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Sustainable Biodiesel Production from Waste Cooking Oil: A Green Path from Grease to Fuel

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Abstract: The environmental impact of improper waste cooking oil (WCO) disposal can be substantial, resulting in serious implications such as soil contamination, water pollution, energy wastage, and increased greenhouse gas emissions. To mitigate these potential impacts, the conversion of WCO into biodiesel offers an attractive alternative to fossil fuel dependency. This investigation focuses on biodiesel production via transesterification reactions, utilizing WCO collected from local food vendors. Biodiesel yield from Gino, Kings, and Mamador WCO were found to range from 55.5 to 58.1%, 55.1 to 53.9%, and 53.7 to 52.6%, respectively. Furthermore, the specific gravities of the produced biodiesel from Gino, Kings, and Mamador WCO ranged between 0.725-0.75, 0.73-0.84, and 0.71-0.80, respectively. Acid values varied from 0.51-0.52 KOH/g for Gino WCO, 0.50-0.57 KOH/g for Kings WCO, and 0.50-0.57 KOH/g for Mamador WCO. Cetane numbers were observed to range from 45.82-46.25 min for Gino WCO, 46.2-46.45 min for Kings WCO, and 46.0-46.25 min for Mamador WCO. Finally, the flashpoints ranged between 135-138°C for Gino WCO, 137-140°C for Kings WCO, and 137-138°C for Mamador WCO, while cloud points hovered between 4.82-5.02°C. Significantly, all physicochemical properties of the resulting biodiesel were found to be within ASTM recommended parameters, highlighting the potential of WCO as a valuable resource for sustainable biodiesel production.

Keywords: Waste cooking oil; Biodiesel production; Feedstock; Fossil fuel; Biofuel

1 Introduction

The prevailing environmental shifts and burgeoning global population have resulted in a significant surge in energy consumption [1, 2]. This heightened demand for energy, historically met by the utilization of fossil fuels, has given rise to concerns of fossil fuel exhaustion and consequent environmental repercussions, including global climate change [3, 4]. Due to the finite supply of fossil fuels, the mounting demand for energy has spurred an investigation into alternative energy sources that are viable from an economic, social, and environmental standpoint [5].

A substantial increase in the demand for transportation fuel has been observed, and projections indicate this trend is likely to persist [6]. Indeed, the surge in global automobile production and the expanding needs of emerging economies are set to exacerbate this demand further. Fossil fuels have been the traditional choice to fulfill this growing need for transportation fuel [7]. However, the finite availability of these resources, the projected cost escalation, and the negative environmental implications associated with their usage have necessitated the exploration of sustainable transportation fuels [7].

Biofuels emerge as a compelling alternative to fossil fuels given their renewable nature, affordability in comparison to fossil fuels, lower environmental impact, and ease of distribution and usage, considering the existing infrastructure and technology [8]. Estimates predict a rise in global fossil fuel consumption due to transportation, with a peak annual rate of 1.4% by 2029, potentially leading to a daily demand increase from approximately 13.6 billion liters in 2006 to over 18.5 billion liters [8, 9].

A significant barrier to the commercialization of biodiesel is its higher cost compared to petroleum-based diesel. It is estimated that the cost of raw materials contributes to between 70% and 85% of the total biodiesel production cost [10, 11]. Waste cooking oil (WCO) presents an affordable feedstock for biodiesel production, potentially bringing its cost on par with petroleum fuel [12, 13]. A considerable volume of waste lipids is generated daily on a global scale by restaurants, the food industry, and fast-food establishments [14, 15]. Over-reliance on edible oils can lead to severe problems, including scarcity in economically disadvantaged countries. However, the adoption of low-cost feedstocks such as animal fats, WCO, and microalgae could reduce the overall cost of biodiesel. This study aims to assess the feasibility and abundance of WCO as a potential feedstock for biodiesel production, explore and optimize the biodiesel production process, and compare the properties of the resulting biodiesel with international standards.

