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Comparative Assessment of Biodiesel Production and Properties from Waste Cooking Liquor, Olive Oil, and Mustard Oil through Transesterification Process

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ABSTRACT

This study presents a comparative experimental analysis of biodiesel production from waste cooking oil (WCO), mustard oil, and olive oil using a potassium hydroxide–methanol transesterification process. The objective was to evaluate how feedstock type influences biodiesel quality and compliance with ASTM D6751 standards. Key properties—density, kinematic viscosity, flash point, and calorific value—were measured and compared with conventional diesel fuel. Among the samples, mustard oil biodiesel showed the most balanced characteristics, with viscosity (4.81 cSt) and calorific value (42 MJ/kg) aligning with ASTM standards. WCO biodiesel exhibited the highest flash point (155 °C), ensuring safer storage, while olive oil biodiesel showed higher energy content (41.22 MJ/kg) but lower flash point (65 °C), suggesting incomplete transesterification. By performing a comparison of edible, non-edible, and waste oils under identical reaction conditions, this work establishes a clear relationship between feedstock composition and biodiesel quality. The results provide practical insight for selecting cost-effective, sustainable feedstocks suitable for biodiesel production in Bangladesh and similar developing regions.

Keywords: Transesterification process, Biodiesel, Waste Cooking Oil, Olive Oil, Mustard Oil

1. Introduction

The recent world-energy crisis and environmental decline has suggested the acute tendency of using long-term and green substitutes of the old fossil fuels. The growing reliance on non-renewable resources such as mostly coal, oil and natural gas has led to alarming levels of greenhouse gas emissions, environmental destruction and depletion of the resources [1]. With the emergence of industrialization, urbanization and digital technologies, rapidly turning the contemporary society into a place of a higher energy expenditure, the disparity between energy demand and supply is only going to grow [2]. This scenario demands some new solution to energy that should provide not only the security as to the long-term delivery but also minimize the ecological footprint. One of the most widespread sustainable strategies attracting significant interest is bio-based technologies that have the capability of generating clean energy, minimize carbon emissions, and ensure the creation of circular economies [3]. Categories of bio-derived materials and fuels, including the bio-diesel, bio-ethanol, bio-gas, and also the lignocellulosic biomass, can provide chances in easing eradicating the energy crisis and concerns of climate change [4,5]. The growing popularity of these bio-based resources on the basis of their sustainability as well as their low environmental impact, and the fact that they can be prepared using a wide variety of organic feedstocks, are contributing to their growing popularity. These characteristics of biofuels such as ethanol, methanol, biodiesel and biogas become alternative to fossil fuels due to their renewability, biodegradability and non-toxicity. These fuels are generated based on a biomass like the waste generated by agriculture and algae, so such fuels have lesser emissions, they boost the economy of rural areas, and enhance rational utilization of energy [7]. Biodiesel**,** in particular, has emerged as a renewable and environmentally friendly substitute for petroleum diesel. Produced through a chemical reaction between alcohol and triglycerides found in vegetable oils, animal fats, or waste oils, biodiesel is recognized globally as a cleaner alternative to fossil fuels due to its low sulfur content, high biodegradability, and significant reduction in greenhouse gas emissions—up to 50–85% lower than conventional diesel [8]. Its high flash point also enhances safety during storage and transportation. Large-scale biodiesel adoption can therefore reduce fossil fuel dependence and mitigate climate change [9].

