RESEARCH ARTICLE

The quality improvement of *Jatropha* biodiesel blend with palm biodiesel

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***Jatropha* and palm oils serve as potential raw materials for biodiesel with the potential to be commercially competitive. While palm biodiesel has been used in blends with diesel fuel, *Jatropha* has not yet been widely utilized due to its high viscosity. The properties of these oils including density, viscosity, and heating value are significantly influenced by their fatty acid compositions. To improve biodiesel quality, this research investigated the effects of blending *Jatropha* and palm oils at various ratios on the biodiesel properties. The results showed that blending *Jatropha* and palm biodiesels led to a reduction in viscosity by up to 20% and an increase in calorific value by approximately 5%. These findings had important implications for both the scientific and industrial communities in the biodiesel sector and provided valuable insights for sustainable energy sources.**

Keywords: biodiesel properties; biodiesel blends; fatty acids; *Jatropha*; palm.

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Introduction

Technological development and population growth have increased the demand for energy, even as fossil fuel reserves deplete [1]. This depletion, while a significant concern, is just one facet of a broader energy dilemma. Increasing global awareness of the environmental consequences of conventional energy production such as greenhouse gas emissions and air pollution has accelerated the search for alternative energy sources. Transitioning to greener energy alternatives like biodiesel is crucial for addressing both the energy crisis and environmental degradation [2]. Biodiesel, a renewable substitute for conventional diesel, has garnered significant attention. It not only offers a pathway to lessen reliance on fossil fuels but also has the potential to ameliorate environmental issues linked to conventional fuel usage. One advantage of biodiesel is its adaptability to diverse raw materials, enabling various regions to utilize local resources for production [1]. Different geographic regions boast varying raw materials suitable for biodiesel production [3]. For instance, *Jatropha*, a non-edible plant, thrives in regions like Central and South America, Southeast Asia, India, and Africa [4]. The plant is highly adaptable, growing well even in challenging soil conditions [5]. Palm oil, on the other hand, is an edible biodiesel feedstock with high oil content, primarily produced in Southeast Asia [6].

Previous studies have explored the use of both *Jatropha* and palm oil as biodiesel raw materials. Research by El Araby *et al*. focused on palm biodiesel and its physical properties [7], while the work of Reddy *et al*. investigated the effects of fatty acid content in *Jatropha* biodiesel on fuel properties [8]. Another study by Kaisan *et al*. confirmed that *Jatropha* oil was a reliable and renewable source for biodiesel that met American Society for Testing and Materials, (ASTM) standards for various fuel properties [9]. However, most research has concentrated on these feedstocks individually, neglecting the potential benefits of their combined use. For example, Sarin *et al*. confirmed that blending *Jatropha* and palm biodiesels could optimize antioxidant requirements as each complemented the other's limitations [10]. Despite many advantages, the relatively high viscosity of biodiesel poses a significant challenge. High viscosity affects the fuel's ability to flow and impacts droplet size and the narrowness of the injection angle, thereby influencing engine performance. One way to mitigate this problem is to blend palm biodiesel with conventional diesel fuel, although this is seen as a temporary solution until biodiesel can assume a more dominant role in the market. In most biodiesel-diesel blends, the percentage of diesel fuel still tends to be higher. A drawback of *Jatropha* oil is its high viscosity. Current applications indicate that *Jatropha* biodiesel excels in low-temperature properties but suffers from poor oxidation stability, whereas palm biodiesel shows the opposite traits. The blending of these oils could be a promising strategy to address the critical issue of viscosity in biodiesel quality.

Improving biodiesel properties could enhance its commercial viability. Each type of biodiesel feedstock has unique fatty acid structures, which significantly influence fuel properties [11]. One commonly used strategy to improve these properties involves modifying fatty acid content [12]. This study aimed to explore the impact of blending *Jatropha* and palm oils based on their differing fatty acid structures on the physical properties of biodiesel, particularly viscosity. The findings of this study could offer valuable insights into boosting biodiesel production and its competitiveness in the energy market.