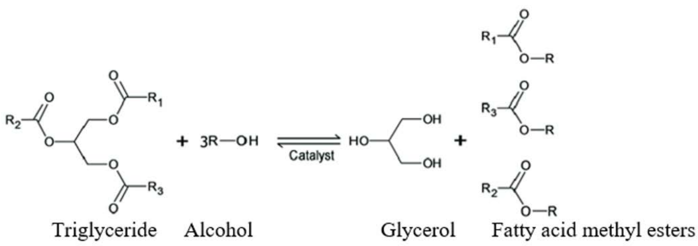
2 Materials and Methods

2.1 Sample Collection and Preparation

The primary feedstock, waste cooking oil (WCO), was sourced from three local food vendors proximal to the Federal University of Technology Akure (FUTA), Ondo state, Nigeria. The collected WCO was classified according to the origin of collection into Gino waste cooking oil (GWCO), Kings waste cooking oil (KWCO), and Mamador waste cooking oil (MWCO). To ensure the integrity of the collected samples, they were meticulously preserved from moisture and stored in a laboratory setting for future analysis. Subsequently, the oil was maintained in a freezer, facilitating subsequent physicochemical analyses [16]. All samples underwent examination in accordance with the official methods of analysis outlined by the Association of Official Analytical Chemist [17], with every test performed in triplicate.

2.2 Production and Analysis of Biodiesel

Biodiesel production was carried out using transesterification reaction as shown in Figure 1. Precisely 100 mL of WCO was procured and heated to a temperature of 60℃, facilitated by a magnetic stirrer. Temperature control was ensured using a laboratory-specific hot plate, with temperature verification through a laboratory thermometer. Catalysts comprising NaOH, KOH, and a combination of NaOH/KOH, weighing 2.0 g, were measured and dissolved in 25 mL of methanol [18]. The resultant methoxide solution was then introduced to the heated WCO and stirred continuously for a period of one hour. Post-reaction, the solution was allowed to revert to room temperature, after which it was transferred to a separating funnel, resulting in a clear demarcation of two distinct phases. To wash the biodiesel, 20 mL of ethyl acetate was added to the upper phase, followed by four portions of 20 mL double distilled water to eliminate residual impurities. The purified biodiesel was subsequently labeled and stored, with its analysis conducted according to the official methods of analysis as stipulated by the Association of Official Analytical Chemist [17] and the produced biodiesel was compared with American Society for Testing Materials (ASTM) standard as illustrated in Table 1.



R_1, R_2, R_3 = Hydrocarbon chain ranging from 15 to 21 carbon atoms

Figure 1. Transesterification reaction

Table 1. Transesterification reaction

Parameters	ASTM Standard
Specific Gravity	0.95 max
Viscosity	1.90 to 6.00
Acid value $\mathrm{mgKOH/g}$	0.60
Cetane Number	46 to 52
Flashpoint ($^{\circ}\mathrm{C}$)	130 min
Cloud point ($^{\circ}\mathrm{C}$)	4.80 to 5.30
Water by distillation ($\%$)	0.5 max
Ash content ($\%$)	0.1 max

2.3 Statistical Analysis

Replicate analyses were performed in triplicate to ascertain experimental reproducibility, with findings reported as Mean ± Standard Deviation. The procured data were subjected to one-way analysis of variance (ANOVA) employing SPSS version 20. Significant mean differences were determined using Duncan's multiple range test at a significance level (α) of 0.05.

3 Results and Discussion

3.1 Physicochemical Analysis of Waste Cooking Oil

The subsequent physicochemical analyses of the waste cooking oil (WCO) samples are elucidated in Table 2.

Table 2. Physicochemical analysis of waste cooking oil samples

Test	GWCO	KWCO	MWCO
pH	$6.30^a \pm 0.10$	$6.60^a \pm 0.50$	$6.80^a \pm 0.30$
Specific Gravity	$0.90^a \pm 0.06$	$0.88^a \pm 0.05$	$0.86^a \pm 0.07$
Refractive Index	$1.35^a \pm 0.06$	$1.45^a \pm 0.2$	$1.46^a \pm 0.12$
Viscosity	$4.23^a \pm 0.58$	$3.54^b \pm 0.23$	$3.50^b \pm 0.21$
Flash Point	$136^a \pm 6.02$	$133^a \pm 7.37$	$123^a \pm 5.13$
Free Fatty Acid	$4.77^a \pm 0.32$	$4.54^a \pm 0.18$	$4.65^a \pm 0.29$
Saponification value (mg KOH/g)	$171^a \pm 6.03$	$167^a \pm 8.74$	$172^a \pm 5.00$
Iodine Value (mg I/g)	$31.7^a \pm 3.51$	$31.33^a \pm 3.50$	$28.3^a \pm 4.00$