Biodiesel is typically produced through the transesterification of triglycerides present in vegetable oils or animal fats, resulting in fatty acid methyl esters (FAME) suitable for combustion engines. While edible oils like soybean or palm oil have traditionally been used, concerns over food security and resource competition have shifted attention toward non-edible and waste-derived feedstocks [10]. Waste cooking oil (WCO), for example, offers both environmental and economic benefits, reducing disposal issues while providing a low-cost raw material [11]. In contrast, oils such as olive oil and mustard oil, though relatively costlier, can yield biodiesel with favorable fuel properties due to their unique fatty acid compositions. Despite promising scenarios, the variation in fuel properties based on feedstock type carriages challenges for biodiesel standardization and engine compatibility. Parameters such as density, viscosity, flash point, and calorific value strongly influence combustion performance, emission characteristics, and overall fuel safety. Hence, understanding how different feedstocks affect these properties is essential for ensuring efficient and reliable biodiesel use [12] While WCO is abundant and cost-effective, it often contains impurities like water and free fatty acids. Mustard oil, containing erucic

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acid, enhances cold flow properties, and olive oil provides high oxidative stability, yet both remain underexplored in terms of commercial-scale biodiesel production [13, 14].
This study aims to evaluate and compare the production and fuel properties of biodiesel synthesized from waste cooking oil, fresh mustard oil, and fresh olive oil using a potassium hydroxide–methanol transesterification process. The resulting biodiesel samples were analyzed for density, kinematic viscosity, flash point, and calorific value in accordance with the ASTM D6751 standard to determine their suitability for diesel engine applications. The experimental design maintains identical reaction conditions across all feedstocks, enabling a direct comparison of their performance. The importance of this work lies in its comprehensive, side-by-side assessment of three locally available feedstocks—representing waste, edible, and non-edible oil sources. By conducting the entire transesterification process under identical conditions, this study provides clear experimental insight into how feedstock composition influences biodiesel quality. The findings not only fill a regional knowledge gap but also offer practical guidance for developing cost-effective and sustainable biofuel strategies in Bangladesh and similar developing economies.

2. Materials and Methodology

2.1 Materials & Instruments Used

In the present work, three types of oils were utilized as feedstocks to make biodiesel: waste cooking oil (WCO), fresh mustard oil, and fresh olive oil. The WCO was collected from a local restaurant nearby the experimental plant, and the mustard and olive oils were bought in a local market in Khulna city, Bangladesh. Methanol was used as the reagent alcohol, and potassium hydroxide (KOH) was used as the transesterification reaction catalyst. The laboratory experiments were conducted using standard laboratory equipment, including beakers, thermometers, a digital balance, and a rotary evaporator, among other equipment necessary.

2.2 Experimental Procedure

The production of biodiesel from waste cooking oil (WCO), olive oil, and mustard oil was carried out using the transesterification process as shown in Fig.1. The procedure consisted of three main steps: preparation of the catalyst mixture, execution of the transesterification reaction, and separation of the resulting biodiesel. Initially, 200 mL of each oil sample was preheated in a beaker to approximately 65 °C to reduce its viscosity and improve reaction kinetics. Concurrently, the catalyst solution was prepared by dissolving potassium hydroxide (KOH) pellets in 150 mL of methanol, forming potassium methoxide, which served as the catalyst for the transesterification reaction as suggested by alamu et al [15]. The prepared methanol–KOH mixture was then added to the preheated oil, and the resulting oil–alcohol mixture was subjected to continuous stirring and heating using a magnetic stirrer with a hot plate. The reaction was maintained at a steady temperature just below 70 °C for a duration of 30 minutes to ensure effective conversion. Following the completion of the reaction, the mixture was transferred to a separating funnel and allowed to stand undisturbed at room temperature for 24 hours to facilitate phase separation. This settling process resulted in two distinct layers: the upper layer containing biodiesel and the lower layer comprising glycerin and residual catalyst. The biodiesel was carefully decanted and collected in a clean, dry container for subsequent analysis. The entire procedure was uniformly applied to all three feedstocks—WCO, olive oil, and mustard oil under identical conditions to ensure the consistency and comparability of the experimental results.

