnetic stirrer at 300 rpm and heated to a temperature of 50˚C for 60 minutes using hot plate. The mixed solution is separated using a rotary evaporator at 105˚C 100 rpm to separate oil from solution. The separated oil and catalyst are centrifuged at 4500 rpm for 5 minutes to separate oil from glycerol as a byproduct. The upper layer, which is the oil, is collected for further processing.

2.3 Alkaline-catalyzed transesterification

Transesterification process of BSFL is carried out to convert triglycerides into Fatty Acid Methyl Ester (FAME) as a biodiesel with glycerol as a byproduct. Its converting oil into biodiesel with the assistance of a based catalyst. In this research, using two various homogenous and heterogenous based catalyst, KOH and CaO. The processing steps reacted involve dissolving 0.5% w/w of KOH and CaO in methanol in round bottom flask with the ratio methanol and oil 6:1. The catalyst dissolved in methanol then mixed with oil from esterification process. The mixture oil and solution is stirred using a magnetic stirrer at 400 rpm and heat at 60˚C for 60 minutes using a hot plate. After the mixing process, the oil-solution mixture is transferred to a separator funnel to segregate the upper layer, which contains a mixture of methanol, catalyst and glycerol. The upper layer obtained using a rotary evaporator at 105˚C, 100 rpm to separate biodiesel from remaining solvent. The oil then centrifuged at 4500 rpm for 5 minutes to separated oil from glycerol, which is a byproduct. The upper later, consisting of biodiesel, is washed three times with distilled water at 50˚C with the ratio biodiesel and distilled water 2:1.

3 Result and Discussion

3.1 The Ability of Black Soldier Fly Larvae (BSF) to Reduce Organic Waste

Based on the exiting literature, the study about BSFL can contribute to waste removal. The research was conducted in laboratory setting and utilized a group of 300 six-day-old larvae. The waste decomposition process by these BSFL was observed for 12 days period, focusing on the larva phase before their transition into prepupae stage. The findings detailing the efficiency of waste removal achieved by BSFL can be found in **Table 1.**

Table 1. Food Waste Removal by BSFL

Type of Waste	Food Waste
Feeding Frequency	Day 1, Day 4, and day 7
Percentage of Waste Removal	66,95%
Measurement Frequency	Day 1 and Day 12
Waste residue:BSFL: BSFL Metabolism	33:20:47
Initial Dry Larval Weight	0,5 mg
Final Dry Larval Weight	51,06 mg

BSFL can accomplish 66.95% reduction in food waste. They utilize food waste as primary source of nutrition, enabling a decrease in total waste volume. BSFL leaves 33% residual waste, 47% metabolism, and 20% BSFL weight [9].

3.2 Lipid Extraction

Extraction is the process of separating two or more compounds using a volatile solvent with a low boiling point and nearly identical polarity to the substance to be dissolved [10]. Oil in BSFL is more easily extracted when using non-polar solvents because same polarity characteristics. Therefore, the use of n-hexane in the extraction process can yield a higher amount of oil [7]. Furthermore, previous researchers have also used n-hexane as the solvent for BSFL extraction, as it was deemed more effective in extracting BSFL [11]. **Table 2** demonstrated the yield obtained in producing BSFL oil, which aligns with references indicating that the oil content in BSFL within the range of 30-40% of weight of BSFL powder used.

Table 2. Comparison of BSFL Powder Weight t Extracted Oil

BSFL Powder (g)	BSFL Oil (g)	BSFL Oil Yield (%)	BSFL Oil Content (% of BSFL Weight)
50	19.55	34.67	30-40 (Park, dkk., 2022)
50	18	32.01	
50	23	40.90	
50	21	37.34	
50	20	35.57	

(a) (b) (c)

Fig.1. BSFL Lipid Extraction

(a) Dry BSFL (b) Wet BSFL (c) BSFL Powder

Fig. 2. BSFL Oil

3.3 Production of Biodiesel

Esterification is a pre-treatment process that involves reacting the extracted oil and alcohol to form esters by converting the FFA present in triglycerides into methyl ester and water as a byproduct [12]. When FFA is greater that 2%, and react with base catalyst, will cause the saponification reaction. Thus, esterification is carried out to prevent failures in biodiesel production. The esterification process is aided by methanol as a solvent and acid catalyst [8]. Based on experiments using H_2SO_4 catalyst, the yield of biodiesel produced 86.38% ± 3.66. Esterification results in byproduct, which is glycerol with dark black color [13]. Based on the experiments, glycerol is produced as a byproduct.