Materials and methods

Oil resources and properties

Jatropha oil obtained from Tekun Jaya, Yogyakarta, Indonesia and palm oil obtained from CV. M&H Farm, Bogor, Indonesia were employed as raw materials for this study. The properties of each oil are listed in Table 1.

Table 1. Properties of *Jatropha* oil and palm oil.

Properties	Jatropha oil	Palm oil
Density, 40^{o}C (kg/m^3)	937.74	862.65
Viscosity, 40^{o}C (cSt)	193.55	46.60
Flash point (^{o}C)	311.60	305.30
Calorific value (MJ/kg)	37.19	39.34

Biodiesel production

Jatropha and palm oils were mixed at different ratios with the first mixture comprised 900 mL of *Jatropha* oil and 100 mL of palm oil, resulting in a total of 1,000 mL of 90%:10% mixed oil. Blending was conducted by stirring the mixture for 60 minutes at 90°C using mixers equipped with temperature control. The same procedure was applied to prepare the different ratio mixtures of *Jatropha*-to-palm oil at 80%:20%, 70%:30%, 60%:40%, 50%:50%, 40%:60%, 30%:70%, 20%:80%, and 10%:90%, respectively. Biodiesel production was carried out in several stages including esterification, transesterification, washing, and drying. Given that *Jatropha* oil has free fatty acids exceeding 1%, esterification was performed to reduce this percentage and to prevent saponification. Esterification was achieved by reacting each *Jatropha* and palm oil mixture with 20% methanol (v/v) with 1% H_2SO_4 (v/v) as an acid catalyst. The reaction was stirred at 60°C for 60 minutes. The transesterification was carried out in a temperature-controlled reactor at 60 °C for 60 minutes. Each mixture was reacted with 20% methanol (v/v) using 1% KOH (w/v) as a catalyst to produce methyl esters and glycerol. Following the separation, the biodiesel was subjected to a washing and drying process. It was washed three times by using 15 mL of hot water and then dried at 105°C for 15 minutes.

Fatty acid and physical property measurements of biodiesel

Each sample underwent evaluation to analyze its fatty acid composition, flash point, viscosity, density, and calorific value. Density was determined by measuring the mass and volume (50 mL) of the sample at 40°C by using Fujitsu FS-AR210 digital scales (Fujitsu, Tokyo, Japan). Viscosity was measured by using an NDj 8S Viscometer (Drawell, Chongqing, Sichuan, China) with 800 mL of each sample at 40°C in a beaker. The rotor type and rotational speed were adjusted to predict the sample's viscosity accurately. The fatty acid composition was determined by using Shimadzu 2010 Gas Chromatography (GC) (Shimadzu, Kyoto, Japan). Briefly, 0.5 mL of sample and 1.5 mL of methanolic sodium solution were heated at 70°C for approximately 5-10 minutes. After cooling, 2 mL of Boron trifluoride methanoate was injected and the sample was heated again at 70°C for an additional 5-10 minutes. The sample was then cooled and extracted by using 1 mL each of heptane and saturated NaCl. The top layer was collected into an Eppendorf tube, and 1 µL was injected into the GC for analysis. The calorific value was assessed in accordance with ASTM (D 240-02). The heat of combustion was determined by subjecting samples to a Parr 6050 Oxygen Bomb Calorimeter (Parr Instrument Company, Moline, IL, USA). Flash points were measured by using the Cleveland Open Cup method. Each experiment was repeated three times.

