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Biodiesel Production from Waste Chicken Fat Oil Using a KOH-Activated Chicken Bone Catalyst

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Abstract **Original Research Article**

Variability of feedstock and inefficiency of catalysts are usually limiting factors in the sustainable production of biodiesel using waste resources. In the present study, the strategy of same-source waste valorization was applied whereby the waste chicken fat oil was treated as the biodiesel feedstock and the waste chicken bones were subjected to controlled calcination (400-1000ºC) and potassium hydroxide (KOH) activation to obtain a heterogeneous base catalyst. Physicochemical examination of the chicken fat oil indicated high kinematic viscosity (49.49mm^{2}s^{-1} at 40ºC), middle free fatty acid level (1.96%), low moisture level (0.079%), low peroxide value (5.63 meqkg^{-1}), and high fraction of the esterifiable, which confirmed that it is suitable in heterogeneous base-catalyzed transesterification. Fourier-transform infrared (FTIR) analysis of the feedstock confirmed the presence of typical triglyceride functional groups, strong ester carbonyl (C=O) and aliphatic C-H stretching vibrations which are characteristic of a high esterifiable lipid fraction. The GC-MS analysis also revealed that the chicken fat oil was mainly composed of saturated and monounsaturated fatty acids with palmitic and oleic acids as the prominent components, which are desirable in the biodiesel production and ignition properties. The biodiesel yield, improvement of fuel properties, and reproducibility of the processes were used to evaluate the performance of catalysts. The temperature of calcification had a strong impact on catalytic activity, and 800ºC was the best temperature to ensure the balanced basicity of the surface and structural stability, and the activation of the catalyst using KOH further increased catalytic activity. A batch reactor experiment showed that the highest biodiesel yield (>80%) was obtained at a catalyst concentration of 1.0 wt%, methanol-to-oil molar ratio of 12:1, reaction temperature of 60ºC, reaction time of 2h, and agitation rate of 400 rpm. The biodiesel produced had a kinematic viscosity of 7.5-8.9 mm^2 s^{-1}, a specific gravity of 0.874-0.887, a flash point of 160-181ºC, and cetane index of more than 52 which showed good ignition quality. Upon purification, the fuel properties were observed to be near to the specifications of ASTM D6751 and EN 14214. In general, the findings indicate that the calcined and KOH-activated chicken bone waste is an efficient, inexpensive heterogeneous catalyst in the production of biodiesel out of waste chicken fat oil, which will contribute to the creation of the circular biofuel and reduce the amount of waste.

Keywords: Calcination, KOH activation, Chicken bones catalyst, Chicken fat oil, Transesterification and Biodiesel Production.

1. Introduction

The worldwide move toward the abandonment of fossil-based fuels has increased the effort in the exploration of renewable and low-carbon energy sources that can help solve the energy security, mitigation of climate changes, and enhancement of air-quality in the vicinity (Toldra-Reig et al., 2020; Adewale et al., 2015). One of these options, that is, biodiesel made up of fatty acid alkyl esters, which are the products of transesterification of triglyceride-based feedstocks, has been a viable drop-in fuel to compression-ignition engines because of its biodegradability, elevated flash point, and desirable emission properties (Kirubakaran et al., 2018; Ayoola et al., 2020). Biodiesel in forms derived not only through waste-based oils but also through edible crops has lower life-cycle greenhouse gas emissions and food-fuel competition (Toldra-Reig et al., 2020). Nevertheless, it is limited regarding scalability of feedstock cost and efficiency of catalytic systems which can convert high-free-fatty-acid (FFA), variable-quality oils into fuel grade biodiesel (Adewale et al., 2015; Basumatary et al., 2023).

Heterogeneous base catalysts are considered to be the promising alternative to the homogeneous systems because of simplified separation, less wastewater generation, less corrosion, and reusability of the catalysts (Ooi et al., 2021; Hussain et al., 2021). CaO-type catalysts and especially calcium-based catalysts, which are highly basic, non-toxic, and available in natural and biogenic waste materials, are a subject of much research (Fayyazi et al., 2018; Ooi et al., 2021). Valorizing wastes rich in calcium, including shells and bones into useful catalysts is consistent with the principles of the circular economy in relation to the production of bio-diesel (Hussain et al., 2021; Basumatary et al., 2023).

Chicken bones waste is one of the largest portions of poultry waste, which is frequently discarded in the landfill source, resulting in odor nuisance, pathogen growth, and greenhouse gases (Tan et al., 2019). Chicken bones are also chemically abundant in the calcium phosphate minerals, mainly hydroxyapatite, which can be converted to catalytically active phases under heat treatment (Nisar et al., 2017). A number of studies have revealed that the transesterification reaction of low-cost feedstock can be successfully catalyzed using calcined bone-derived catalysts, producing biodiesel with high recovery and reusability (Tan et al., 2019).

Although these are merits, bone-derived catalysts can be characterized by low basic site density, blockage of pores, high temperature sintering and slow deactivation by carbonation or leaching, leading to unstable performance and poor scalability (Hussain et al., 2021). Moreover, the differences in the animal source, calcinations, and post-treatment procedures considerably affect the catalyst activity, which makes the reproducibility and the structure-activity relationship more complicated (Nisar et al., 2017; Basumatary et al., 2023). As a result, surface activation approaches that would facilitate improved basicity, accessibility of pores, and chemical stability have become a necessity (Hussain et al., 2021; Li et al., 2024).

Calcination is the major process in transforming the waste of chicken bones into catalytically useful substances by eliminating organic compounds and enhancing crystallinity (Nisar et al., 2017). Nevertheless, the calcination itself might not be effective to produce the strong and abundant basic sites needed to realize the high-rate transesterification in the conditions that are relevant to industry (Ooi et al., 2021). The alkali activation, especially potassium hydroxide (KOH) impregnation has been shown to increase surface basicity, methanol activation, and catalytic kinetics without altering heterogeneous catalyst properties (Changmai et al., 2020.)

In this work, the same-source waste valorization plan is suggested where the chicken fat oil is used as a biodiesel feedstock, and the chicken bone waste is transformed into a heterogeneous base catalyst, which completes the material loop in one stream of poultry-waste. The innovation is that a rational two-step calcination-KOH activation route is used and gradually increases the basicity of catalysts, pore accessibility, and deactivation resistance.

This study is focused on the development of a high-performance, reusable calcium-based heterogeneous catalyst using waste chicken bones and determining its effectiveness in the transesterification of chicken fat oil. The goals are to examine how the structure of catalysts can be affected by calcification and KOH activation, to determine biodiesel yield and quality of the fuels and to examine the stability and reusability of the catalysts.

2. Materials and Methods

2.1 Materials used and chemicals

Chemicals and reagents used were all of analytical grade and were used without additional purification. Methanol, ethanol, potassium hydroxide (KOH) sodium hydroxide (NaOH), all the chemicals were and indicator were purchased at May and Baker. The experiments were done in standard Pyrex laboratory glassware.

2.2 Preparation and Characterization of Feedstock.

The waste chicken fat was collected from Abakaliki International Market Ebonyi State, Nigeria. Wet rendering was done at 50^{o}C in about 25 min and filtration was done to eliminate solid residue and stored in an air tight plastic (Figure 1). Standard analytical procedures were used to extract the oil and measure its moisture content, free fatty acid (FFA), acid value, iodine value, peroxide value, saponification value, kinematic viscosity, specific gravity, refractive index, flash point, cloud point, pour point, smoke point, and boiling point as per ASTM D6751 guideline. FFA was determined by the use of acid value and the ester value and molecular weight were determined using saponification and acid values.

