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CHARACTERIZATION AND UTILIZATION OF GUINEA FOWL EGGSHELLS AS A RENEWABLE SOURCE OF CALCIUM OXIDE IN BIODIESEL PRODUCTION

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ABSTRACT

This study investigates the characterization and sustainable production of calcium oxide (CaO) derived from guinea fowl eggshells, emphasizing its application in biodiesel production. The calcination of eggshells at 1000 °C for three hours resulted in a CaO catalyst with a basicity of 2.92 mmol/g, indicating a high number of basic sites conducive to catalytic activity. Fourier Transform Infrared Spectroscopy (FTIR) analysis confirmed the presence of significant functional groups, including the Ca-O bond and hydroxyl groups. The transesterification process was optimized, achieving a maximum biodiesel conversion rate of 92.8% at a 1:15 oil-to-methanol molar ratio, 2% catalyst loading, and a reaction temperature of 60 °C after three hours. These findings highlight the potential of utilizing agricultural waste, such as guinea fowl eggshells, for sustainable energy production, contributing to the reduction of environmental impacts associated with fossil fuel usage.

Keywords:), Biodiesel Production, Calcium Oxide (CaO), Guinea Fowl Eggshells Heterogeneous Catalysis, Transesterification

INTRODUCTION

The exponential growth in the world's population and the overuse of fossil fuels have raised concerns worldwide. The usage of renewable energy has been increasingly popular around the world in recent years due to two main factors: the depletion of non-renewable energy sources and the negative environmental effects of using fossil fuels. Nation is shifting to greener, more sustainable energy systems as global awareness of the need to address climate change grows. In addition to lowering greenhouse gas (GHG) emissions, this change is necessary to guarantee long-term energy security if fossil fuels become unprofitable in the future ((BP 2023).

These plus the injurious environmental effect associated with fossil fuels necessitated the search for alternative renewable sources(Bello & Haladu, 2023). In the presence of either homogeneous or heterogeneous catalysts, short-chain alcohol and oil or fat are used in the manufacture of biodiesel. (Bello & Haladu, 2023) The fact that heterogeneous catalysts may regenerate themselves, do not require washing the biodiesel product to remove them, and are inexpensive and non-corrosive makes them ideal for industrial use. These and other benefits have drawn more attention to heterogeneous catalysts. (Díaz-Muñoz L et al., 2022). Biodiesel burned cleaner and released far less sulfur dioxide, hydrocarbons, particulate matter, and carbon monoxide into the atmosphere than conventional petroleum diesel. In addition, compared to petroleum diesel, the biodiesel possessed higher miscibility and lubricity, a higher cetane number, and a higher flash point.(Oyelaran et al., 2021).

Eggshells, particularly those from poultry, have gained attention as a viable bio-waste resource rich in calcium carbonate ($CaCO_3$) as heterogenous catalyst. (Waheed et al., 2020) Through thermal decomposition, this $CaCO_3$ can be converted into calcium oxide. While chicken eggshells have been widely studied, guinea fowl eggshells remain underexplored despite their higher density and structural advantages, making them a promising candidate for sustainable calcium oxide production.(Waheed et al., 2020)

The process of producing biodiesel involves the use of either homogeneous or heterogeneous catalysts along with oil, fat, or short-chain alcohol (Bello & Haladu, 2023). Due to their advantages for industrial applications, heterogeneous catalysts have garnered more interest. These advantages include the fact that the catalyst may regenerate itself, does not require washing the biodiesel product to remove it, and is both affordable and non-corrosive.(Bello & Haladu, 2023)

This study delves into the characterization and sustainable production of calcium oxide from guinea fowl eggshells, with a focus on their application in biodiesel production. Biodiesel, a renewable alternative to fossil fuels, has gained momentum as part of global efforts to reduce greenhouse gas emissions and dependence on petroleum. Calcium oxide plays a critical role in the transesterification process, where it catalyzes the conversion of fats and oils into biodiesel. Utilizing guinea fowl eggshells, an often-discarded waste product, not only contributes to the circular economy but also provides an eco-friendly alternative to traditional limestone-based calcium oxide.

The specific objectives of this study are to characterize the structural and chemical properties of guinea fowl eggshells for calcium oxide production. It aims to optimize the calcination process to efficiently convert eggshell calcium carbonate into calcium oxide. The study also seeks to evaluate the catalytic performance of the produced calcium oxide in biodiesel production. Finally, it will assess the sustainability and environmental impact of using guinea fowl eggshells as a resource for both calcium oxide production and biodiesel catalysis.