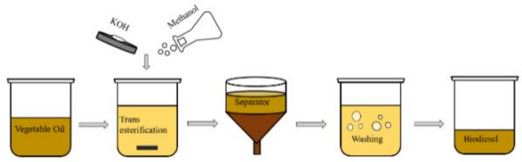

Fig.1: Transesterification Procedure for Biodiesel Production

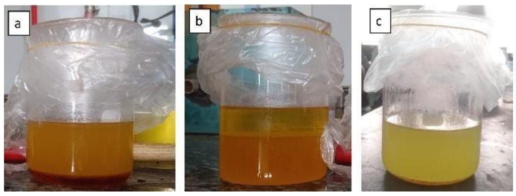

Fig.2: Biodiesel Production from (a) Waste Cooking Oil (WCO) (b) Fresh Mustard Oil (c) Fresh Olive Oil

2.3 Product Analysis Procedure

To evaluate the quality, performance, and applicability of biodiesel derived from waste cooking oil, mustard oil, and olive oil, many essential physico-chemical parameters were analysed according to established procedures. The analysed characteristics encompass density, kinematic viscosity, flash point, and calorific value, which are essential indicators of fuel performance in combustion systems. The density and kinematic viscosity of the biodiesel samples were manually evaluated at ambient temperature utilising conventional laboratory glassware and calibrated tools. Density signifies the fuel's compactness and energy content, whereas viscosity denotes its fluidity and atomization efficiency which is crucial for diesel engine performance. The flash point, defined as the lowest temperature at which fuel vapours burn briefly in the presence of an ignition source, was determined using the Pensky-Martens closed cup apparatus (AIM 509). This feature is crucial for establishing the safe handling and storage temperature of biodiesel. A GDY-1C Oxygen Bomb Calorimeter was utilised to ascertain the calorific value, which measures the total energy released during the complete burning of the fuel. This research offers insights into the energy efficiency and combustion characteristics of each biodiesel sample. All assessments were performed under regulated conditions to guarantee precision and uniformity. The results were subsequently compared to ASTM D6751 biodiesel standards and conventional diesel characteristics to assess the viability of these bio-derived fuels as alternatives to diesel.

3. Results and Discussion

The quality of biodiesel is primarily determined by its physicochemical properties, including density, flash point, calorific (heating) value and viscosity. In this study, the biodiesel samples produced from waste cooking oil, fresh mustard oil, and fresh olive oil were characterized based on these essential parameters. The measured values were then compared with the standard specifications for commercial diesel fuel, as outlined in ASTM D6751, to assess their suitability for engine use. A summary of the results and comparative analysis is presented in Table 1.

Table 1: Comparison of Physicochemical Properties of Biodiesel Derived from Studied Samples with Conventional Diesel Fuel

Properties	Olive Oil	Waste Cooking Oil	Mustard Oil	Biodiesel Standard ASTM D6751
Density (Kg/m^3)	860.3	960	904	880
Kinematic Viscosity (cSt)	31.19	30.48	4.81	1.9-6
Flash Point (°C)	65	155	123	130
Calorific Value (MJ/Kg)	41.22	40.76	42	37-41

The density of biodiesel significantly influences the fuel injection quantity and combustion characteristics. The highest density was observed in biodiesel derived from waste cooking oil (960 kg/m³), followed by mustard oil (904 kg/m³), and olive oil (860.3 kg/m³). Both WCO and mustard oil biodiesels exceeded the ASTM D6751 maximum limit of 880 kg/m³, while olive oil biodiesel fell within the acceptable diesel range (820–860 kg/m³). Although higher density may deliver more energy per injection, it can negatively affect atomization and engine performance in systems not designed for dense fuels. On the other hand, viscosities of olive oil and WCO biodiesels were quite high, at 31.19 cSt and 30.48 cSt, which is much higher than the ASTM range of 1.9 to 6 cSt. These high readings mean that transesterification wasn't finished or that there was still oil that hadn't reacted. This can lead to bad spray patterns, incomplete combustion, and engine deposits. With a viscosity of 4.81 cSt, mustard oil biodiesel was well within the parameters set by ASTM and regular diesel, which means it is better for engines.