Figure 1: Extracted chicken fat oil

2.3. Preparation and Activation of Catalysts.

The chicken bones materials used were obtained from Roban Stores, Abakaliki and washed, dried in the sun, ground and sieved to a particle size that is less than 100 um (Figure 2). Calcination of the bone powder was done in a muffle furnace at 400, 600, 800 and 1000^{o}C over 4 h. In the case of alkaline activation, 2.5 N NaOH solution was used to reflux the selected calcined samples at 100^{o}C for 90 min. Solids were filtered, rinsed with distilled water and dried and re-calcined again in the same temperature range in limited access to air over 4 h. The catalysts were activated and ground to a fine powder and kept in airtight containers.

Figure 2: Raw, dried and ground chicken bones

The temperature was in line with peer-reviewed articles that found that thermal treatment of animal bones at temperatures ranging between 700-800^{o}C leads to the breakdown of organic matter and the formation of catalytically active CaO and calcium phosphate derivatives that can be used in the production of biodiesel transesterification reactions (Obadiah et al., 2012; Farooq et al., 2015). Bone-based catalysts made by the same procedures of poultry and other animals have been widely described to be sufficiently basic and active enough to catalyze the production of biodiesel with a range of different feedstocks (Smith et al., 2013; Nisar et al., 2017).

Even though more sophisticated methods of physicochemical characterization methods like XRD, SEM, BET, etc were not utilized in this study,the catalytic performance was assessed in terms of the performance parameters of the reaction such as the yield of biodiesel, the reproducibility of the experimental run, and the adherence of the resulting fuel to the specifications of ASTM D6751 and EN 14214 standards. This is a performance-based assessment method that is commonly used in waste-based CaO-based heterogeneous catalysts with functional catalytic activity and fuel standard compliance regarded as trustworthy metrics on the appropriateness of the catalyst to biodiesel generation.The functional approach of evaluation has become very common and justified in the literature of waste-based heterogeneous catalysts to produce biodiesel (Boro et al., 2012; Chouhan and Sarma, 2011; Birla et al., 2012).

2.4 Biodiesel Manufacturing through Transesterification.

Transesterification reactions were carried out in a three-neck round-bottom flask that had a reflux condenser and magnetic stirring. The prepared heterogeneous catalyst was reacted with moisture-free chicken fat oil (50mL) and methanol. According to the experimental design (Table 1), reaction temperature, catalyst loading, reaction time, molar ratio of methanol to oil, and the agitation speed were modified. The mixture was reacted upon and then transferred into a separating funnel and washed using warm distilled water followed by drying to yield biodiesel.

Table 1: Experimental Design

Factor	Units	Symbol	Coded Levels				
			-α	-1	0	+1	+α
Catalyst Dosage	w%	A	0.5	1.0	1.5	2.0	2.5
Reaction Temperature	^{o}C	B	30	40	50	60	70
Reaction Time	hr	C	1	2	3	4	5
Methanol/Oil Ratio	Mol/mol	D	6:1	8:1	10:1	12:1	14:1
Agitation	rpm	E	100	200	300	400	500

2.5 Evaluation of Design and Process parameters Experimental Design and Process.

The effects of the catalyst dosage, reaction temperature, reaction time, methanol to oil molar ratio, and agitation speed on biodiesel yield were studied using experimental design factor (Table 1). Individual parameter effects were also evaluated using one-factor-at-a-time analysis with other parameters being maintained at their central level.

3. Results and Discussion

3.1 Feedstock Suitability and Relevance of Transesterification.

Physicochemical characteristics of the chicken fat oil prove that it can be used as a biodiesel feedstock in heterogeneous base-catalyzed conditions. Long-chain saturated triglycerides dominate the viscosity ($49.49mm^2s^{-1}$ at 40^oC) which explains the high kinematic viscosity, so that transesterification to fatty acid methyl esters is necessary to obtain reasonable fuel-flow characteristics (Knothe, 2016).

Acidity, Moisture Content and Catalyst Compatibility.

The acid number of 3.93 $mgKOHg^{-1}$ (FFA of 1.96%) is moderate acidity in the range of toleration of alkali-activated calcium-based catalysts. The low moisture content (0.079%) reduces the presence of hydrolysis and the formation of soaps, which favors the heterogeneous catalysis (Adewale et al., 2015).

Oxidative stability and degree of unsaturated.

This indicates how readily the compound can be oxidized by oxygen or other substances (Dixon, 2008, par. 5). Oxidative Stability and Degree of Unsaturation: This is the measure of the ease at which the substance can be oxidized by oxygen or other substances (Knothe and Razon, 2017).

The peroxide value of 5.63 $meqkg^{-1}$ confirms low oxidative degradation, whereas the iodine value of 27.29 gI^2 100 g^{-1} confirms low unsaturation, preferring oxidative degradation and better ignition quality (Atabani et al., 2015).

The Esterifiable Fraction and Conversion Potential

The saponification value ($302.94mgKOHg^{-1}$) and value of ester (98.70) show that a big proportion of the components that may be esterified and the extent of conversion is large. The expression of the estimated molecular weight ($562.86gmol^{-1}$) is consistent with the poultry-fat triglycerides (Basumatary et al. 2023).

Moderate FFA content combined with low moisture and high esterifiable fraction are the characteristics that make chicken fat oil to be processed with the waste-based heterogeneous base catalysts, allowing a high degree of conversion and recycling of catalysts (Boey et al., 2017).

3.2. GC–MS Characterization of Waste Chicken Fat Oil

The analysis of waste chicken fat oil using GC-MS (Figure 3) indicated that the sample consists of the long-chain fatty acid components that are predominant as evidenced by mass spectra of the strongest chromatographic peaks. The mass spectrum of the most abundant peak at a retention time of 14.55 min (Figure 4a) was n-hexadecanoic acid (palmitic acid, C16:0), which had typical fatty acid fragmentation patterns with a large m/z 74 ion due to McLafferty rearrangement and a series of alkyl chain cleavage fragments (Knothe & Razon, 2017).. The second strong peak of 17.63 min (Figure 4b) was attributed to cis-vaccenic/oleic acid (C18:1), which is the major unsaturated fatty acid component in the oil, and fragmentation ions were in line with monounsaturated C18 fatty acids. These saturated and monounsaturated fatty acids (Table 2) are the reason for the high cetane index and relatively high viscosity normally linked to biodiesel made out of waste chicken fat oil, and the relative moderation of unsaturation is also the reason of the improved flow properties of the fuel (Boichenko et al., 2025**).**