Table 3. Yield of The Esterification Process

Type of Catalyst	BSFL Oil (g)	Catalyst Quantity (g)*	Esterified Oil (g)	Esterified Oil Yield (%)	Average Esterified Oil Yield (%)
H_2SO_4	60	1.8	49.32	82.2	86.38 ± 3.66
	60	1.8	53.42	89.0	
	60	1.8	52.75	89.2	

*3% w/w

Fig. 3. Esterification Result

(a) Esterified Oil (b) Glycerol

Transesterification is conducted using two variations of homogeneous (KOH) and heterogeneous (CaO) base catalysts. Based on the type of catalyst used, both catalysts yield biodiesel above 90% w/w. Transesterification with KOH catalyst results in a yield of 92.71 ± 2.55, while with CaO catalyst, it's 90.64 ± 4.42. The use of homogeneous and heterogeneous base catalyst variations is employed to investigate the impact of these different catalyst types. In the experiments, KOH is the homogeneous base catalyst, while CaO is the heterogeneous base catalyst. Based on the conducted experiments, the biodiesel yield from using KOH base catalyst is higher than that from using CaO base catalyst. This aligns with the literature study stating that homogeneous catalysts can yield high values in a short reaction time [13]. However, the use of homogeneous catalysts has disadvantages as they are challenging to separate from the solvent and cannot be reused after the reaction. On the other hand, the use of heterogeneous catalysts is considered more advantageous as they are easy to separate from the solvent and can be reused effectively for subsequent processes, with a catalyst usage efficiency of over 70% after three uses [14].

Table 4. The Influence of Catalyst Variations on Biodiesel Yield

Type of Catalyst	Oil (g)	Catalyst Quantity (g)*	Biodiesel (g)	Biodiesel Yield (%)	Average Biodiesel Yield (%)
KOH	60	0.3	57.18	95.30	92.71 ± 2.55
	60	0.3	54.12	90.20	
	60	0.3	55.57	92.63	
CaO	60	0.3	57.3	95.5	90.64 ± 4.42
	60	0.3	52.11	89.6	
	60	0.3	53.76	86.84	

0,5% w/w

(a) (b) (c)

Fig. 4. Physical Comparison of Biodiesel BSFL and Biosolar

(a) KOH Catalyst Biodiesel (b) CaO Catalyst Biodiesel (c) Biosolar B30

3.4 Characteristic of Biodiesel

Table 5. Comparison of FAME Composition in Biodiesel Using KOH and CaO Catalysts

Fatty Acids	KOH Catalyst for Biodesel (%)	CaO Catalyst for Biodesel (%)
Butyric acid	-	0,17
Capric acid	1,21	1,69
Lauric acid	22,45	37,23
Lauroleic acid	0,21	0,21
Myristic acid	7,11	4,57
Pentadecylic acid	-	0,11
Palmitic acid	47,14	8,31
Arachidonic acid	0,48	1,59
Heptadecanoic acid	0,21	1,17
Heptadecenoic acid	2,87	-
Stearic acid	7,86	-
Oleic acid	2,78	6,96
Elaidic acid	-	2,51
Linolenic acid	0,26	-
Eicosenoic acid	2,12	-
Eicosapentaenoic acid	0,29	-
Total FAME	**97.89**	**64.52**

Based on the GC-MS testing conducted, the compound content in biodiesel with KOH catalyst variation contains 97.89% methyl ester or FAME. Referring to the quality standards, the FAME content percentage should be greater than 96.5% (Ministry of Energy and Mineral Resources, 2019). Therefore, biodiesel with KOH catalyst variation complies with the quality standards for FAME content. The fatty acids with high values in KOH-catalyzed biodiesel are palmitic acid C16:0 at 47.14%, lauric acid C12:0 at 22.45%, and stearic acid C18:0 at 7.86%.

