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Biodiesel Production from Rubber Seed Oil (RSO) Using Calcined Eggshells as Nano Heterogeneous Catalyst

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Abstract

This research focuses on the application of calcined eggshell as a heterogenous catalyst in the production of biodiesel from Rubber Seed Oil (RSO). The heterogeneous catalyst was synthesized through calcination, wherein the eggshell powder was maintained at a temperature of 900°C for 3 hours. SEM and EDX analysis were utilized to characterize the elemental composition, surface morphology, and particle size of calcinated eggshell. After calcination, the eggshell creates an agglomerated microstructure with an average particle size of 63.954 nm and 66.162% porosity. The elemental composition of calcinated eggshell consists of mainly calcium and oxygen, constituting 83.69 and 16.31 weight percentages, respectively. The impact of reaction parameters on biodiesel yield, encompassing the methanol-to-oil ratio, amount of catalyst, reaction temperature, and reaction duration, was examined. Through the investigation, the highest yield of 89% was obtained at 9:1 methanol-to-oil molar ratio, 1 wt. % of catalyst, a reaction temperature of 62°C and a reaction time of 1.5 hours. Additionally, the characteristics of the biodiesel were determined to align with the fuel standards established by the ASTM D6571 regulations.

Keywords: Biodiesel, FFA, Heterogenous Catalyst, Eggshell, Rubber Seed Oil (RSO)

1. Introduction

For the past few decades, energy has been the crucial resource for sustainable development. Fossil fuels have been the primary source of energy since ancient times. The continuous depletion of fossil fuel reservoirs due to global population growth and industrialization has prompted efforts worldwide to investigate alternative and potentially sustainable energy sources [1, 2]. Biodiesel has become more popular in several countries among various renewable energy sources because of its advantageous environmental characteristics, cleaner combustion, and renewability [1, 3, 4]. Biodiesel is a biodegradable, non-toxic fuel formed from animal or vegetable fats [5]. It can be used in diesel engines without any changes, and it makes less sulfur and hydrocarbons than regular diesel fuel [6,7]. Biodiesel production involves the transesterification of triglycerides, predominantly derived from animal fat or vegetable oil, using a short-chain alcohol (often methanol), along with an appropriate catalyst [8]. Edible oils such as sunflower oil, palm oil and others are used to produce biodiesel mostly all over the world. However, the high cost of edible oils and the food security concerns associated with them present significant challenges for the production and commercialization of biodiesel [5, 9, 10, 11]. Therefore, the utilization of non-edible sources as feedstocks for biodiesel production has been the most recent area of emphasis [12].

Rubber tree (*Hevea brasiliensis*) is classified as a euphorbiaceae family and its seed oil is regarded as a non-edible oil [13]. The oil content of rubber seed is between 40% and 50%, designating it a highly potential source of biodiesel [14]. Numerous research in literature have demonstrated the potential of Rubber Seed Oil (RSO) as a highly promising non-edible feedstock. Lakshmi et al. [15] investigated that a reusable eggshell-driven heterogenous catalyst could convert 99.6% of RSO to biodiesel. Gimbun et al. [16] achieve a 96.9% biodiesel conversation from a high free fatty acid-based RSO at a 5 wt. % catalyst, a methanol-to-oil molar ratio of 5:1, a reaction temperature of 65°C, and a reaction time of 4 hours. A limestone-based heterogenous catalyst was employed in this study. Morshed et al. found that 86% of biodiesel yield can be possible from rubber seed oil (RSO) [17]. Devi et al. [18] conducted a comparative analysis of heterogenous and homogeneous catalysts for the application of biodiesel production from RSO. In terms of biodiesel production, the results indicate that

homogeneous catalysts outperform heterogenous catalysts. The transesterification process is crucial in the production of biodiesel, as it significantly impacts the cost and yield [19]. One potential approach to decreasing the cost of this integrated process is the utilization of heterogeneous catalysts, which eliminate the washing phase and the wastewater produced during this process [20]. Furthermore, this heterogeneous catalyst may be reused without losing its catalytic activity, which makes the biodiesel process more cost-effective and simple [21, 22]. CaO is a promising heterogeneous catalysts which can be easily obtained from waste sources [23-25]. The primary components of eggshell are calcium carbonates, which undergo decomposition into calcium oxides when exposed to temperatures exceeding 700°C [20]. Prior research has shown the exceptional characteristics of these eggshell oxides in transesterification reactions [20, 26, 27, 28].
The main goal of this work is to investigate the use of a low-cost and waste material derived nano heterogenous catalyst obtained from chicken eggshells to produce biodiesel utilizing Rubber Seed Oil (RSO) in conjunction with methanol.

