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Production Optimization of Biodiesel from African Elemi (*Canarium schweinfurthii*) Oil via Base-Catalysed Transesterification Using Response Surface Methodology

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Abstract-* *The increasing global energy demand, depletion of fossil fuel reserves, and environmental concerns have intensified the search for sustainable alternative fuels. This study investigated the production and optimization of biodiesel from African elemi (**Canarium schweinfurthii*****) oil through base-catalysed transesterification using sodium hydroxide (NaOH) and Central Composite Design (CCD) in Design-Expert software. The study involved oil extraction, physicochemical characterization, process optimization, biodiesel production, and product characterization. Mechanical extraction produced oil containing 71.46% volatile matter and several long-chain fatty acids, including oleic, palmitic, linoleic, myristic, decosenoic, octanoic, tetradecanoic, pentanoic, eicosanoic, and heptacosanoic acids. The initial high acid value of the oil was reduced through acid esterification using hydrochloric acid (HCL). A total of 30 experimental runs were conducted to optimize the effects of reaction temperature, catalyst concentration, methanol-to-oil ratio, and reaction time. The optimum conditions of 70°C, 120 min, 1.0 wt.% NaOH, and a 1:1 methanol-to-oil ratio produced the highest biodiesel yield of 95.2%. The gas chromatography and mass spectroscopy (GC–MS) analysis confirmed fatty acid methyl ester (FAME) conversions of 88–97%, while the Fourier Transform Infra-Red Spectrophotometer (FTIR) analysis identified characteristic functional groups associated with biodiesel. The biodiesel exhibited flash point (126–150°C), viscosity (4.8–6.7 cP), density (0.95–1.00 g/cm³), acid value (0.69–2.56 mg KOH/g), calorific value (34–36 MJ/kg), and cetane number (45.92–46.19), indicating satisfactory fuel properties. The findings demonstrate that African elemi oil is a promising feedstock for biodiesel production and that CCD effectively optimizes the transesterification process for high biodiesel yield.***

Keywords: Sustainable Materials, Synthesis, Processing and Recycling; Empirical Study, Transesterification, African Elemi Oil, Process Optimization, Biodiesel.

I. INTRODUCTION

The continued dependence on fossil fuels has raised concerns about greenhouse gas emissions, climate change, energy insecurity, and the depletion of petroleum resources, creating the need for sustainable alternative fuels. Biodiesel has emerged as a promising renewable substitute for conventional diesel due to its biodegradability, renewability, low toxicity, and favourable combustion characteristics, including reduced emissions of particulate matter, carbon monoxide, hydrocarbons, and sulfur oxides (Meher et al., 2006; Awogbemi et al., 2021; Mandari & Kumar, 2022; Wang et al., 2023). Although edible vegetable oils are widely used for biodiesel production, concerns over food security, land use, and production cost have encouraged research into non-edible and underutilized feedstocks (Norjannah et al., 2016; Mandari & Kumar, 2022). African elemi (*Canarium schweinfurthii*) oil is considered a promising feedstock because of its relatively high oil content, favourable fatty acid composition, and availability in sub-Saharan Africa (Odjobo & Umar, 2019; Omeje et al., 2022). However, studies optimizing biodiesel production from African elemi oil remain limited.

Biodiesel is commonly produced through transesterification, in which triglycerides react with a short-chain alcohol in the presence of a catalyst to produce fatty acid methyl esters and glycerol. The process is influenced by reaction temperature, reaction time, catalyst concentration, and methanol-to-oil ratio, making optimization of these parameters essential for achieving high biodiesel yield and quality (Thanh et al., 2012; Talha & Sulaiman, 2016;

Mandari & Kumar, 2022). Response Surface Methodology (RSM), particularly Central Composite Design (CCD), provides an effective statistical approach for optimizing multiple process variables while reducing experimental runs and identifying their interactions (Myers et al., 2016; Box & Draper, 2007; Montgomery, 2020). In this study, RSM-CCD was employed to optimize biodiesel production from African elemi oil through alkaline-catalyzed transesterification using sodium hydroxide (NaOH), while physicochemical analyses, FTIR, and GC–MS were used to evaluate the fuel properties and chemical composition of the oil and biodiesel (Silverstein et al., 2014; Ishaya et al., 2025). The study therefore seeks to establish optimum production conditions and assess the suitability of African elemi oil as a sustainable non-edible feedstock for biodiesel production.