The biodiesel with CaO catalyst variation contains only 64.52% Fatty Acid Methyl Ester (FAME). This figure does not meet the quality standard for FAME content, which should be higher than 96.5% [15]. Lauric acid C12:0 dominates the FAME content in biodiesel with CaO catalyst variation, accounting for 37.23%, followed by palmitic acid C16:0 at 8.31%, and oleic acid C18:1 at 6.96%. The percentage of FAME content below the quality standard is due to the presence of substances other than FAME, such as residual catalyst, solvent, and glycerol still present in the biodiesel. This can occur because the biodiesel washing process is not yet optimal [16].

Table 6. Properties of Biodiesel

Properties	SK EBTKE 189/2019	Units	Biodiesel Katalis KOH	Biodiesel Katalis CaO
Density	850-890	Kg/m^3	851.69±0.55	883.85±1.71
Viscosity Kinematic 40°C	2.3-6.0	cSt	3.23±0.02	18.15±0.003

Calorific Value	>35	Mj/Kg	38.71	38.15
Carbon Residue	0.05	%, m/m	0.014	0
Methyl Ester	96.5	%	97.89	64.52

3.4.1 Density

Density or mass density is one of the crucial parameters in fuel. This is because the mass density of fuel can determine the type of combustion reaction that occurs. A mass density that complies with the biodiesel quality standard can facilitate perfect combustion reactions, while biodiesel with a mass density exceeding the standard may result in incomplete combustion reactions [17]. Incomplete combustion can lead to the emission of hydrocarbon (HC) exhaust gases. This can occur because some of the fuel has not had a chance to burn and is emitted in the form of hydrocarbons along with other combustion byproducts [18]. Hydrocarbons produced from incomplete combustion can lead to the formation of smoke or smog [19]. Based on the production of KOH and CaO-catalyzed biodiesel, the density contained in biodiesel complies with the SK Dirjen EBTKE No. 189/2019. Therefore, KOH and CaO-catalyzed biodiesel will result in perfect combustion reactions when considering the density parameter.

3.4.2 Viscosity

Viscosity is one of the characteristic parameters of biodiesel that describes its fluidity. Based on the experiments conducted, the viscosity of biodiesel with KOH catalyst variation meets the quality standard of SK Dirjen EBTKE No. 189/2019 with a range of values between 2.3-6.0 cSt. However, the viscosity of biodiesel with CaO catalyst variation does not meet the quality standard. From the experiments conducted, the transesterification process of biodiesel with CaO catalyst variation does not produce byproducts such as glycerol. This is the reason for the high viscosity in CaO-catalyzed biodiesel [20]. Additionally, the low ratio of oil to methanol molar ratio is another factor, leading to suboptimal reaction conditions. Methanol with the appropriate ratio can dissolve the oil and activate the carbon bonds in the oil, reducing its viscosity and boiling point [21]

3.4.3 Calorific Value

The calorific value of a fuel, in this case, biodiesel, is a parameter indicating the amount of energy available within it. The calorific value is directly proportional to the energy produced. The higher the calorific value, the more energy is released, and vice versa. A low calorific value results in increased fuel consumption to deliver the same amount of energy [22]. Based on the literature study, biodiesel made from castor oil has a calorific value of 36.180 MJ/kg. In contrast, the calorific values contained in KOH and CaO-catalyzed biodiesel have higher values.

3.4.4 Carbon Residue

Carbon residue in biodiesel can be determined through Thermogravimetric Analysis (TGA) testing. TGA is a thermal analysis technique used to determine the remaining mass of a test sample at specific temperatures and times [23]. According to the tests, KOH-catalyzed biodiesel has a carbon residue value of 0.014%, while CaO-catalyzed biodiesel has 0%. Both of these values comply with the quality standard, which is below 0.05% by mass, as specified in the

Decision of the Director General of New and Renewable Energy and Energy Conservation of the Ministry of Energy and Mineral Resources No. 189 2019.