2.Materials and Methods

2.1 Materials

Rubber seed oil (principle feedstock), methanol (99.9 %, Merck KGaA, Gemany) and sulfuric acid (98%, BDH Chemicals Ltd., England) were collected from a local chemical shop in Bangladesh. The egg shells were collected from the Q.K Hall dining, CUET. After collecting the eggshells, they were washed properly with hot distilled water to clean the impurities inside them. Following that, the eggshells underwent overnight drying in a hotbox oven set at 120°C to eliminate the water content. Next, the desiccated eggshells were pulverized in a blender and then filtered through a sieve mesh. Later, more fine powder was obtained by using manual mortar pestle. Afterwards, the fine powdered eggshell was calcined in a muffle furnace at a temperature of 900°C for 3 hours to convert the calcium carbonate ($CaCO_3$) in chicken eggshell into calcium oxide (CaO) [29]. The obtained heterogenous catalyst, calcium oxide (CaO), was stored in sealed desiccators to prevent contamination by excessive atmospheric moisture and carbon dioxide (CO_2) [30, 31].

2.2 Methods

The acid value of raw feedstock oil was determined to be 31.96 mg KOH/g of oil, attributed to a free fatty acid (FFA) content of 15.98%. For alkaline catalyst transesterification, it is essential to have FFA content in oil below 1% [32]. If this requirement is not met, issues such as saponification can arise during the transesterification process. Therefore, the pre-treatment process is necessary. In order to reduce the FFA content of RSO, the pretreatment process was implemented at a reaction temperature of 61°C, a molar ratio of 6:1 between methanol and oil, a catalyst concentration of 1.2 wt.%, and a reaction time of 60 minutes. Here, sulfuric acid (H_2SO_4) is employed as an acid catalyst. Following the pretreatment process, the FFA content decreased from 15.98% to 0.98%, demonstrating that the oil has been ready for the transesterification process. After the pre-treatment process, the treated oil was collected by separation, heating, and filtration. Subsequently, the oil underwent transesterification. The transesterification reaction was carried out at molar ratios of 5:1, 6:1, 7:1, 8:1, and 9:1 (methanol to oil). All the reactions achieved completion within a time frame of less than 90 minutes, spanning a temperature range of 62 to 70 °C. In the transesterification process, the eggshell driven heterogenous catalyst (CaO) is employed as a catalyst. The catalyst ratios used are 0.3, 0.75, 1, 1.2, and 1.5 as weight % of oil, respectively.
The transesterification process was conducted in a 500 ml three-neck funnel, utilizing a magnetic hot plate equipped with a controllable temperature probe for precise heating and temperature regulation, thereby minimizing uncertainty in the reaction. A magnetic stirrer was used in conjunction with a magnetic hot plate to improve the oil, catalyst, and methanol mixture's mixing, and the stirring speed was maintained at 750 rpm throughout the reaction. Initially, the rubber speed oil was measured and introduced into the three-neck funnel, where it was preheated until it exceeded a temperature of 40°C. Subsequently, the calcium methoxide solution was added to the three-neck funnel. After completing the reaction, the oil was placed in a separator funnel overnight, resulting in the formation of two distinct layers: fatty acid methyl ester (FAME) and glycerol. Then the methyl ester was obtained by a sequential washing, heating, and filtration methods which is known as biodiesel.

3. Results and Discussion

3.1 Catalyst characterization

3.1.1 SEM analysis

The morphology of the obtained catalyst was examined using SEM, providing valuable insights into its structure. In Fig. 1(a), the eggshell that was heated to 900°C for 3 hours displayed a structure with irregular rod-like shapes that tended to clump together. The figure also indicates that the high temperature and heat transferred to the sample caused the formation of large agglomerates and clusters. This was due to the cohesion and adhesion phenomena, resulting in a decrease in particle size, similar to the findings of Rashid et al [33].