Experiments

Materials

The Rice bran oil was purchased from Kura market, Kura Local Government area Kano. The guinea fowl eggshells were Purchase from the Kwanar Dangora Market at Kano State, Nigeria. Sodium hydroxide (NaOH), methanol with purity greater than 99% and 37% purity Hydrochloric acid (HCl) were purchased from Shugaba Scientific and chemical Reagent, Katsina road, Kano State. Chemicals of analytical grade were used without further purification.

Sample Preparation

The guinea fowl eggshells were carefully washed with running water, rinsed with distilled water, and dried in a hotair oven at 100 °C. The dried eggshells were crushed, sieved through 65 mesh and stored in a tie container.

Calcination

The Prepared Egg shell was converted into CaO through calcination at 1000 °C temperature for three hours in a muffle furnace under static air conditions as described by (Pedavoah et al., 2018). The produced CaO catalyst was stored in a desiccator to prevent it from absorbing moisture and reacting with CO_2 in the atmosphere.

Catalyst Characterization

Basic Back Titration

A centrifuge tube Containing 0.15 g of the CaO catalyst was filled precisely with 10 ml of pure water, and the tube was allowed to stand for 24 hours. After the mixture was centrifuged, 10 mL of 0.05 M HCl solution, three drops of methyl orange indicator, and 0.02 M NaOH solution were added to the separated supernatant solution and titrated.

FTIR Analysis

FTIR analysis was conducted using Cary 630 Agilent technology FTIR spectrophotometer. The sample was placed directly onto the ATR crystal, and the spectrometer was recorded in the range of 4000 to 400 cm^{-1}. The analysis of both uncalcined and calcined eggshells was performed.

Transesterification Reaction

Transesterification is the technological route used for biodiesel production, and can be applied on a small scale, as in laboratories, or in industry, producing millions of gallons of biofuel. Although the esterification also results in biodiesel and is recommended when the raw material is composed of oils rich in free fatty acids, this technique is applied commercially in a few industries (Friedrich, 2003).

A precise 10 milliliters of Rice bran oil were put into a conical flask and heated to 60 degrees Celsius using a magnetic stirrer on a hot plate. Subsequently, 0.5 weight percent of calcium oxide catalyst was weighed, combined with methanol in a 1:9 oil to methanol molar ratio, and mixed with the heated oil while continuously stirred at 60 degrees Celsius for an hour. After that, the products were left to cool and settle in a separation funnel for the entire night to extract the biodiesel from the glycerol and settled catalyst. The process was repeated for optimization of the biodiesel, changing the catalyst amount to 1%, 1.5%, and 2%, the oil to methanol ratio to 1:12, 1:15, and 1:18; and the time to one and a half hours, two hours, two and a half hours, and three hours. The percentage conversion was computed by comparing the acid value of biodiesel with that of oil using Equation (1) (Bello & Haladu, 2023).

$$Conversion(\%) = 1 - \frac{Acid\ value\ of\ Biodiesel}{Acid\ value\ of\ Oil} \qquad 1.$$

Free Fatty Acid (FFA) Determination

To determine the free fatty acid (FFA) content of the oil, a standard solution of 0.1 M KOH was prepared as the titrant. Exactly 1.5 g of the oil sample was weighed and transferred to a conical flask to which 50 cm^3 of Propan-2-ol was added with stirring until dissolution. 3-4 drops of Phenolphthalein indicator were added to the mixture. The potassium hydroxide solution was titrated against the mixture in the conical flask to the immediate purple colour change and the volume of the titrant (V) recorded. The acid value (AV) of the sample was then calculated using Equation 2.(Ejeh & Aderemi, 2019.)

$$\mathrm{AV} = \frac{\mathrm{M} \times \mathrm{V} \times 56.1}{\mathrm{W\ of\ the\ oil}} \qquad 2.$$

Where M is the concentration of KOH, V is the volume of titrant used; W is the weight of oil sample. The free fatty acid (FFA) content was determined using Equation 3.

$$FFA = \frac{AV}{2} \qquad 3$$

RESULTS AND DISCUSSION

Characterization of the Catalyst

The functional groups found in the GFE-CaO were verified using Fourier transform spectra (Figures 1 and 2). The uncalcined GFEs showed two medium absorption peaks 877 and 717 cm^{-1}, one broad band at 1082 cm^{-1}, and a sharp peak at 1402 cm^{-1}. These peaks correspond to carbonate CO_3^{2-} ion vibration bands. The FT-IR spectra display strong peaks at approximately 3644 cm^{-1}, which are indicative of the –OH groups of Ca $(OH)_2$, which are generated when CaO absorbs water(Sulaiman et al., 2020).