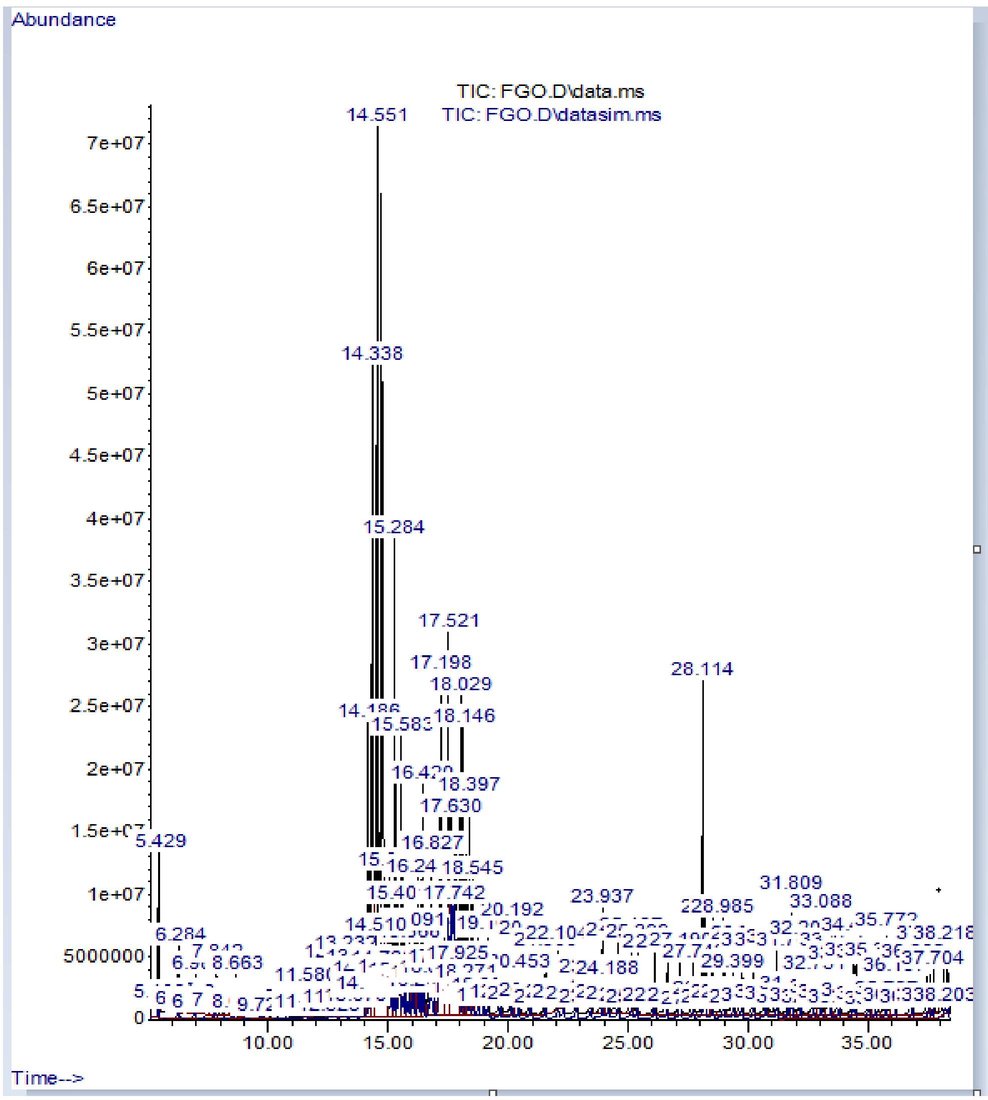

Figure 3: GC–MS analysis of total ion chromatogram (TIC) of waste chicken fat oil.

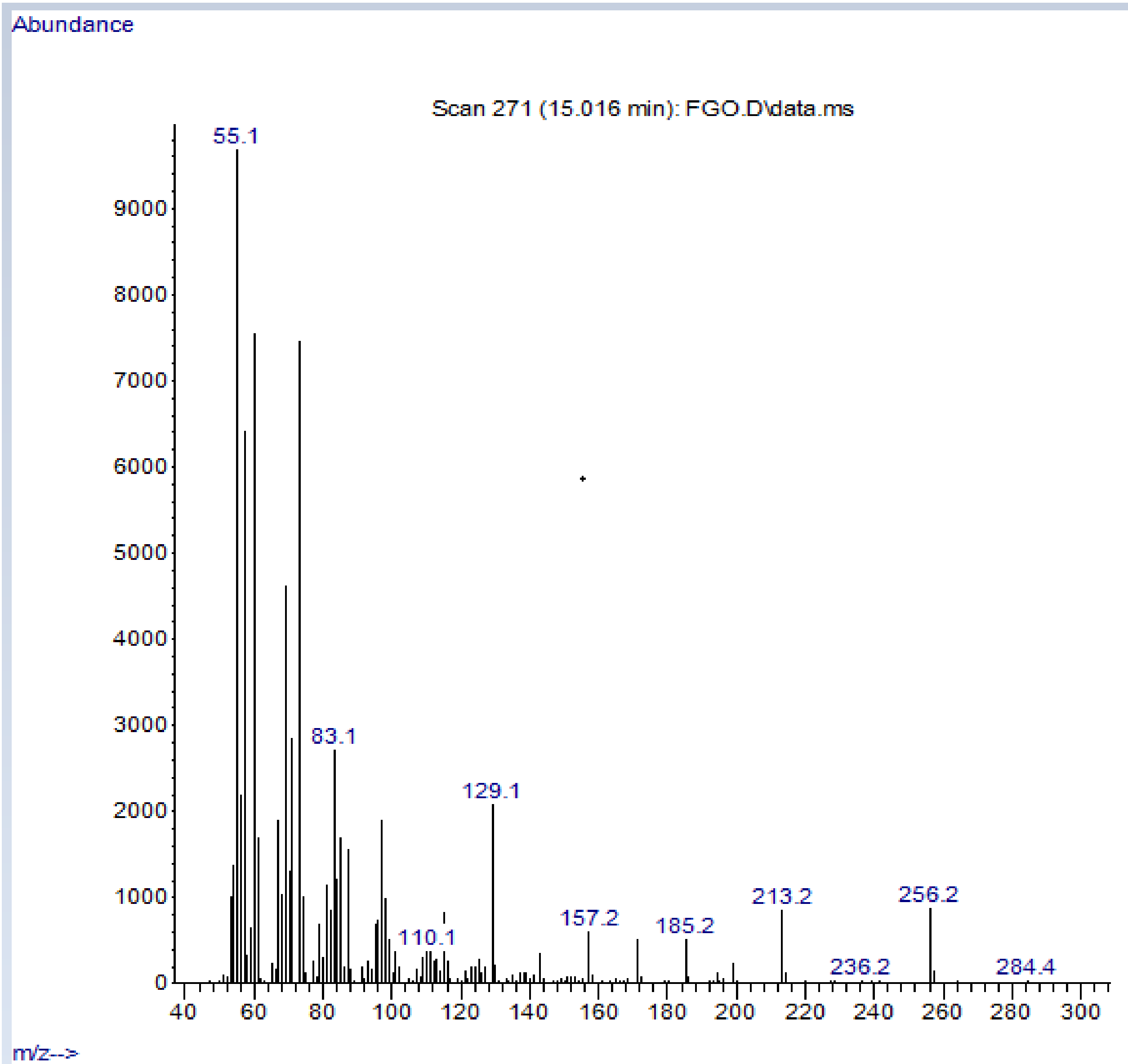

Figure 4a. GC-MS mass spectra of palmitic acid (C16:0) at RT 14.55 min components found in waste chicken fat oil.