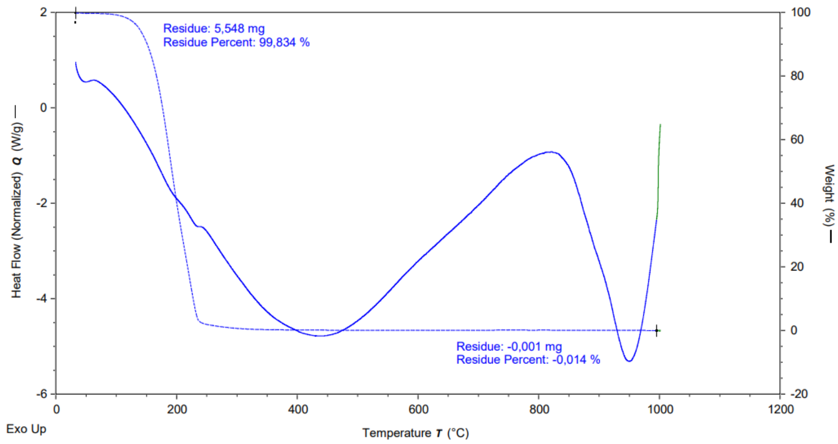

Fig. 5. Thermogravimetric Analysis (TGA) Test Results of B100 with KOH Catalyst

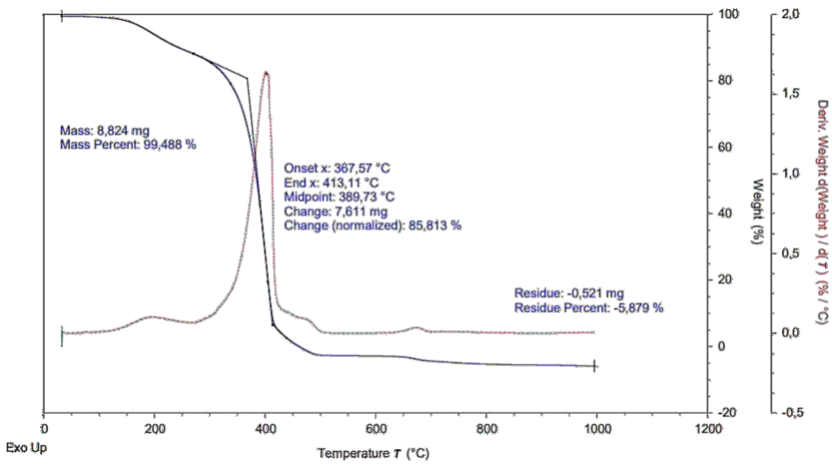

Fig. 6. Thermogravimetric Analysis (TGA) Test Results of B100 with CaO Catalyst

4 Conclusion

The conclusion drawn from the research is that it contains lipids that can be utilized as raw materials for biodiesel production. The biodiesel yield obtained from Black Soldier Fly Larvae (BSFL) oil with KOH and CaO base catalyst variations is 92.71% and 90.64%, respectively. Furthermore, the Fatty Acid Methyl Ester (FAME) composition in biodiesel produced from BSFL oil with KOH catalyst variation is 97.89%, while the biodiesel composition with CaO base catalyst variation is 64.52%. Biodiesel with KOH and CaO catalyst variations has a density of 851.693 kg/m³ and 883.852 kg/m³, respectively. Additionally, the kinematic viscosity of biodiesel with KOH and CaO catalyst variations is 3.235 cSt and 18.151 cSt, respectively. The calorific values for both biodiesel variations are 38.708 MJ/kg and 38.116 MJ/kg. Biodiesel with KOH catalyst variation has a carbon residue value of 0.014%, while there is no carbon residue in biodiesel with CaO catalyst variation.

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