Number of replicates = 3; Mean ± Standard Deviation; Mean with different superscript across rows are significantly different at (P>0.05). Gino waste cooking oil (GWCO), Kings waste cooking oil (KWCO), Mamador waste cooking oil (MWCO)

The pH readings displayed variations with GWCO, KWCO, and MWCO recording 6.30, 6.60, and 6.80 respectively. It was observed that MWCO bore the closest resemblance to the neutral pH of 7.0. Interestingly, the pH values obtained were within the permissible range for edibility, indicating the adequacy of these WCO samples for consumption. The differences in the pH readings among GWCO, KWCO, and MWCO may be attributed to disparities in the production processes and ingredient mix ratios of the utilized oil brands.

In the investigation of specific gravity, it was discerned that GWCO exhibited a higher S.G of 0.90 compared to KWCO's 0.88 and MWCO's 0.86. These values bore a resemblance to the S.G of 0.89 from alkaline treated WCO reported by the study [19] and were slightly higher than the 0.84 recorded for oil extracted from sawdust [11]. The significance of specific gravity lies in its widespread application in the international trade of edible oils (ASTM D6751-09), with acceptable ranges typically between 0.86 and 0.93. A potential correlation was identified between the specific gravity of the utilized WCOs and their pH, with specific gravity seemingly decreasing with pH increments. The specific gravity, or relative density, is indicative of the density ratio of the liquid to water at 40℃, which directly affects the object's buoyancy in water or air.

The refractive index readings demonstrated MWCO having the highest value of 1.46, followed by KWCO's 1.45, and GWCO's 1.35. These findings aligned with earlier reports by the study [20] for waste frying oil, and the study [21] for *luffa cylindrica* seed oil. Interestingly, the refractive index serves as an indicator for potential oil rancidity, with an increased likelihood of oxidative deterioration corresponding to increased refractive index values. GWCO was found to possess the greatest viscosity (4.23), followed by KWCO (3.54), and MWCO (3.50). Despite these observations, all values remained significantly lower than the 52.89 reported by the study [20] for waste frying oil. These variations in viscosity could be attributed to different production processes and ingredient ratios. A trend was identified where viscosity increased as refractive index decreased. Notably, viscosity, indicative of oil's flow at a specific temperature, is crucial as it determines the effectiveness and strength of oil's friction-reducing coat.

Furthermore, it was established that GWCO exhibited the highest flashpoint of 136℃, followed by KWCO's 133℃, and MWCO's 123℃. These flashpoints, vital safety parameters, determine the lowest temperature and atmospheric pressure under which a vapor-air mixture can ignite in an enclosed space.

In the examination of Free Fatty Acid (FFA) values, GWCO was found to possess the highest FFA (4.77), followed by MWCO's 4.65, and KWCO's 4.54. These values were lower than the 5.12 reported by the study [20] for waste frying oil. These disparities in FFA could be a result of variances in production procedures, ingredient mixing ratios, and duration of oil brand usage.

Further, the saponification value for MWCO (172 mg KOH/g) was higher than that of GWCO (171 mg KOH/g) and KWCO (167 mg KOH/g), but closely aligned with the 174 reported by the study [19] for waste frying oil. These values were also notably higher than the 168 mg KOH/g reported by the study [21] for *luffa cylindrica* seed oil. This value is essentially indicative of the average molecular mass of all the fatty acids contained within the material in the form of triglycerides.

Lastly, the iodine value results exhibited GWCO having the highest value (31.70 mg I/g), followed by KWCO's 31.33 mg I/g and MWCO's 28.30 mg I/g. Interestingly, there were no significant differences in the iodine values of the three WCO samples. Notably, the iodine value serves as an estimate of the unsaturated nature of wax, fat, or oil.

3.2 Physicochemical Analysis of Biodiesel

The physicochemical properties of biodiesel, as revealed by the data displayed in Figures 2 to 8, demonstrated that the biodiesel yield from GWCO varied between 55.5% and 58.1%. The highest yield was noted in the case of $GWCO_{NaOH/KOH}$, while the lowest yield was associated with $GWCO_{NaOH}$. Yields from KWCO and MWCO biodiesel production were found to fluctuate within the range of 55.1% to 53.9% and 53.7% to 52.6%, respectively. It was discerned that the utilization of a 1:1 ratio of NaOH and KOH as a catalyst enhances biodiesel production, surpassing the yields achieved by using NaOH and KOH separately. This observation was noteworthy, as it showed an improvement over previous research.