II. Materials and Methods

i. Materials

African elemi (*Canarium schweinfurthii*) fruits were sourced from Jos Plateau State, Nigeria, while methanol (99.8%) and sodium hydroxide (NaOH) were used as the alcohol reagent and alkaline catalyst, respectively. Analytical-grade KOH, sulphuric acid, phenolphthalein, isopropyl alcohol and distilled water were also used. The experimental work employed a temperature-controlled magnetic stirrer, digital weighing balance, Fourier Transform Infrared Spectrometer (FTIR), and Gas Chromatography–Mass Spectrometry (GC–MS).

ii. Methods

a. Oil Extraction and Characterization

The African elemi fruits were sorted, washed, softened in hot water and separated to obtain the pulp, which was sun-dried and mechanically pressed for oil extraction. The crude oil was filtered and oven-dried to remove impurities and residual moisture. Its physicochemical properties, including density, specific gravity, viscosity, acid value, free fatty acid, peroxide value, saponification value, iodine value and refractive index, were determined. GC–MS was used to determine the fatty acid composition, while FTIR identified the characteristic functional groups in the oil, following established procedures for the characterization of vegetable oils for biodiesel production (Meher et al., 2006; Knothe et al., 2015; Silverstein et al., 2014; Ishaya et al., 2025).

b. Biodiesel Production

Biodiesel was produced through homogeneous alkaline-catalysed transesterification using methanol and sodium hydroxide (NaOH). Sodium methoxide was prepared by dissolving the catalyst in methanol before it was added to the preheated African elemi oil. The reaction mixture was continuously stirred under the conditions specified by the experimental design. After the reaction, the mixture was allowed to settle for separation of biodiesel and glycerol. The biodiesel layer was collected, washed with warm distilled water to remove residual catalyst and impurities, and dried before characterization. This procedure is consistent with established alkaline transesterification methods for biodiesel production (Meher et al., 2006; Ejikeme et al., 2010; Thanh et al., 2012; Mandari & Kumar, 2022; Naseef & Tulaimat, 2025).

c. Experimental Design and Process Optimization

Response Surface Methodology (RSM) based on Central Composite Design (CCD) was employed to optimize the transesterification process. The investigated variables were reaction temperature (40–70 °C), reaction time (30–120 min), catalyst concentration (0.4–1.0 wt.% NaOH), and methanol-to-oil ratio, while biodiesel yield was selected as the response. Thirty experimental runs were generated using CCD to develop a second-order polynomial model for predicting biodiesel yield. The experimental data were analysed using Design-Expert® software, while analysis of variance (ANOVA) was used to determine the significance of the model and interactions among the process variables. Response surface and contour plots were subsequently generated to identify the optimum operating conditions (Myers et al., 2016; Box & Draper, 2007; Montgomery, 2020). The use of RSM and CCD for biodiesel optimization has been widely demonstrated to improve process prediction and yield while reducing the number of experimental runs (Silva et al., 2011; Goyal et al., 2012; Enweremadu & Rutto, 2015; Najafi et al., 2018; Aseibichin et al., 2024).

d. Biodiesel Characterization

The optimized biodiesel samples were evaluated for important physicochemical and fuel properties, including density, kinematic viscosity, acid value, flash point, cloud point, pour point, iodine value, cetane number, calorific value and sulphur content. The results were compared with the requirements of ASTM D6751 and EN 14214 biodiesel standards (Knothe et al., 2015). GC–MS was used to determine the fatty acid methyl ester (FAME) composition, while FTIR was employed to confirm the conversion of triglycerides into fatty acid methyl esters through the identification of characteristic ester functional groups (Silverstein et al., 2014; Mustafa et al., 2023; Ishaya et al., 2025)