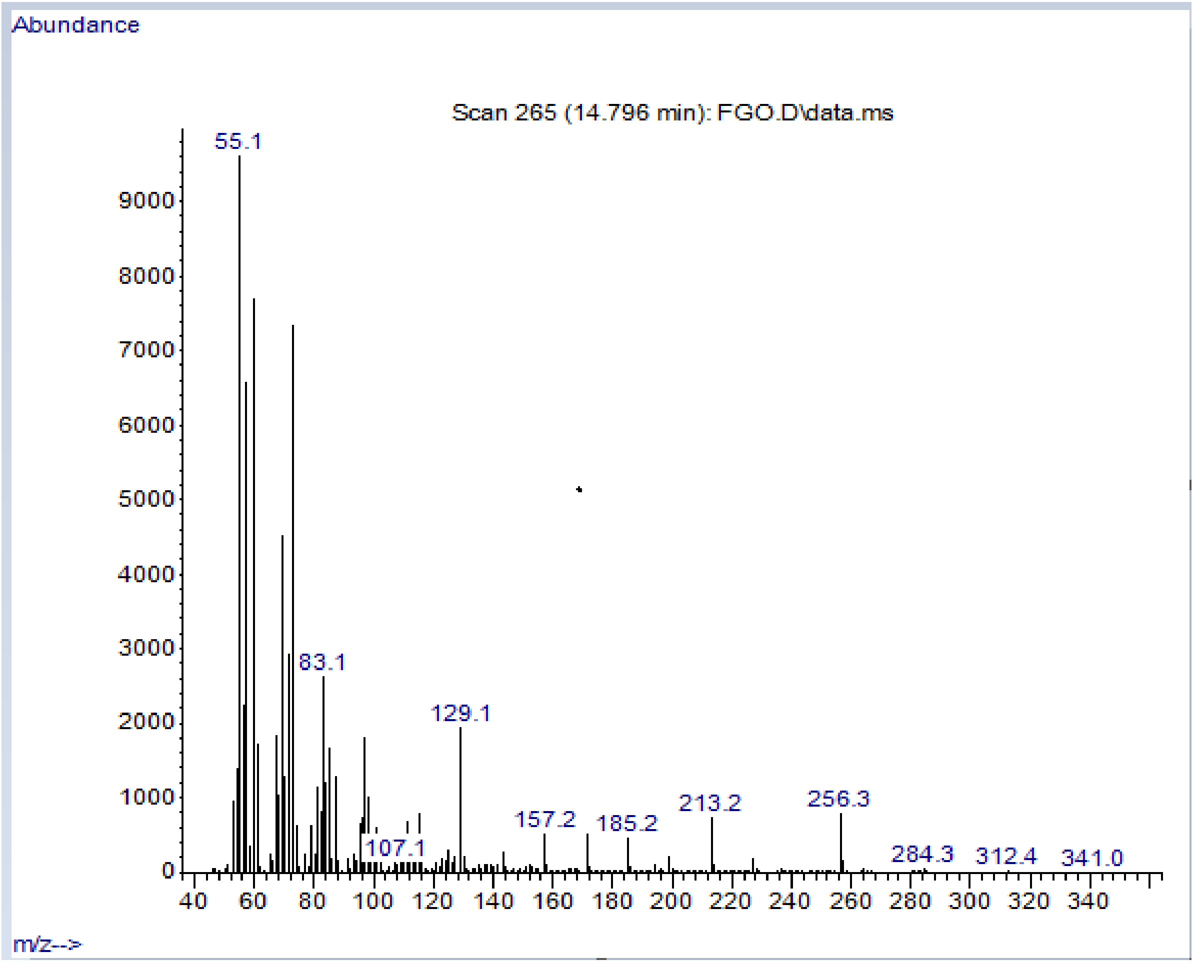

Figure 4b. GC-MS mass spectra of palmitic acid (C16:0) at RT 14.34 min components found in waste chicken fat oil:

Table 2. Major GC–MS peaks identified in waste chicken fat oil.

Retention time (min)	Relative peak area (%)	Probable compound	Classification
~14.34	~5.16	Methyl myristate / related ester	Saturated FAME
~15.07–15.58	~2.4–2.7	Pentadecanoate derivatives	Saturated FAME
~17.20–17.63	~4.1–6.2	**Methyl palmitate (C16:0)**	Saturated FAME

~18.40	~2.37	**Methyl oleate (C18:1)**	Unsaturated FAME
~28.11	~2.78	Long-chain fatty ester	Saturated FAME

3.3. FTIR Characterization of Waste Chicken fat oil.

The FTIR analysis of waste chicken fat oil confirmed the lipidic structure and the biodiesel suitability of the substance because of the typical absorption bands in the FTIR spectrum (Figure 5). Good aliphatic C-H stretching vibrations at 2920 and 2855cm^{-1} denote long chains of hydrocarbons whereas the high-intensity ester carbonyl (C=O) band at 1742cm^{-1} confirms the abundance of triglyceride ester functional groups, which are critical in the production of biodiesel (Shanthini et al., 2025). Other bands associated with -CH2/-CH3 bending, C-O stretching of esters and methylene rocking also confirm the presence of saturated and monounsaturated fatty acids components as summarized in Table 3. These spectral characteristics align with the FTIR measurements of functional groups of biodiesel and its mixtures, which also confirm the structural interpretation (Bhikuning et al., 2020). The high cetane number and reasonable flow characteristics of the waste animal fats biodiesel are also supported by the observed functional groups because of the presence of both saturated and moderately unsaturated fatty acid moieties.

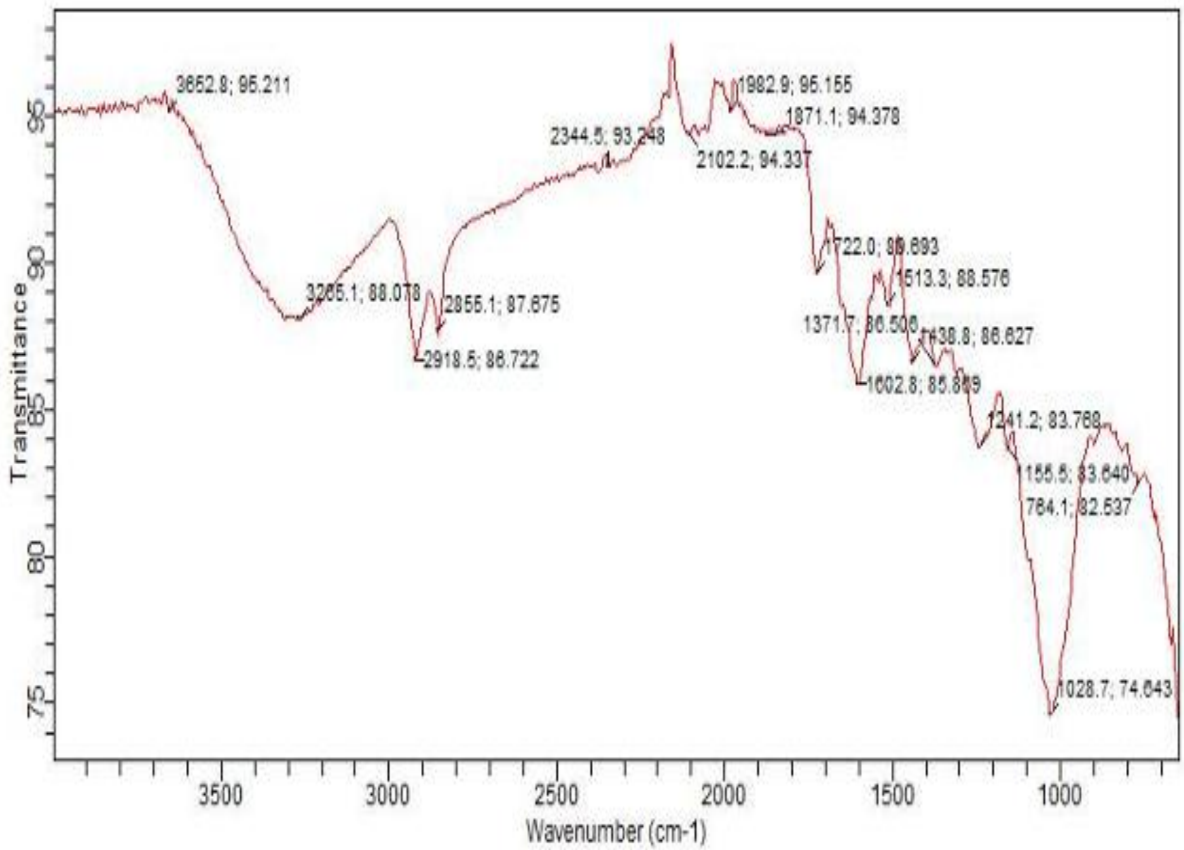

Figure 5. FTIR spectrum of waste chicken fat oil

Table 3: Summary of key FTIR absorption bands of the waste chicken fat oil and the functional group identification.