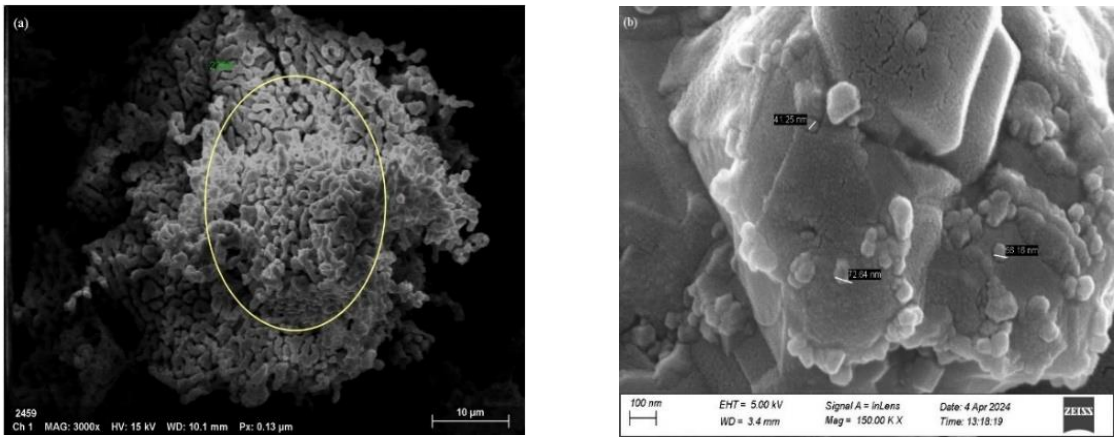


Fig. 1: FE-SEM image of calcined eggshell driven nano-heterogenous catalyst under (**a**) 10 µm and (**b**) 100 nm magnifications.

By employing image analysis software on the FE-SEM image from Fig.1(b), it was determined that the sizes of the particles ranged from 39.152 nm to 123.56 nm, with an average particle size of 63.954 nm. Additionally, the porosity of the sample was found to be 66.162%. Based on the observations in Fig. 1(b), it is conspicuous that the particles underwent scattering and irregularity in shape due to calcination. Additionally, the eggshell particles decreased in size and exhibited a more cohesive and smooth arrangement [34]. Through the reduction of particle size, calcinated eggshell can generate a more porous microstructure [35]. By increasing the porosity in microstructures, can obtain a higher level of catalytic activity [36].

3.1.2 EDX analysis

The EDX analysis is used to diagnose the elemental composition of the prepared heterogenous catalyst. Based on the EDX analysis, it was determined that the primary components of the heterogenous catalyst derived from eggshells are calcium and oxygen, accounting for 67.24% and 32.76% of the atomic composition, respectively. This information is visually represented in Fig. 2.

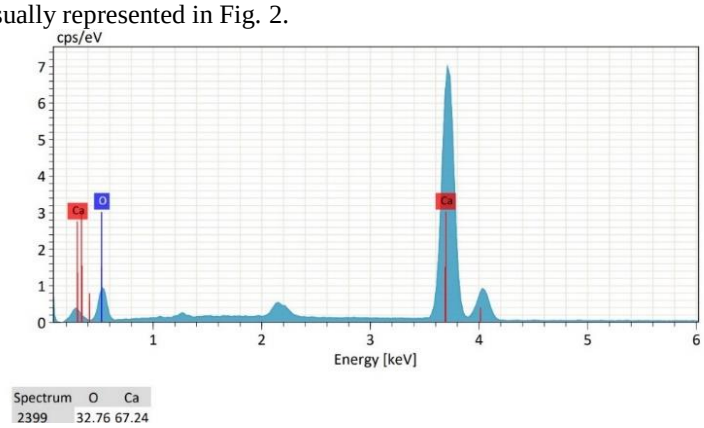


Fig. 2: Elemental compositions of the eggshell driven heterogenous catalyst using EDX

Upon calcination, it was observed that the small particles had merged together, resulting in the formation of large agglomerates. This is due to the sample being in the oxide form. The alterations in the eggshell's structure could potentially be attributed to variations in its composition. Elemental composition of the eggshell driven heterogenous catalyst is shown below in Table 1.

Table 1: EDX analysis of eggshell driven heterogenous catalyst calcinated at 900°C for 3 hours

Calcination Temperature (°C)	**Calcination Time (hours)**	**Element**	**Weight (%)**	**Atomic (%)**
900°C	3 hours	Ca	83.69	67.24
		O	16.31	32.76

Through the process of calcination, the majority of the components found in the eggshell, such as $CaCO_3$, are decomposed into CaO and CO_2. Therefore, there is a decrease in particle sizes, as evidenced by the results presented in Fig. 1(b) [31].