Results and discussion

Fatty acid composition

Each type of vegetable oil has a unique fatty acid composition. Table 2 displayed the compositions of *Jatropha* biodiesel, palm biodiesel, and their various blends. The primary constituents of fatty acids in *Jatropha* oil included linolelaidic acid methyl ester (C18:2) and methyl palmitate (C16:0). Linolelaidic acid methyl ester was a polyunsaturated fatty acid with two double bonds, while methyl palmitate was a saturated fatty acid. The fatty acid composition of palm oil was relatively evenly distributed, although a larger proportion comprised Cis-9-oleic methyl ester (C18:1) and methyl linoleate (C18:2). The results showed that the fatty acids in each biodiesel blend could be categorized into saturated, monounsaturated, and polyunsaturated types [13], which were shown in Figure 1. In biodiesel blends containing 60% to 100% *Jatropha*, saturated and polyunsaturated fatty acids were more dominant than monounsaturated acids. Conversely, in blends containing 70% to 100% palm biodiesel, the proportion of monounsaturated fatty acids was higher than polyunsaturated fatty acids.

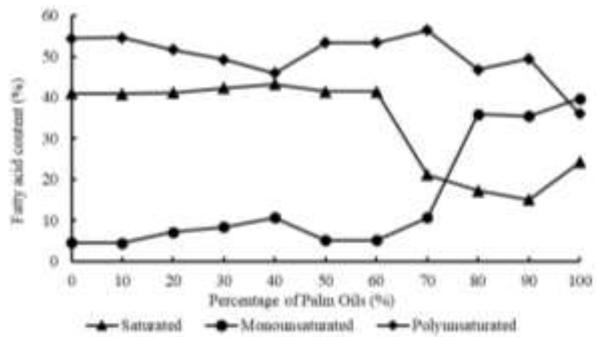

Figure 1. Fatty acids compositions based on the unsaturation level.

Density

Density is a crucial physical property used to calculate the precise volume of fuel needed for adequate combustion [14]. In oil blending, density is influenced by the degree of unsaturation with the higher the degree of unsaturation in the oil, the greater its density [11]. As shown in Figure 1, blends with a higher percentage of *Jatropha* biodiesel contained more polyunsaturated fatty acids. Blends dominated by *Jatropha* oil had higher levels of both saturated and polyunsaturated fatty acids. Polyunsaturated and saturated fatty acids are relatively more polar than monounsaturated fatty acids [15]. Fatty acids with greater polarity exhibit stronger intermolecular forces, resulting in higher density for the oil. Table 2 demonstrated that *Jatropha* oil had a high percentage of linolelaidic acid methyl ester that

Table 2. Fatty acids composition in a blending of *Jatropha* and palm biodiesel.

Molecular Formula	Abbreviation	Percentage of Palm Oils (%)										
		0	10	20	30	40	50	60	70	80	90	100
$C_5H_{10}O_2$	C4:0	1.02	1.22	1.93	2.64	2.96	7.97	7.97	6.32	8.91	-	3.33
$C_{17}H_{34}O_2$	C16:0	39.08	38.76	35.82	33.26	27.97	32.86	32.86	14.60	8.18	1.49	7.97
$C_{19}H_{38}O_2$	C18:0	-	-	2.58	5.64	11.86	-	-	-	-	0.31	-
$C_{19}H_{36}O_2$	C18:1	3.96	3.83	6.30	7.71	10.07	4.29	4.29	13.04	5.78	9.08	5.96
$C_{19}H_{36}O_2$	C18:1	-	-	-	-	-	-	-	33.86	29.21	21.04	22.17
$C_{19}H_{34}O_2$	C18:2	44.04	43.97	41.17	39.08	36.51	39.74	39.74	8.80	12.19	18.41	10.16
$C_{19}H_{34}O_2$	C18:2	10.24	10.55	10.26	9.99	9.14	13.32	13.32	22.39	34.01	30.57	23.74
$C_{19}H_{32}O_2$	C18:3	-	-	-	-	-	-	-	-	-	-	1.78
$C_{21}H_{42}O_2$	C20:0	-	-	-	-	-	-	-	-	-	13.23	12.79
$C_{21}H_{40}O_2$	C20:1	0.47	0.48	0.54	0.53	0.50	0.70	0.70	0.34	1.00	5.38	11.63

possessed a long and relatively straight carbon chain, causing the molecules in *Jatropha* biodiesel to be denser. In contrast, palm oil predominantly contained Cis-9-oleic methyl ester and methyl linoleate. The biodiesel blends with a higher percentage of *Jatropha* oil exhibited greater density values (Figure 2).