Wavenumber (cm^{-1})	Functional group	Assignment
~3365	O–H stretching	Moisture / free fatty acids
2920	C–H stretching	Asymmetric $–CH_2$
2855	C–H stretching	Symmetric $–CH_2$
1742	C=O stretching	Ester carbonyl (triglycerides)
1462	C–H bending	$–CH_2$ scissoring

1371	C–H bending	$–CH_3$ bending
1155–1028	C–O stretching	Ester linkage
~721	$–(CH_2)_n$ rocking	Long-chain saturated fatty acids

3.4. Applicability to Waste-Derived Heterogeneous Catalysis.

The catalyst prepared using the bone of chicken showed good catalytic activity in transesterification of waste chicken fat, which was demonstrated by biodiesel yields of over 80 per cent using optimum conditions of reaction and reproducible outcomes of the experiment replicated. Similar yield rates have been observed with CaO-based heterogeneous catalysts based on animal bones, which validates the appropriateness of animal-based materials in the biodiesel production (Obadiah et al., 2012; Farooq et al., 2015).

The catalytic efficiency was observed to be caused by the existence of strong basic active sites related to CaO and thermally modified calcium phosphate phases developed during the high-temperature calcination. These are the fundamental sites that facilitate the formation of methoxide ions and the conversion of triglycerides to fatty acid methyl esters that is the most prevalent reaction pathway in the heterogeneous base-catalyzed biodiesel production with bone-derived catalysts (Smith et al., 2013; Nisar et al., 2017). The resultant decrease in the kinematic viscosity and specific gravity of the obtained biodiesel also confirm successful conversion of catalysts and limited residual glycerides as previous studies have indicated with animal-bone-derived catalysts (Chakraborty et al., 2011; Ayodeji et al.,

Moreover, the reproducibility of experimental runs at the center of point suggests adequate stability of the catalysts during the experimented operating conditions. It was already demonstrated that waste-based CaO catalysts made of animal bones can be stable during catalytic activity even at relatively low temperatures without a sophisticated surface characterization, given that proper preparation instructions are observed (Obadiah et al., 2012; Nisar et al., 2017; Viriya-empikul et al., 2010).

Although the structural and surface characterization is not provided directly, and thus, does not allow one to correlate the catalyst physicochemical properties and the reaction mechanism in detail, the catalytic activity achieved in the current study is similar to the well-characterized animal and poultry bone catalysts reported in the literature. This observation justifies the correctness of the catalyst preparation methodology and the accuracy of the experimental data.

3.5 Effect of Calcination Temperature on Catalyst Activity.

Raw chicken bone waste is converted to catalytically active calcium-rich phases through calcination. A good balance between surface basicity and structural stability lies at an optimal calcification temperature of about 800°C, and is higher than is needed to cause sintering and loss of active sites (Nisar et al., 2017).

3.6. Effect of KOH Activation

The catalyst intensification with KOH activation depends on the incorporation of potassium species that enhance surface basicity (Ooi et al., 2021).

The catalytic performance of KOH activation is characterized by a larger density and stronger surface basic sites, which stimulate the activation of methanol and shorten the reaction kinetics, compared to the catalysts subjected to calcification only (Ooi et al., 2021).

3.7. Effect of Parameters on Transesterification

3.7.1 Catalyst Loading Effects

The optimum amount of catalyst loading was found to be 1.0 wt% (Table 4 and Figure 6). Reduced loadings minimized the availability of active-sites, whereas high loadings enhanced the slurry viscosity and soap generation, which decreased the yield of biodiesel (Adewale et al., 2015).

Table 4: Effect of Catalyst Concentration

Catalyst (wt.%)	Yield (%)
0.5	73.4
1.0	78.2
1.5	70.9
2.0	67.1
2.5	61.8

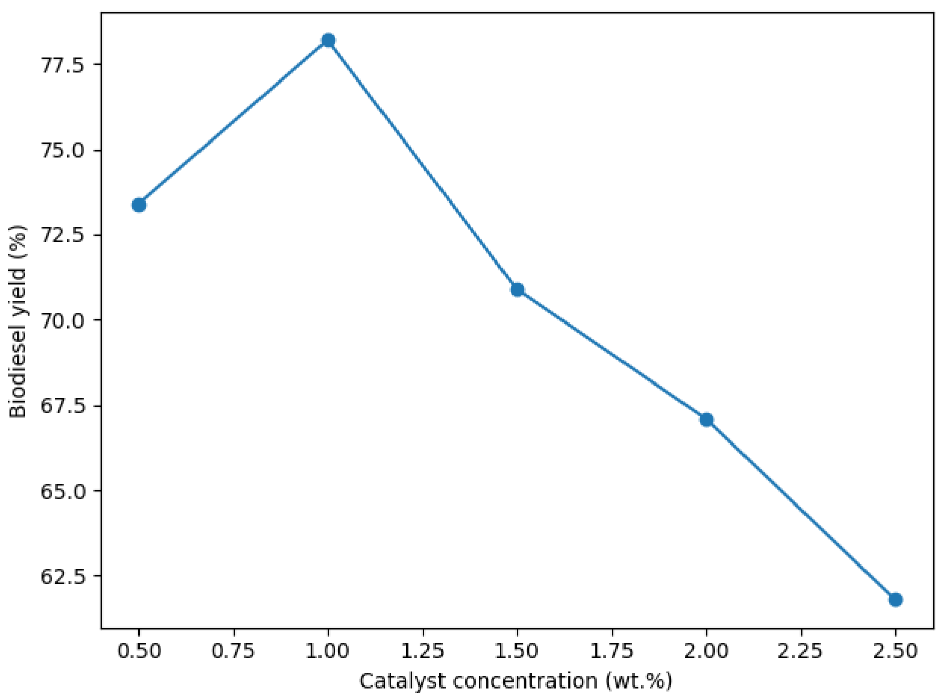

Figure 6: Effect of Catalyst Concentration

3.7.2. Methanol-to-Oil Molar Ratio

The yield of biodiesel rose with the ratio of methanol to molar oils to the highest ratio of 12:1 because of the enhanced reaction equilibrium (Table 5 and Figure 7). The presence of excess methanol lowered the yield because it inhibited the separation of glycerol (Borges & Diaz, 2017).