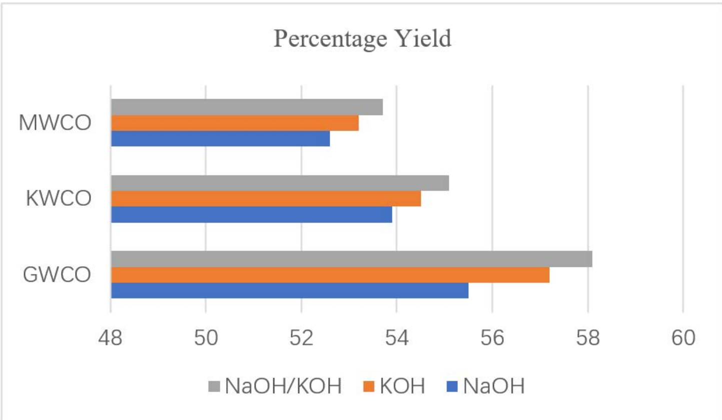


Figure 2. Percentage yield of biodiesel

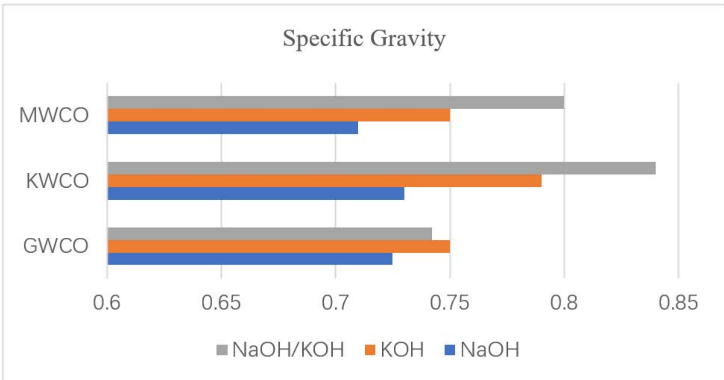


Figure 3. Specific gravity of biodiesel

An examination of the specific gravity of the biodiesel revealed varying results, depending on the oil used. For GWCO-derived biodiesel, the specific gravity ranged from 0.725 to 0.75, with the highest being linked to $GWCO_{KOH}$ and the lowest to $GWCO_{NaOH}$. In contrast, biodiesel derived from KWCO showed a specific gravity ranging from 0.73 to 0.84, and from MWCO, it ranged between 0.71 and 0.80. The recorded specific gravity was within the ASTM standard of 0.95 maximum, providing a comparative measure of floating capability in air or water. This result represented a decrease compared to the 0.91 reported by the study [22].

Viscosity, a parameter indicative of a material's resistance to flow, was another assessed characteristic. It ranged from 2.71 to 2.95 for GWCO biodiesel, from 2.53 to 2.92 for KWCO biodiesel, and from 2.45 to 2.61 for MWCO biodiesel. The recorded viscosities fell within the ASTM standard range (1.90 to 6.00), corroborating the findings of the study [22] and emphasizing the significance of viscosity for proper functioning of various engine parts.

Furthermore, the acid value, a measure related to the degree of rancidity, exhibited a range from 0.51 KOH/g to 0.52 KOH/g for GWCO biodiesel, from 0.50 KOH/g to 0.57 KOH/g for KWCO biodiesel, and from 0.50 KOH/g to 0.57 KOH/g for MWCO biodiesel. These values, within the acceptable limit as per the ASTM standard (0.6 KOH/g max), indicated a considerable variation from the 1.3 KOH/g reported by the study [19] for alkaline-treated waste cooking oil biodiesel. This observation is critical as higher acid values could potentially result in engine corrosion and fuel degradation.