3.2 Effect of process parameters

Table 2 represents the biodiesel yield with respect to different process parameters. It is observed that methanol to oil molar ratio is the most significant factor in the production biodiesel from RSO using eggshell driven heterogenous catalyst [37].

Table 2: Data of transesterification process

Sample No.	Methanol to oil ratio	Amount of catalyst (wt.%)	Reaction temp. (°C)	Reaction time (minutes)	Experimental yield (%)
1	6:1	0.3	65	90	77.6%
2	5:1	0.75	66	90	78%
3	7:1	1.2	69	90	81%
4	9:1	1	62	90	89%
5	8:1	1.5	70	90	85%

It has been observed that, by increasing the methanol-to-oil molar ratio, yield increases which is illustrated in Fig. 3. Further observation in Fig. 4 reveals that the yield also increases with the increase in catalyst ratio.

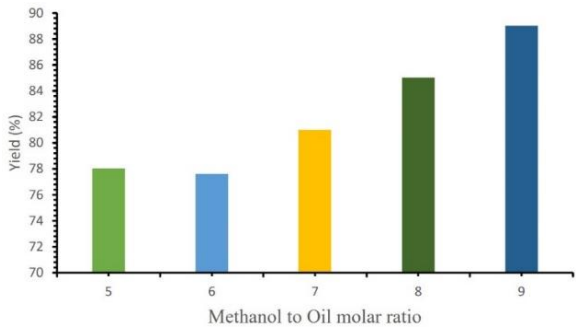


Fig .3: Yield vs Methanol to Oil molar ratio

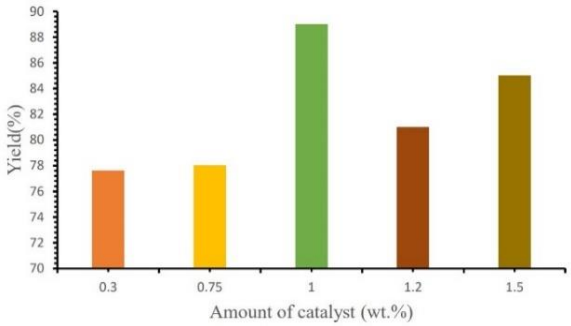


Fig. 4: Yield vs Amount of Catalyst (wt. %)

Conversely, increasing the reaction temperature reduces the reaction yield, as illustrated in Figure 5. However, the optimal process parameters among the five samples are a methanol-to-oil molar ratio of 9:1, a catalyst ratio of 1 wt. % and a reaction temperature of 62°C at a reaction time of 90 minutes.

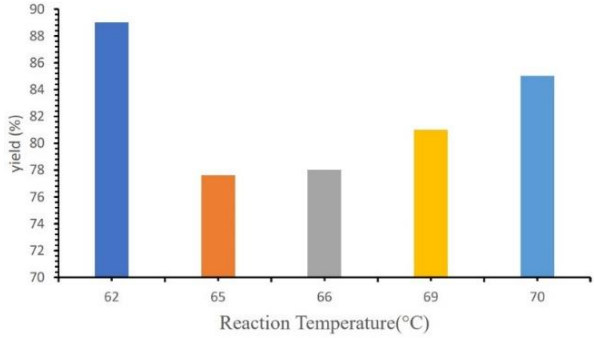


Fig. 5: Yield vs Reaction Temperature (°C)

3.4 Properties of biodiesel

Table 3 illustrates the fuel characteristics of the maximum-yield biodiesel. The characteristics of biodiesel were measured for the biodiesel which was produced under optimal the condition. Furthermore, the obtained biodiesel characteristics are compared with standard ASTM D6751 and standard ASTM D 975 petro-diesel.

Considering this, all the characteristics of the produced biodiesel were within the limit of the standard biodiesel ASTM D6751, except the calorific value. In this case, the produced biodiesel's heat of combustion was excessively high, almost equal to that of petro-diesel. However, in general, the heat of combustion of biodiesel is 11% lower than that of petro-diesel [38]. This may be attributed to the high content of FFA in the feedstock, as previously observed by Godson and Vinoth [39].