Table 5: Effect of Methanol-to-Oil Ratio

Molar ratio	Yield (%)
6	52.9
8	59.8
10	66.6
12	81.1
14	73.2

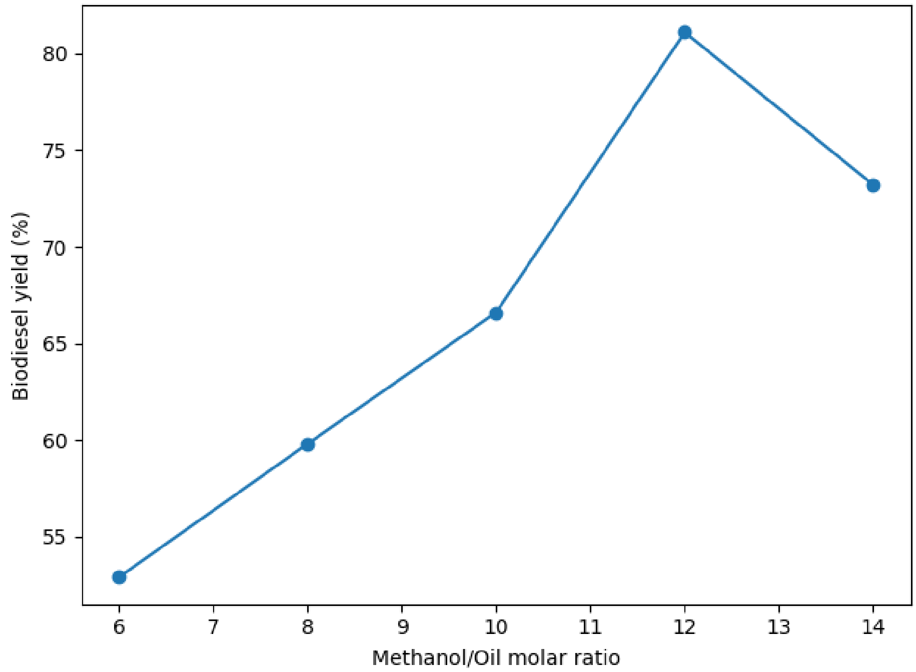

Figure 7: Effect of Methanol-to-Oil Ratio

3.7.3. Reaction Time Dependence

The highest level of biodiesel production was achieved after 2 h as illustrated in Table 6 and Figure 8. Long reaction times led to poor yield because of reverse reactions and hydrolysis of esters (Tan et al., 2019).

Table 6: Effect of Reaction Time

Time (h)	Yield (%)
1	68.2
2	77.8
3	72.5
4	69.1
5	62.9

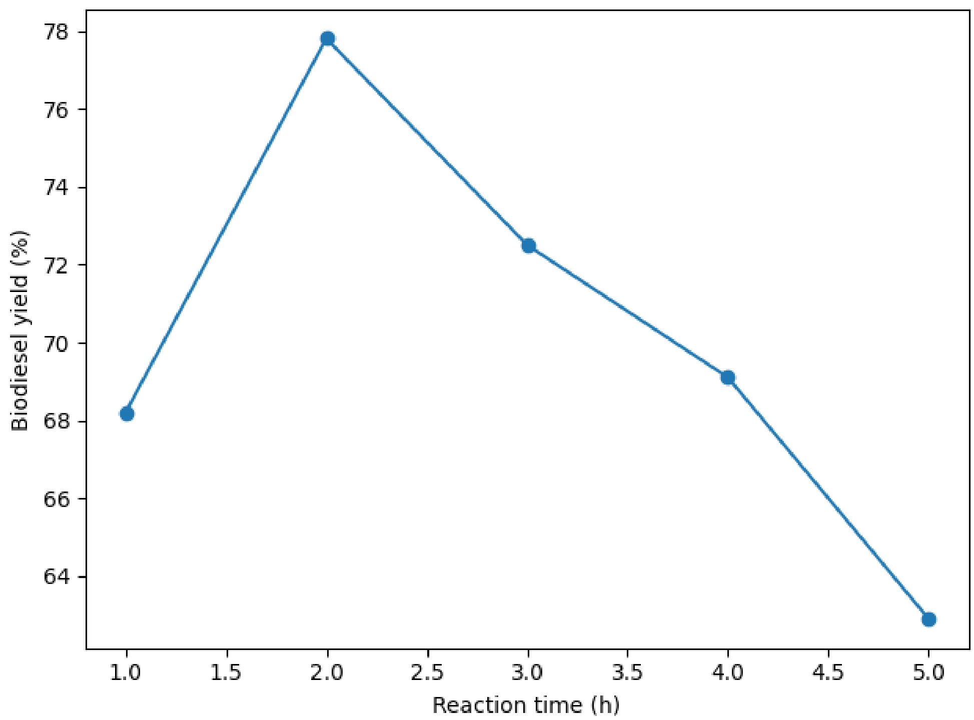

Figure 8: Effect of Reaction Time

3.7.4. Reaction Temperature Influence

The reaction temperature affects the rate of the reaction with the first order reaction mechanism. The ideal temperature of reaction was 60^{o}C, in which the best yield was maximized by the improved kinetics and minimum yield was minimized by the high viscosity of oil. Increased temperatures led to loss of methanol and a decrease in the conversion efficiency as illustrated in Table 7 and Figure 9 (Knothe and Razon, 2017).

Table 7: Effect of Reaction Temperature

Temperature (°C)	Yield (%)
30	39.5
40	49.2
50	73.5
60	84.1
70	82.7

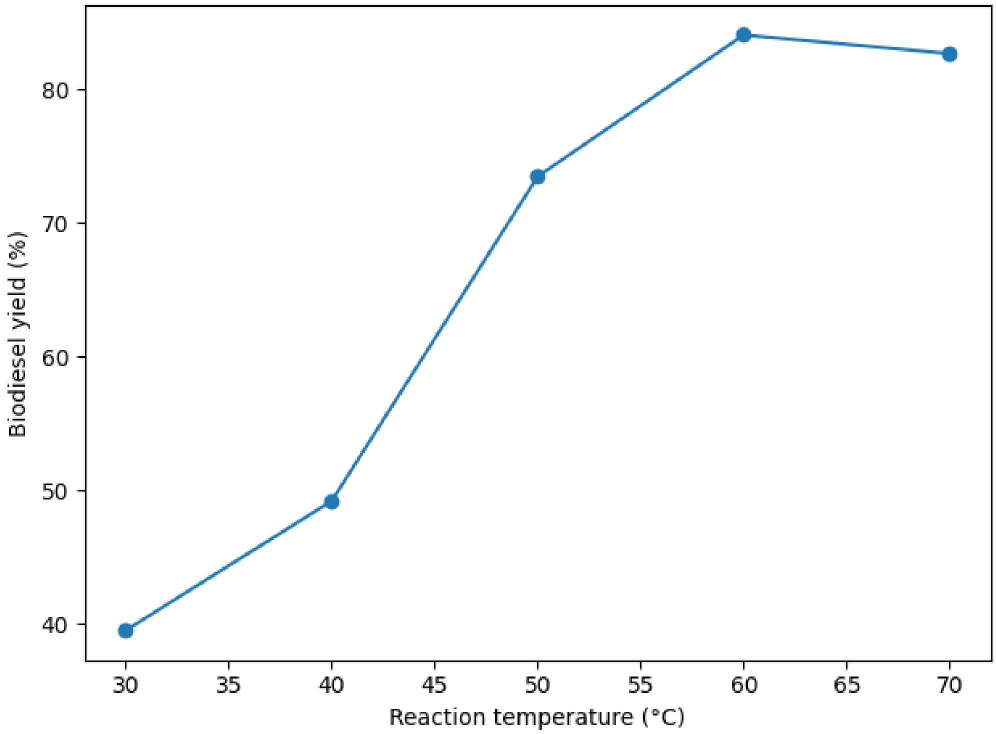

Figure 9: Effect of Reaction Temperature

3.7.5 Effect of Agitation Speed

The agitation speed up to 400 rpm resulted in higher biodiesel yield because of better mass transfer, and further agitation led to the formation of vortices and lower yield as shown in Table 8 and Figure 10 (Aghbashlo et al., 2017).