Furthermore, Flash point is a critical safety parameter indicating the temperature at which fuel vapors ignite. WCO biodiesel exhibited the highest flash point (155 °C), ensuring safe handling and storage. Mustard oil biodiesel had a flash point of 123 °C, slightly below the ASTM threshold of 130 °C but still acceptable for general use. In contrast, olive oil biodiesel showed a low flash point of 65 °C, below the ASTM standard, suggesting the presence of residual alcohol or volatiles, which may increase fire hazards during storage and handling.

Moreover, Calorific value reflects the energy content of fuel. Mustard oil biodiesel showed the highest value (42 MJ/kg), comparable to that of conventional diesel (42–46 MJ/kg), indicating strong performance potential. Olive oil (41.22 MJ/kg) and WCO biodiesel (40.76 MJ/kg) were slightly lower but still competitive. All three samples approached or exceeded the lower ASTM limit (37 MJ/kg), confirming their viability as energy-dense alternatives.

Table 2: Comparison of properties of biofuel derived through transesterification with conventional diesel, and other biofuel sources

Properties	Diesel	Mango seed kernel oil [5]	Current study		
			Olive oil	Waste cooking oil	Mustard oil
Density (Kg/m^3)	820 to 860	778.8	860.3	960	904
Kinematic Viscosity (cSt)	2 to 4.5	1.74	31.19	30.48	4.81
Flash Point (°C)	50 to 95	70	65	155	123
Calorific Value (MJ/Kg)	42 to 46	22	41.22	40.76	42

Among the three biodiesel samples, mustard oil biodiesel showed the most balanced and engine-compatible properties. It met the required viscosity standard and exhibited a high energy content, making it suitable for efficient combustion. Although its density and flash point slightly deviated from the standard, they were still within acceptable operational limits. The table compares the key fuel properties of diesel with various vegetable oils, including mango seed kernel oil (current study), olive oil, waste cooking oil, and mustard oil. In contrast, biodiesels from olive oil and waste cooking oil displayed significantly high viscosities, indicating incomplete transesterification. These can lead to poor atomization and combustion problems in engines. The flash point of olive oil biodiesel was also notably low, suggesting the presence of residual volatiles, which poses safety concerns. Overall, while all three samples are viable as alternative fuels, mustard oil biodiesel stands out as the most suitable for direct use in engines without further treatment.

4. Conclusion

This study conducted a comparative experimental analysis of biodiesel derived from waste cooking oil, mustard oil, and olive oil via a KOH–methanol transesterification process, focusing on the impact of feedstock variation on key fuel properties. Measurements of density, viscosity, flash point, and calorific value revealed distinct performance trends among the samples.

Among the three feedstocks, mustard oil biodiesel showed the most favorable balance between efficiency and engine compatibility, with viscosity (4.81 cSt) and calorific value (42 MJ/kg) meeting ASTM D6751 standards. Waste cooking oil biodiesel, though characterized by higher viscosity and density, showed an exceptionally high flash point (155 °C)—a valuable trait for storage and handling safety. Olive oil biodiesel offered high calorific value (41.22 MJ/kg) but fell short in flash point and viscosity, signaling incomplete transesterification. The scientific value-added of this work lies in its controlled, feedstock-specific experimental comparison, which isolates the influence of raw material composition on biodiesel quality—something rarely addressed in prior studies. The results not only confirm the technical feasibility of converting low-cost waste oils into usable biodiesel but also identify mustard oil as a regionally accessible and high-performing candidate for blending or direct engine application. The novelty of this study is demonstrated through its uniform reaction framework applied to three oil types of differing origins (edible, non-edible, and waste), allowing a direct performance hierarchy to be established based on experimental data rather than literature estimations. This provides a scientific benchmark for future biodiesel research in feedstock selection, optimization, and process standardization.

Furthermore, the study holds strong practical importance for developing nations like Bangladesh, where abundant waste cooking oil and mustard oil resources can be used to reduce fuel imports, minimize environmental pollution, and promote circular energy practices. Future research should extend these findings through engine performance testing, emission profiling, and techno-economic evaluation to support industrial-scale implementation.

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