Table 3: Fuel properties of produced biodiesel

Property	Units	Standard biodiesel ASTM D6751	Standard Diesel ASTM D975	Produced biodiesel
Density @ 25°C	Kg/m^3	880 at 15°C	800-820	883.33
Kinematic viscosity, 33°C	mm^2/s	1.9-6.0@ 40°C	1.9-4.1	5.66
Flash Point	(°C)	`130 Min.	60-80	>100
Fire Point	(°C)	─	─	>100
Calorific Value	MJ/Kg	─	42-46	46.126

4. Conclusion

A non-edible rubber seed oil is implemented in this research to find out its potentiality for biodiesel production using an eggshell-driven nano heterogenous catalyst with an average particle size of 63.95 nm. The following key findings are observed from this work:

- Heterogenous catalyst obtained from calcination of chicken eggshell at 900 °C for 3 hours. FE-SEM and EDX tests are deployed for characterization of the obtained eggshell.
- The maximum 89% yield was obtained under conditions of a 9:1 methanol to oil molar ratio, 1% catalyst loading, a reaction temperature of 62 °C, and a reaction time of 90 minutes.
- Finally, the fuel characteristics of the produced biodiesel were tested and compared with ASTM D6751 standard biodiesel and ASTM D975 standard diesel.

5. References

[1] M. Takase *et al.*, "Application of zirconia modified with KOH as heterogeneous solid base catalyst to new non-edible oil for biodiesel," *Energy Convers Manag*, vol. 80, pp. 117–125, Apr. 2014, doi: 10.1016/j.enconman.2014.01.034.

[2] M. Farooq and A. Ramli, "Biodiesel production from low FFA waste cooking oil using heterogeneous catalyst derived from chicken bones," *Renew Energy*, vol. 76, pp. 362–368, Apr. 2015, doi: 10.1016/j.renene.2014.11.042.

[3] K. Noiroj, P. Intarapong, A. Luengnaruemitchai, and S. Jai-In, "A comparative study of KOH/Al2O3 and KOH/NaY catalysts for biodiesel production via transesterification from palm oil," *Renew Energy*, vol. 34, no. 4, pp. 1145–1150, Apr. 2009, doi: 10.1016/j.renene.2008.06.015.

[4] F. Ma, L. D. Clements, and M. A. Hanna, "The e€ect of mixing on transesteri®cation of beef tallow."

[5] J. M. Fonseca, J. G. Teleken, V. de Cinque Almeida, and C. da Silva, "Biodiesel from waste frying oils: Methods of production and purification," Mar. 15, 2019, *Elsevier Ltd*. doi: 10.1016/j.enconman.2019.01.061.

[6] M. Kirubakaran and V. Arul Mozhi Selvan, "A comprehensive review of low cost biodiesel production from waste chicken fat," 2018, *Elsevier Ltd*. doi: 10.1016/j.rser.2017.09.039.

[7] G. Baskar, I. Aberna Ebenezer Selvakumari, and R. Aiswarya, "Biodiesel production from castor oil using heterogeneous Ni doped ZnO nanocatalyst," *Bioresour Technol*, vol. 250, pp. 793–798, Feb. 2018, doi: 10.1016/j.biortech.2017.12.010.

[8] Z. J. Predojević, "The production of biodiesel from waste frying oils: A comparison of different purification steps," *Fuel*, vol. 87, no. 17–18, pp. 3522–3528, Dec. 2008, doi: 10.1016/j.fuel.2008.07.003.

[9] F. Jamil *et al.*, "Biodiesel production by valorizing waste Phoenix dactylifera L. Kernel oil in the presence of synthesized heterogeneous metallic oxide catalyst (Mn@MgO-ZrO2)," *Energy Convers Manag*, vol. 155, pp. 128–137, Jan. 2018, doi: 10.1016/j.enconman.2017.10.064.

[10] N. Mansir *et al.*, "Modified waste egg shell derived bifunctional catalyst for biodiesel production from high FFA waste cooking oil. A review," Feb. 01, 2018, *Elsevier Ltd*. doi: 10.1016/j.rser.2017.10.098.