Table 8: Effect of Agitation Speed

Speed (rpm)	Yield (%)
100	55.0
200	67.6
300	79.6
400	84.5
500	81.7

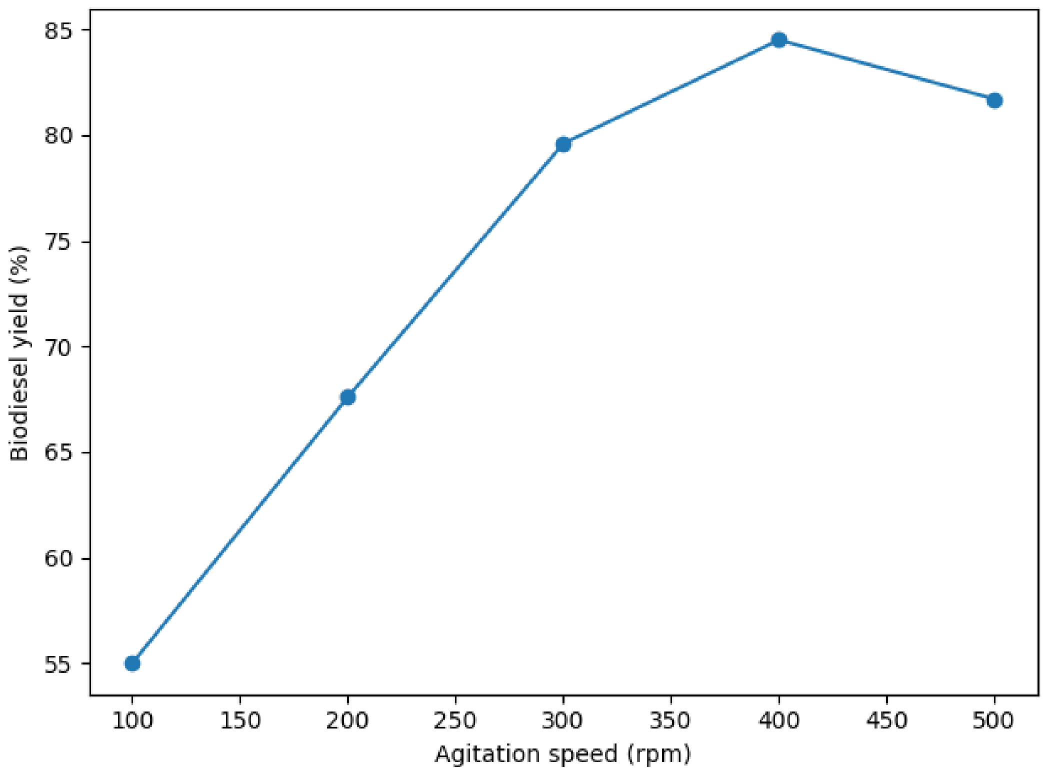

Figure 10: Effect of Agitation Speed

3.8. Proprieties and Standard Compliance of Fuel.

The quality of biodiesel produced through a waste chicken fat via a heterogeneous catalyst Derived through chicken bone was assessed based on the main physicochemical and combustion Related characteristics since these parameters are globally accepted as indicators of the usability, safety, and engine performance of biodiesel, especially those of animal-fat-derived fuels Table 9 (Knothe and Razon, 2017).

The kinematic viscosity of the resulting biodiesel was between 7.51 and 20.97mm^2s^{-1} with a very strong and negative correlation with conversion efficiency. The samples with high yields (≥75%) showed low viscosities (less than 9mm^2s^{-1}), whereas those with low yields maintained high viscosity because of remaining glycerides, which is common to poultry fat and tallow biodiesel fuels (Mu et al., 2023).

The specific gravity was in the range of 0.8742 to 0.9216 with optimum converted samples within the range of 0.875-0.890, which is characteristic of the fatty acid methyl ester fuels. The reduction in density with enhanced conversion is an indication of substituting the heavy molecules of glyceride with methyl esters which is consistent in animal-fat biodiesel studies (Giakoumis and Sarakatsanis, 2018).

Flash point values of high quality samples were between 160-181°C which were indicative of low traces of residual methanol and successful purification. High flash points are well-known safety benefits of biodiesel compared to petroleum diesel that have been proven in extensive biodiesel property tests (Zhang et al., 2018).
The values of the cetane index were between 48.2 and 53.8, with the high-yield samples having a

constant high value of over 50 that is a good indication of high-quality ignition. Animal fats give biodiesel higher cetane indices because of higher levels of saturated fatty acids, which lead to shorter ignition delay and easier combustion (Knothe, 2016).

Table 9: Comparison of this study Biodiesel Properties with International Fuel Standards

Property	Unit	Produced Biodiesel*	ASTM D6751	EN 14214	Remarks
Kinematic viscosity (40 °C)	mm² s⁻¹	7.51 – 8.93	1.9 – 6.0	3.5 – 5.0	Slightly above limits; typical of animal-fat biodiesel
Specific gravity (40 °C)	-	0.874 – 0.890	0.86 – 0.90	0.86 – 0.90	Compliant
Flash point	°C	160 – 181	≥130	≥120	Fully compliant
Cetane index	-	48.2 – 53.8	≥47	≥51	Meets ASTM; upper range meets EN
Diesel index	-	50 – 56	≥45 (indicative)	-	Good ignition quality
Boiling point	°C	346 – 355	Report	Report	Typical FAME range

4. Conclusion

This paper showed the technical feasibility and sustainability of the biodiesel production process based on a same-source poultry waste valorization process that used waste chicken fat oil as feedstock and waste chicken bones as a heterogeneous base catalyst. Physicochemical analysis of the chicken fat oil revealed that it was suitable in the heterogeneous base-catalyzed transesterification because of its moderate free fatty acid and low moisture content, high esterifiable fraction and excellent oxidative stability. The functional group composition of the chicken fat oil was confirmed using FTIR and GC-MS profiling showed that the fatty acid composition was composed of saturated and monounsaturated species, especially palmitic and oleic acids, which would give them good esterification qualities and positive ignition properties.

The calcium burning and chemical activating processes played a significant role in the conversion of chicken bone waste to a viable catalyst. The combination of the surface basicity and structural stability was best achieved at 800ºC, and further activation of KOH could greatly increase the catalytic activity, by raising the density and strength of basic active sites. This synergy treatment enhanced methanol activation, reaction rate, and biodiesel.

Optimization of the processes showed that the best yield of biodiesel (more than 80) was obtained at a catalyst load of 1.0 wt, methanol-oil molar ratio of 12:1, reaction temperature of 60 degC, 2 h of reaction time, and 400 rpm agitation speed. The Biodiesel that was produced in these conditions possessed good fuel characteristics such as low kinematic viscosity

(7.5-8.9 mm2 s-1), acceptable specific gravity (0.874-0.887), high flash point (160-181^{o}C) and cetane index values that were above 52 which implies good ignition quality. The fuel characteristics were near to the ASTM D6751 and EN 14214 requirements after the purification.

On the whole, the results attest to the fact that calcined, and KOH-activated chicken bone waste can be used as a low-cost, reusable, and effective heterogeneous catalyst in biodiesel production using waste chicken fat oil. The proposed waste-to-fuel approach helps to reduce wastes, increase resource utilization, and create a cycle of biofuels, which provides a scalable avenue to the production of sustainable biodiesel using poultry wastes.

References

Adewale, P., Dumont, M.-J., & Ngadi, M. (2015). Recent trends of biodiesel production from animal fat wastes and associated production techniques. Renewable and Sustainable Energy Reviews, 45, 574–588. https://doi.org/10.1016/j.rser.2015.02.039

Aghbashlo, M., Peng, W., Tabatabaei, M., Kalogirou, S. A., Soltanian, S., Hosseinzadeh-Bandbafha, H., Mahian, O., & Lam, S. S. (2017). Machine learning technology in biodiesel research. Progress in Energy and Combustion Science, 85, 100904.