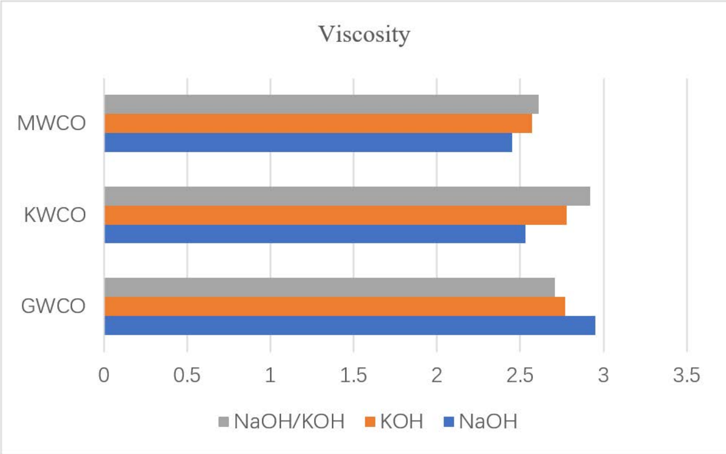


Figure 4. Viscosity of biodiesel

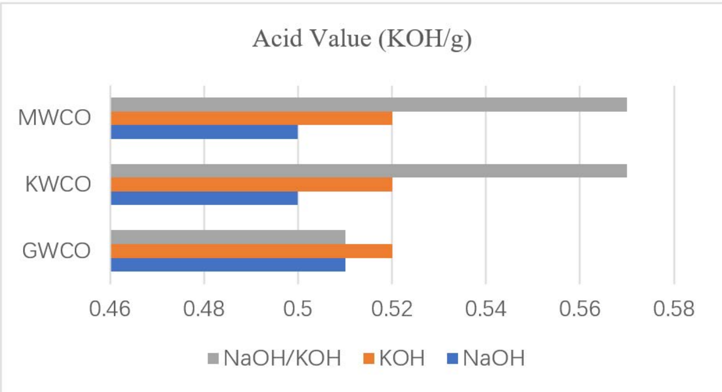


Figure 5. Acid value of biodiesel

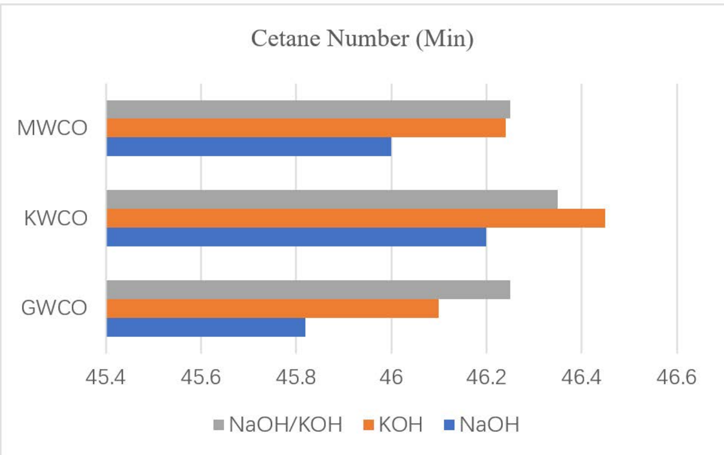


Figure 6. Cetane number of biodiesel

Cetane number, an indicator of the fuel's ignition quality, exhibited a range from 45.82 min to 46.25 min for GWCO biodiesel, from 46.2 min to 46.45 min for KWCO biodiesel, and from 46.0 min to 46.25 min for

MWCO biodiesel. This parameter's observed values fell within the ASTM standard range (46-52), underscoring the importance of cetane number in ensuring efficient combustion, particularly in high-speed diesel engines.