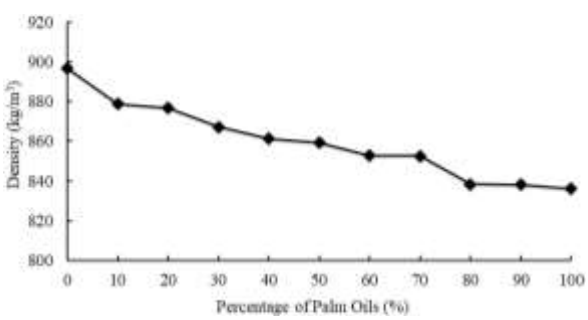

Figure 2. Biodiesel density of *Jatropha* and palm oil mixture.

Viscosity

Viscosity measures a liquid's resistance to flow and significantly influences fuel injection behavior [16]. Generally, higher viscosity hampers fuel extraction [17], resulting in larger droplets, slower evaporation, and narrower injection spray angles [18]. These factors contribute to inefficient combustion and elevated emissions. Viscosity is affected by the degree of fatty acid unsaturation. Reduced levels of unsaturation lead to increased viscosity [19]. *Jatropha* biodiesel, which was rich in saturated fatty acids, exhibited higher viscosity. In contrast, palm oil was predominantly monounsaturated and therefore had lower viscosity. Linolelaidic acid methyl ester, a long and relatively straight-chain fatty acid, had stronger intermolecular forces, which made *Jatropha* biodiesel more viscous than that of palm biodiesel dominated by Cis-9-oleic methyl ester and methyl linoleate. Polar polyunsaturated and saturated fatty acids generated stronger intermolecular forces [15], contributing to higher viscosity in biodiesel blends with a greater percentage of *Jatropha* oil. The viscosity of biodiesel blends decreased as the percentage of palm biodiesel increased (Figure 3). Incorporating up to 40% palm biodiesel reduced the blend's viscosity by up to 50%. The higher levels of palm biodiesel enabled a reduction in viscosity of up to 20%.

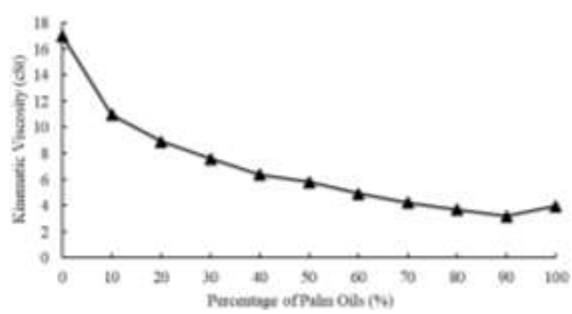

Figure 3. Biodiesel viscosity of *Jatropha* and palm blending.

Heating Value

One of the key parameters for fuel selection is the heating value, which represents the amount of thermal energy released during the combustion of a specific quantity of fuel [8]. Figure 4 showed that the heating value of the biodiesel blend increased with the percentage of palm oil. Specifically, palm biodiesel contained fatty acids with carbon chains that were, on average, longer than those in *Jatropha* biodiesel. The fatty acid methyl esters in palm biodiesel often contained 18 carbon atoms, whereas those in *Jatropha* biodiesel were primarily linolelaidic acid methyl esters (C18:2) and methyl palmitate (C16:0) (Table 2). For this reason, palm biodiesel possessed a higher heating value [19].