Andas, J., & Jusoh, N. (2022). Conversion of waste chicken bones into heterogeneous catalysts for biodiesel production. Malaysian Journal of Analytical Sciences, 26(5), 905–916.

Atabani, A. E., Silitonga, A. S., Ong, H. C., Mahlia, T. M. I., Masjuki, H. H., Badruddin, I. A., & Fayaz, H. (2015). Non-edible vegetable oils: A critical evaluation of oil extraction, fatty acid compositions, biodiesel production, characteristics, engine performance and emissions. *Renewable and Sustainable Energy Reviews, 47*, 80–112. https://doi.org/10.1016/j.rser.2015.03.012

Ayodeji, A.A., Modupe, O.E., Rasheed, B., Ayodele, J.M.** (2018). Data on calcium oxide and cow bone catalysts used for soybean biodiesel production. *Data in Brief*, 18, 512–517.

Ayoola, A. A., Anafi, F. O., & Adebayo, O. F. (2020). Biodiesel production from waste cooking oil using eggshell-derived CaO catalyst. AIMS Energy, 8(3), 527–544.

Basumatary, S. F., Kalita, P., & Baruah, D. C. (2023). Advances in CaO-based catalysts for sustainable biodiesel production: A critical review. Journal of Cleaner Production, 388, 135931.

Bhikuning, A., & Senda, J. (2020). The properties and FTIR characteristics of biodiesel and biodiesel–water emulsions. *Indonesian Journal of Science and Technology*, **5**(1), 95–108. https://doi.org/10.17509/ijost.v5i1.23103

Birla, A., Singh, B., Upadhyay, S.N., Sharma, Y.C.** (2012). Kinetics studies of synthesis of biodiesel from waste frying oil using a heterogeneous catalyst derived from snail shell. *Bioresource Technology*, 106, 95–100.

Boey, P.-L., Maniam, G. P., & Hamid, S. A. (2017). Biodiesel production via transesterification of palm olein using waste animal bone catalyst. Renewable Energy, 101, 146–154.

Boichenko, S., Vovk, O., Leontiev, O., Chernyak, L., & Yefimenko, V. (2025). A comparative study of lipid-based feedstocks: Influence of fatty acid composition on biodiesel properties. *Energies*, **18**(16), 4274. https://doi.org/10.3390/en18164274

Borges, M. E., & Díaz, L. (2017). Recent developments on heterogeneous catalysts for biodiesel production by oil esterification and transesterification reactions. Renewable and Sustainable Energy Reviews, 16(5), 2839–2849.

Boro, J., Deka, D., Thakur, A.J.** (2012). A review on solid oxide derived from waste shells as catalyst for biodiesel production. *Renewable and Sustainable Energy Reviews*, 16(1), 904–910.

Chakraborty, R., Bepari, S., Banerjee, A.** (2011). Application of calcined waste fish (Labeo rohita) scale as low-cost heterogeneous catalyst for biodiesel synthesis. *Bioresource Technology*, 102(3), 3610–3618.

Changmai, B., Vanlalveni, C., Ingle, A. P., Bhagat, R., & Rokhum, S. L. (2020). **Widely used catalysts in biodiesel production: A review.** *RSC Advances*, *10*(69), 41625–41679. https://doi.org/10.1039/D0RA07931F

Chouhan, A.P.S., Sarma, A.K.** (2011). Modern heterogeneous catalysts for biodiesel production: A comprehensive review. *Renewable and Sustainable Energy Reviews*, 15(9), 4378–4399.

Farooq, M., Ramli, A., Naeem, A.** (2015). Biodiesel production from low FFA waste cooking oil using heterogeneous catalyst derived from chicken bones. *Renewable Energy*, 76, 362–368.

Fayyazi, E., Ghobadian, B., Najafi, G., Hosseinzadeh, B., & Mirsalim, M. (2018). Optimization of biodiesel production over chicken eggshell-derived CaO catalyst. Industrial & Engineering Chemistry Research, 57(11), 3856–3866. https://doi.org/10.1021/acs.iecr.8b02678

Giakoumis, E. G., & Sarakatsanis, C. K. (2018). Estimation of biodiesel cetane number, density and viscosity from fatty acid composition. Fuel, 222, 574–585. https://doi.org/10.1016/j.fuel.2018.02.187

Hussain, F., Alshahrani, S., Abbas, M. M., Khan, H. M., Jamil, A., Yaqoob, H., et al. (2021). Waste animal bones as catalysts for biodiesel production: A mini review. Catalysts, 11(5), 630. https://doi.org/10.3390/catal11050630

Kirubakaran, M., Selvan, V. A. M., & Jayaprabakar, J. (2018). Eggshell as heterogeneous catalyst for biodiesel production from chicken fat. Energy Reports, 4, 77–85.

Knothe, G. (2016). Dependence of biodiesel fuel properties on the structure of fatty acid alkyl esters. Fuel Processing Technology, 86(10), 1059–1070. https://doi.org/10.1016/j.fuproc.2004.11.002

Knothe, G., & Razon, L. F. (2017). Biodiesel fuels. Progress in Energy and Combustion Science, 58, 36–59. https://doi.org/10.1016/j.pecs.2016.08.001

Mu, Z., Fu, J., Zhou, F., Yuan, K., Yu, J., Huang, D., Cui, Z., Duan, X., & Liu, J. (2023). *Comparative study on the performance and emission characteristics of a diesel engine fueled with tung oil-based biodiesel blends (B10, B20, B50).* **Energies, 16(14): 5577.** https://doi.org/10.3390/en16145577

Nisar, J., Razaq, R., Farooq, M., Iqbal, M., & Khan, R. A. (2017). Enhanced biodiesel production from Jatropha oil using calcined waste animal bones as catalyst. Renewable Energy, 101, 111–119.

Obadiah, A., Swarup, G.A., Kumar, S.V., Jeganathan, K.R., Ramasubbu, A.** (2012). Biodiesel production from palm oil using calcined waste animal bone as catalyst. *Bioresource Technology*, 116, 512–516.

Ooi, H. K., Lee, H. V., Juan, J. C., & Cheng, C. K. (2021). Progress on modified calcium oxide derived waste-shell catalysts for biodiesel synthesis. Catalysts, 11(2), 194. https://doi.org/10.3390/catal11020194

Smith, S.M., Oopathum, C., Weeramongkhonlert, V., Smith, C.B., Chaveanghong, S., Ketwong, P., Boonyuen, S.** (2013). Transesterification of soybean oil using bovine bone waste as new catalyst. *Bioresource Technology*, 143, 686–690.

Tan, Y. H., Abdullah, M. O., Kansedo, J., Mubarak, N. M., Chan, Y. S., & Nolasco-Hipolito, C.

(2019). Biodiesel production from used cooking oil using green solid catalyst derived from calcined waste chicken and fish bones. Renewable Energy, 139, 696–706.

Viriya-empikul, A., Krasae, P., Puttasawat, B., Yoosuk, B., Chollacoop, N., Faungnawakij, K.** (2010). Waste shells of mollusk and egg as biodiesel production catalysts. *Bioresource Technology*, 101(10), 3765–3767.

Zhang, Y., Dubé, M. A., McLean, D. D., & Kates, M. (2018). Biodiesel production from waste cooking oil: Process design and technological assessment. Bioresource Technology, 249, 593–601.