The calcined sample has this absorption band visible. Since peak size is correlated with compound concentration, the intensities of the distinctive $CaCO_3$ peaks at 717cm^{-1} and 877 cm^{-1} disappeared and decreased as the calcination temperature increased. It suggested that the amount of $CaCO_3$ reduced as it transformed into CaO. (Pedavoah et al., 2018)

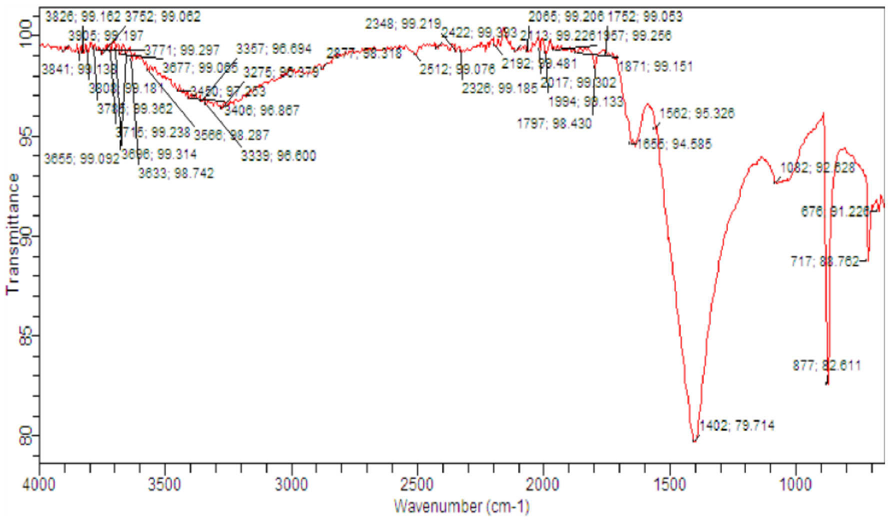

figure 1. FTIR of uncalcined guinea fowl eggshell

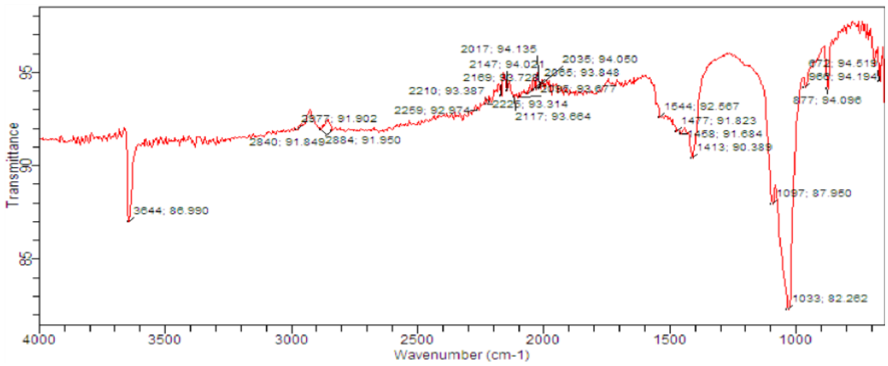

Figure 2. FTIR of calcined guinea fowl eggshell

High basic sites for the eggshell-derived catalyst were indicated by the basic back titration analysis that was conducted on the calcined eggshell, with results as high as 2.933 mmol/g. Because of this, it is very likely that the CaO catalyst made from eggshells will exhibit greater catalytic activity when evaluated in a methanolysis reaction.

3.2 Transesterification Reaction

The study investigated various biodiesel production processes, focusing on their limitations, advantages, and necessary improvements. Results showed that using calcium oxide (CaO) as a catalyst significantly enhances methyl ester yield. The methanol to oil molar ratio is a key factor in biodiesel conversion, with the conversion rate increasing from 60% to 80.4% as the molar ratio rises from 1:6 to 1:15. The highest conversion rate of 92.8% was achieved at a 1:15 molar ratio after 3 hours. However, further increasing the methanol ratio did not improve conversion due to dilution of the catalyst.