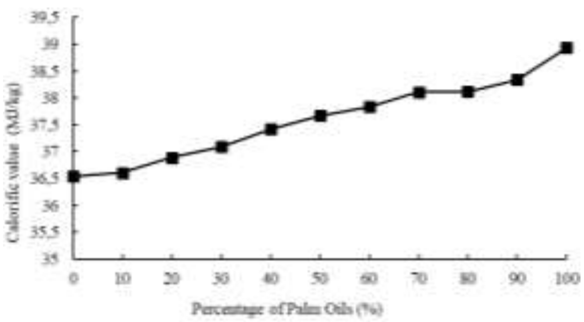

Figure 4. Biodiesel heating value of *Jatropha* and palm blending.

Flash Point

The flash point is the minimum temperature at which a fuel emits sufficient vapor to ignite. It indicates the fuel's volatility and flammability, being inversely proportional to its volatility. A low flash point is a critical consideration for diesel engines, as they don't have external ignition assistance. However, fuels with low flash points are hazardous during storage, handling, and transportation due to an elevated risk of fire. Biodiesel, having a higher flash point, minimizes this fire hazard [20]. The flash point of *Jatropha*-palm biodiesel blends decreased as the percentage of palm biodiesel increased (Figure 5). This trend could be attributed to the rising levels of unsaturated fatty acids in the blended biodiesel, along with a decrease in long-chain fatty acids. This finding aligned with research by Carareto *et al*., which stated that the flash point value of biodiesel was influenced by the length and degree of unsaturation of its fatty acids [21].

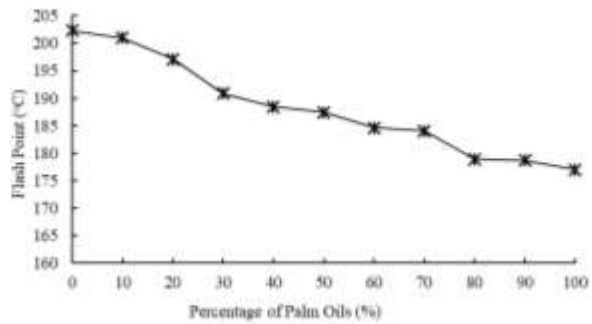

Figure 5. Biodiesel flash point of *Jatropha* and palm blending.

Conclusion

This study investigated the effects of blending *Jatropha* and palm oils at various ratios on the resulting biodiesel's key properties. *Jatropha* oil was found to be high in saturated fatty acids, specifically linolelaidic acid methyl ester and methyl palmitate. On the other hand, palm oil was enriched in monounsaturated fatty acids, predominantly Cis-9-Oleic methyl ester and methyl linoleate. Blending these oils resulted in a change in fatty acid composition, which, in turn, significantly impacted various properties of the biodiesel produced including its viscosity, density, heating value, and flash point. The study found that a blend ratio of 40% palm biodiesel to 60% *Jatropha* biodiesel yielded the most balanced biodiesel properties in terms of density, viscosity, and calorific value. Overall, blending had shown to positively influence the fuel characteristics, notably reduce viscosity, and increase the heating value, while also cause fluctuations in density and flash point values. The research indicated that strategic blending of *Jatropha* and palm biodiesels could optimize desired fuel properties.

References

1. Gopal KN. 2014. Investigation of emissions and combustion characteristics of a CI engine fueled with waste cooking oil methyl ester and diesel blends. Alex Eng J. 53:281–287.
2. Eloka-Eboka AC, Igbum GO, Inambao FL. 2017. Biodiesel methyl ester production and testing from selected African tropical seed oil feedstocks. Energy Procedia 142:755–767.