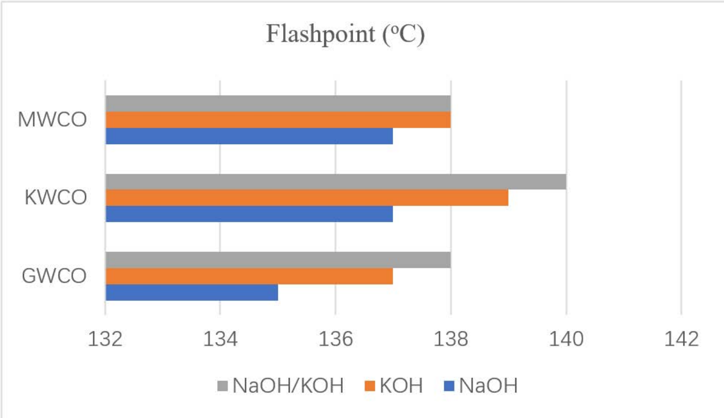


Figure 7. Flashpoint of biodiesel

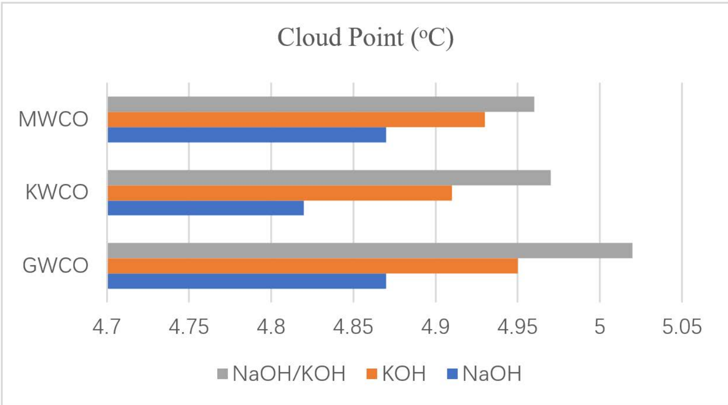


Figure 8. Cloud point of biodiesel

The flashpoint, or the lowest temperature at which vapors above a volatile combustible substance ignite, was found to range from 135°C to 138°C for GWCO biodiesel, from 137°C to 140°C for KWCO biodiesel, and from 137°C to 138°C for MWCO biodiesel. These values were lower than 174.15°C, reported by the study [19] for biodiesel from alkaline-treated waste cooking oil, and in close proximity to 145°C reported by the study [21] for *luffa cylindrica* seed oil biodiesel. Nonetheless, the observed flashpoints satisfied the ASTM minimum standard of 130°C.

The cloud point, referring to the temperature below which wax forms, giving the fuel a cloudy appearance, was observed to range from 4.87°C to 5.02°C for GWCO biodiesel, from 4.82°C to 4.97°C for KWCO biodiesel, and from 4.87°C to 4.96°C for MWCO biodiesel. These values, within the ASTM standard range (4.80°C to 5.30°C), were slightly lower than the 6°C reported by the study [21] for *luffa cylindrica* seed oil biodiesel, highlighting its importance for engine performance as solidified waxes can lead to filter clogs.

Lastly, no evidence was found regarding the presence of distilled water or ash content in the biodiesel. This finding is in agreement with the ASTM standard range, thereby confirming the absence of water, which could potentially degrade the performance of the engine. Furthermore, the absence of ash content, the inorganic residue left over from oil burning, also meets the ASTM standard, further verifying the physicochemical properties of the biodiesel produced.

4 Conclusion

The environmentally favorable attributes of biodiesel production from waste cooking oil (WCO), coupled with potential economic implications, are undeniable. The collection and subsequent repurposing of WCO into biodiesel negates the otherwise environmentally deleterious effects of improper disposal, such as pollution in terrestrial and aquatic ecosystems [23, 24]. This transition contributes significantly towards effective waste management, mitigating adverse environmental consequences. Furthermore, a net reduction in greenhouse gas emissions is achieved when comparing biodiesel from WCO to traditional fossil fuels. During combustion, the released carbon dioxide is balanced by the quantity absorbed during the production of the oil-bearing plants, fostering a more harmonious carbon cycle. Biodegradability is an added advantage of WCO-derived biodiesel, with its decomposition in the event of spills or leaks occurring with considerably less environmental impact than conventional diesel. A noteworthy economic advantage is observed in the sourcing of feedstock for biodiesel production, as waste cooking oil, typically considered a disposal problem, may serve as a low-cost or even cost-neutral raw material, significantly reducing the overall production expenditure.

Investigations within this study have shown that the physicochemical parameters of biodiesel obtained via transesterification of WCO using catalysts NaOH, KOH, and a combination thereof, reside comfortably within the ranges recommended by ASTM, indicative of high-quality fuel production. Thus, it is suggested that WCO represents a valuable and underutilized feedstock for biodiesel production. Its conversion into biodiesel has been identified as a promising research and development domain.

However, prospective investigations ought to prioritize the discovery and optimization of novel enzymatic or microbial systems capable of efficient and higher yielding biodiesel production from WCO. The use of nanocatalysts could greatly enhance the efficacy of the transesterification process, enabling faster reaction times and the possibility to utilize lower quality feedstock. The development of integrated systems capable of directly processing WCO at the site of food establishments may revolutionize the collection, conversion, and distribution of biodiesel, rendering the overall process more economically feasible and ecologically responsible.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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