Table 1. Biodiesel conversion at different oil: methanol molar ratio and catalyst amount

Oil: methanol /catalyst amount	1:6	1:9	1:12	1:15
0.5%	60.20%	65.50%	72.20%	79.40%
1.0%	72.10%	74.50%	80.32%	84.20%
1.5%	76.40%	79.10%	84.90%	83.70%
2.0%	80.10%	84.00%	90.20%	90.80%

Tables 1.0 present the results of the conversion of biodiesel under various reaction conditions. The study of the conversion of biodiesel revealed that the use of CaO as a catalyst had a significant effect on the methyl esters yield. One of the most important variables affecting the conversion of rice bran oil to biodiesel is the methanol to oil molar ratio; as it increases from 1:6 to 1:15, the methyl ester conversion increases from 60 to 90.20%, indicating the effect of the methanol to oil ratio on the purity of the methyl ester in the product. The highest conversion (90.8%) was obtained at the molar ratio of 1:15 for three hours. However further increases in the methanol to oil molar ratio did not promote the conversion of biodiesel(Muhammad Bello et al., 2017)

Eggshells, particularly from poultry, are emerging as a promising bio-waste material rich in calcium carbonate ($CaCO_3$), which can be thermally decomposed to produce calcium oxide. Most studies have focused on chicken eggshells due to their widespread availability. However, guinea fowl eggshells, which are less studied, have unique properties that may offer advantages in calcium oxide production. Guinea fowl eggshells, characterized by a higher density and stronger structure than chicken eggshells, present an untapped potential for sustainable calcium oxide production.

CONCLUSION

In this study CaO catalyst was Produce from waste guinea fowl eggshells, and from the result of FTIR Analysis the Peak from the spectrum shows that the band at 665 cm^{-1} and disappearing of 717 cm^{-1} Due to increase in temperature corresponding to the Ca-O bond. This is also confirmed by the appearance of Ca (OH) peak around 3644cm^{-1}, due to absorption of water attached to Ca^{2+}. A result of 2.92 mmol/g was obtained from the basic back titration, which suggests many numbers of basic sites. As a result, the catalyst's activity test indicated that an 3hour of reaction duration, a 1:15 oil to methanol molar ratio, 2% catalyst loading, and a reaction temperature of 60 °C produced the highest yield, or 90.80% conversion. In addition to reducing environmental threats, the inexpensive manufacturing of CaO catalyst from eggshell waste will lower the cost of biodiesel.

REFERENCES

Bello, A. M., & Haladu, I. (2023). A Guinea Fowl Eggshells Derived Calcium Oxide Catalyst for Transesterification of Coconut Oil. Universal Journal of Catalysis Science, 2–8. https://doi.org/10.37256/ujcs.1120232184

BP p.l.c. (2023). Statistical Review of World Energy 2023.

Díaz-Muñoz L, Reynel-Ávila H, Mendoza-Castillo D, & Bonilla-Petriciolet. (2022). . Preparation and Characterization of Alkaline and Acidic Heterogeneous Carbon-Based Catalysts and Their Application in Vegetable Oil Transesterification to Obtain Biodiesel. International Journal of Chemical Engineering., 1–13.

Ejeh, J., & Aderemi, B. (n.d.). Production of Biodiesel from Shea Butter Oil using Homogeneous Catalysts. http://ljs.academicdirect.org/

Muhammad Bello, A., Rahim Yacob, A., & Suleiman Kabo, K. (2017). Optimization study of corn oil methanolysis using NaOH-modified mesoporous γ-Alumina. In Malaysian Journal of Catalysis (Vol. 2). http://mjcat.utm.my/

Oyelaran, O. A., Oluwatoyin Ogundana, T., Adetayo, O. A., Borisade, S. G., & Adedayo, O. A. (2021). Waste shells of chicken and guinea fowl eggs as catalysts for the production biodiesel (Vol. 23, Issue 1). http://www.cigrjournal.org

Pedavoah, M.-M., Badu, M., Boadi, N. O., & Awudza, J. A. M. (2018). Green Bio-Based CaO from Guinea Fowl Eggshells. Green and Sustainable Chemistry, 08(02), 208–219. https://doi.org/10.4236/gsc.2018.82015

Sulaiman, N. F., Yacob, A. R., & Lee, S. L. (2020). Transesterification reaction from rice bran oil to biodiesel over heterogeneous base calcium oxide nanoparticles catalyst. Science and Technology Indonesia, 5(3), 62–69. https://doi.org/10.26554/sti.2020.5.3.62-69

Waheed, M., Yousaf, M., Shehzad, A., Inam-Ur-Raheem, M., Khan, M. K. I., Khan, M. R., Ahmad, N., Abdullah, & Aadil, R. M. (2020). Channelling eggshell waste to valuable and utilizable products: A comprehensive review. Trends in Food Science & Technology, 106, 78–90. https://doi.org/10.1016/J.TIFS.2020.10.009