III. RESULTS AND DISCUSSION

3.1 Characterization of African Elemi Oil

Mechanical pressing of African elemi (*Canarium schweinfurthii*) fruits produced approximately 35% oil recovery, confirming its potential as a non-edible biodiesel feedstock. The extracted oil exhibited physicochemical characteristics suitable for biodiesel production, although its relatively high acid value and free fatty acid content indicated the need for appropriate pretreatment before alkaline transesterification. The oil also showed favourable elemental characteristics, including relatively low sulfur content.

3.2 Optimization of Biodiesel Production

Response Surface Methodology using Central Composite Design was employed to investigate the effects of catalyst concentration, reaction temperature, reaction time and methanol-to-oil ratio on biodiesel yield. The optimization produced a maximum experimental biodiesel yield of 95.2%. The optimum conditions were 70 °C reaction temperature, 120 min reaction time, 1.0 wt.% NaOH catalyst concentration and a 1:1 methanol-to-oil ratio. These results demonstrate the suitability of RSM-CCD for optimizing biodiesel production from African elemi oil.

3.3 Biodiesel Fuel Properties

The optimized biodiesel exhibited generally favourable physicochemical and fuel characteristics, including appropriate acid value, density, flash point, pour point, calorific value and cetane number. These properties indicate that the produced biodiesel possesses characteristics relevant to its potential application as a renewable diesel substitute.

3.4 FTIR and GC–MS Analysis

FTIR analysis confirmed the presence of characteristic ester functional groups associated with fatty acid methyl esters, while GC–MS verified the formation of methyl ester compounds following transesterification. The combined analytical results therefore confirmed the successful conversion of African elemi oil into biodiesel and support its potential as a sustainable non-edible feedstock.

IV. CONCLUSION

The study showed that African elemi (*Canarium schweinfurthii*) oil is a promising non-edible feedstock for biodiesel production, achieving an optimized biodiesel yield of 95.2% using Response Surface Methodology and Central Composite Design. The favourable fuel properties and successful confirmation of fatty acid methyl esters by FTIR and GC–MS further support its potential as a sustainable alternative feedstock for biodiesel production.

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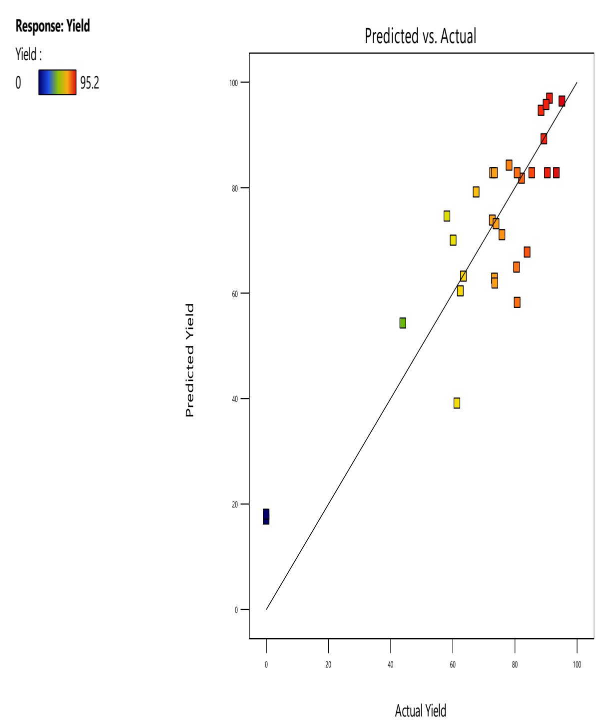
APPENDIX



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