3. Crabbe E, Nolasco-Hipolito C, Kobayashi G, Sonomoto K, Ishizaki A. 2001. Biodiesel production from crude palm oil and evaluation of butanol extraction and fuel properties. Process Biochem. 37:65–71.
4. Koh MY. 2011. A review of biodiesel production from *Jatropha curcas* L. oil. Renew Sust Energ Rev. 15:2240–2251.
5. Kamel DA, Farag HA, Amin NK, Zatout AA, Ali RM. 2018. Smart utilization of jatropha (*Jatropha curcas Linnaeus*) seeds for biodiesel production: Optimization and mechanism. Ind Crops Prod. 111:407–413.
6. Ong HC. 2011. Comparison of palm oil, Jatropha curcas and Calophyllum inophyllum for biodiesel: A review. Renew Sust Energ Rev. 15:3501–3515.
7. El-Araby R, Amin A, El Morsi AK, El-Ibiari NN, El-Diwani GI. 2018. Study on the characteristics of palm oil–biodiesel–diesel fuel blend. Egypt J Pet. 27:187–194.
8. Reddy ANR, Saleh AA, Islam MS, Hamdan S, Rahman MR, Masjuki HH. 2018. Experimental evaluation of fatty acid composition influence on Jatropha biodiesel physicochemical properties. J Renew Sust Energ. 10:1–20.
9. Kaisan MU, Abubakar S, Ashok B, Balasubramanian D, Narayan S, Grujic I, *et al*. 2018. Comparative analyses of biodiesel produced from jatropha and neem seed oil using a gas chromatography–mass spectroscopy technique. Biofuels. 12:1–12.
10. Sarin R, Sharma M, Sinharay S, Malhotra RK. 2007. *Jatropha*–Palm biodiesel blends: An optimum mix for Asia. Fuel. 86:1365–1371.
11. Hoekman SK, Broch A, Robbins C, Ceniceros E, Natarajan M. 2012. Review of biodiesel composition, properties, and specifications. Renew Sust Energ Rev. 16:143–169.
12. Siddique BM, Ahmad A, Ibrahim MH, Hena S, Rafatullah M. 2010. Physico-chemical properties of blends of palm olein with other vegetable oils. Grasas y Aceites. 61:423–429.
13. Ramos MJ, Fernández CM, Casas A, Rodríguez L, Pérez Á. 2009. Influence of fatty acid composition of raw materials on biodiesel properties. Bioresour Technol. 100:261–268.
14. Silitonga AS, Masjuki HH, Mahlia TMI, Ong HC, Chong WT, Boosroh MH. 2013. Overview properties of biodiesel diesel blends from edible and non-edible feedstock. Renew Sust Energ Rev. 22:346–360.
15. Marlina E, Wijayanti W, Yuliati L, Wardana ING. 2020. The role of pole and molecular geometry of fatty acids in vegetable oils droplet on ignition and boiling characteristics. Renew Energ. 145:596–603.
16. Knothe G, Steidley KR. 2005. Kinematic viscosity of biodiesel fuel components and related compounds. Influence of compound structure and comparison to petrodiesel fuel components. Fuel. 84:1059–1065.
17. Haşimoğlu C, Ciniviz M, Özsert İ, İçingür Y, Parlak A, Sahir Salman M. 2008. Performance characteristics of a low heat rejection diesel engine operating with biodiesel. Renew Energ. 33:1709–1715.
18. Agarwal D, Agarwal AK. 2007. Performance and emissions characteristics of Jatropha oil (preheated and blends) in a direct injection compression ignition engine. Appl Therm Eng. 27:2314–2323.
19. Martínez G, Sánchez N, Encinar JM, González JF. 2014. Fuel properties of biodiesel from vegetable oils and oil mixtures. Influence of methyl esters distribution. Biomass Bioenergy. 63:22–32.
20. Acharya N, Nanda P, Panda S, Acharya S. 2019. A comparative study of stability characteristics of mahua and jatropha biodiesel and their blends. J King Saud Univ Engineering Sci. 31:184–190.
21. Carareto ND, Kimura CY, Oliveira EC, Costa MC, Meirelles AJ. 2012. Flash points of mixtures containing ethyl esters or ethylic biodiesel and ethanol. Fuel. 96:319–326.