[11] Hossain MR, Islam MA, and Siddiki MNA. (2024). Analysis of compression ignition engine performance of a produced B20 flaxseed biodiesel. Am. J. Pure Appl. Sci., 6(5), 152-159. https://doi.org/10.34104/ajpab.024.01520159

[12] A. A. Refaat, "Different techniques for the production of biodiesel from waste vegetable oil," *Int. J. Environ. Sci. Tech*, vol. 7, no. 1, pp. 183–213, 2010, [Online]. Available: www.SID.ir

[13] J. Ahmad, S. Yusup, A. Bokhari, and R. N. M. Kamil, "Study of fuel properties of rubber seed oil based biodiesel," *Energy Convers Manag*, vol. 78, pp. 266–275, 2014, doi: 10.1016/j.enconman.2013.10.056.

[14] A. S. Ramadhas, S. Jayaraj, and C. Muraleedharan, "Biodiesel production from high FFA rubber seed oil," *Fuel*, vol. 84, no. 4, pp. 335–340, Mar. 2005, doi: 10.1016/j.fuel.2004.09.016.

[15] S. B. A. V. Satya Lakshmi, S. Niju, M. S. B. Khadhar Mohamed, and A. Narayanan, "Catalyst Reusability and Kinetic Modeling of Biodiesel Produced from Rubber Seed Oil," *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, pp. 1–16, 2020, doi: 10.1080/15567036.2020.1785056.

[16] J. Gimbun *et al.*, "Biodiesel Production from Rubber Seed Oil Using A Limestone Based Catalyst," *Advances in Materials Physics and Chemistry*, vol. 02, no. 04, pp. 138–141, 2012, doi: 10.4236/ampc.2012.24b036.

[17] M. Morshed, K. Ferdous, M. R. Khan, M. S. I. Mazumder, M. A. Islam, and M. T. Uddin, "Rubber seed oil as a potential source for biodiesel production in Bangladesh," *Fuel*, vol. 90, no. 10, pp. 2981–2986, Oct. 2011, doi: 10.1016/j.fuel.2011.05.020.

[18] R. Meena Devi, R. Subadevi, S. Paul Raj, and M. Sivakumar, "Comparative Studies on Biodiesel from Rubber Seed Oil Using Homogeneous and Heterogeneous Catalysts," *Int J Green Energy*, vol. 12, no. 12, pp. 1215–1221, Dec. 2015, doi: 10.1080/15435075.2014.893879.

[19] R. K. Elango, K. Sathiasivan, C. Muthukumaran, V. Thangavelu, M. Rajesh, and K. Tamilarasan, "Transesterification of castor oil for biodiesel production: Process optimization and characterization," *Microchemical Journal*, vol. 145, pp. 1162–1168, Mar. 2019, doi: 10.1016/j.microc.2018.12.039.

[20] A. Navajas, T. Issariyakul, G. Arzamendi, L. M. Gandía, and A. K. Dalai, "Development of eggshell derived catalyst for transesterification of used cooking oil for biodiesel production," *Asia-Pacific Journal of Chemical Engineering*, vol. 8, no. 5, pp. 742–748, Sep. 2013, doi: 10.1002/apj.1715.

[21] S. Tang, H. Zhao, Z. Song, and O. Olubajo, "Glymes as benign co-solvents for CaO-catalyzed transesterification of soybean oil to biodiesel," *Bioresour Technol*, vol. 139, pp. 107–112, 2013, doi: 10.1016/j.biortech.2013.04.022.

[22] W. Suryaputra, I. Winata, N. Indraswati, and S. Ismadji, "Waste capiz (Amusium cristatum) shell as a new heterogeneous catalyst for biodiesel production," *Renew Energy*, vol. 50, pp. 795–799, Feb. 2013, doi: 10.1016/j.renene.2012.08.060.

[23] S. Niju, K. M. M. S. Begum, and N. Anantharaman, "Preparation of biodiesel from waste frying oil using a green and renewable solid catalyst derived from egg shell," *Environ Prog Sustain Energy*, vol. 34, no. 1, pp. 248–254, Jan. 2015, doi: 10.1002/ep.11939.

[24] X. Liu, H. He, Y. Wang, S. Zhu, and X. Piao, "Transesterification of soybean oil to biodiesel using CaO as a solid base catalyst," *Fuel*, vol. 87, no. 2, pp. 216–221, Feb. 2008, doi: 10.1016/j.fuel.2007.04.013.

[25] P. L. Boey, G. P. Maniam, and S. A. Hamid, "Performance of calcium oxide as a heterogeneous catalyst in biodiesel production: A review," Mar. 15, 2011. doi: 10.1016/j.cej.2011.01.009.

[26] Y. B. Cho and G. Seo, "High activity of acid-treated quail eggshell catalysts in the transesterification of palm oil with methanol," *Bioresour Technol*, vol. 101, no. 22, pp. 8515–8519, Nov. 2010, doi: 10.1016/j.biortech.2010.06.082.

[27] Z. Wei, C. Xu, and B. Li, "Application of waste eggshell as low-cost solid catalyst for biodiesel production," *Bioresour Technol*, vol. 100, no. 11, pp. 2883–2885, Jun. 2009, doi: 10.1016/j.biortech.2008.12.039.

[28] N. Viriya-Empikul, P. Krasae, W. Nualpaeng, B. Yoosuk, and K. Faungnawakij, "Biodiesel production over Ca-based solid catalysts derived from industrial wastes," *Fuel*, vol. 92, no. 1, pp. 239–244, Feb. 2012, doi: 10.1016/j.fuel.2011.07.013.

[29] A. Piker, B. Tabah, N. Perkas, and A. Gedanken, "A green and low-cost room temperature biodiesel production method from waste oil using egg shells as catalyst," *Fuel*, vol. 182, pp. 34–41, Oct. 2016, doi: 10.1016/j.fuel.2016.05.078.

[30] Y. C. Sharma, B. Singh, and J. Korstad, "Application of an efficient nonconventional heterogeneous catalyst for biodiesel synthesis from pongamia pinnata oil," *Energy and Fuels*, vol. 24, no. 5, pp. 3223–3231, May 2010, doi: 10.1021/ef901514a.

[31] Y. H. Tan, M. O. Abdullah, C. Nolasco-Hipolito, and Y. H. Taufiq-Yap, "Waste ostrich- and chicken-eggshells as heterogeneous base catalyst for biodiesel production from used cooking oil: Catalyst characterization and biodiesel yield performance," *Appl Energy*, vol. 160, pp. 58–70, Dec. 2015, doi: 10.1016/j.apenergy.2015.09.023.

[32] M. G. Kulkarni and A. K. Dalai, "Waste cooking oil - An economical source for biodiesel: A review," Apr. 26, 2006. doi: 10.1021/ie0510526.

[33] I. M. Rashid, M. A. Atiya, and B. H. Hameed, "Production of Biodiesel from Waste Cooking Oil using Cao-Egg Shell Waste Derived Heterogeneous Catalyst," *International Journal of Science and Research (IJSR)*, vol. 6, no. 11, pp. 94–103, Nov. 2017, doi: 10.21275/art20177723.

[34] O. Awogbemi, F. Inambao, and E. I. Onuh, "Modification and characterization of chicken eggshell for possible catalytic applications," *Heliyon*, vol. 6, no. 10, Oct. 2020, doi: 10.1016/j.heliyon.2020.e05283.

[35] Y. S. Erchamo, T. T. Mamo, G. A. Workneh, and Y. S. Mekonnen, "Improved biodiesel production from waste cooking oil with mixed methanol–ethanol using enhanced eggshell-derived CaO nano-catalyst," *Sci Rep*, vol. 11, no. 1, Dec. 2021, doi: 10.1038/s41598-021-86062-z.

[36] W. Roschat *et al.*, "Catalytic performance enhancement of CaO by hydration-dehydration process for biodiesel production at room temperature," *Energy Convers Manag*, vol. 165, pp. 1–7, Jun. 2018, doi: 10.1016/j.enconman.2018.03.047.

[37] B. A. V. S. L. Sai, N. Subramaniapillai, M. S. B. Khadhar Mohamed, and A. Narayanan, "Optimization of continuous biodiesel production from rubber seed oil (RSO) using calcined eggshells as heterogeneous catalyst," *J Environ Chem Eng*, vol. 8, no. 1, Feb. 2020, doi: 10.1016/j.jece.2019.103603.

[38] A. Okullo, A. K. Temu, P. Ogwok, and J. W. Ntalikwa, "Physico-Chemical Properties of Biodiesel from Jatropha and Castor Oils," 2012.

[39] S. A. Shaban, "Biodiesel production from waste cooking oil," 2012. doi: 10.18510/ijsrtm.2015.383.