



## ENGINE PERFORMANCE AND EMISSION CHARACTERISTICS OF GMELINA-MUCUNA BIODIESEL OIL BLENDS PRODUCED USING TITANIUM OXIDE CATALYST

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### Abstract

This study investigates the engine performance and emission characteristics of biodiesel blends produced from *Mucuna pruriens* and *Gmelina arborea* oils using a titanium oxide catalyst. Biodiesel-diesel blends ranging from B10 to B100 were tested in a single-cylinder compression ignition engine under varying load conditions and compared with conventional diesel fuel. Performance parameters including brake power, mechanical efficiency, and specific fuel consumption were evaluated alongside exhaust emissions such as smoke opacity and carbon dioxide. Results indicate that brake power and mechanical efficiency increased with load for all fuels, with moderate blends (B10-B20) showing performance comparable to diesel. Biodiesel blends exhibited higher fuel consumption but significantly lower smoke emissions and improved combustion efficiency. Overall, B20 emerged as the most balanced blend, combining acceptable engine performance with enhanced emission and sustainability benefits.

**Keywords:** Biodiesel blends; *Mucuna pruriens*; *Gmelina arborea*; Engine performance; Exhaust emissions.

### Introduction

Escalating concerns about climate change, fossil fuel depletion, and energy insecurity have accelerated the global transition toward renewable, clean, and sustainable energy systems [1]. Among renewable options, biodiesel has emerged as among the leading renewable candidates to displace conventional diesel due to its

biodegradability, lower greenhouse gas emissions, improved lubricity, and compatibility with existing compression-ignition (CI) engines, which require only minor modifications [2]. Biodiesel is typically produced through the transesterification of triglycerides from vegetable oils or animal fats with short-chain alcohols, yielding fatty acid methyl esters

(FAMES) that are suitable for use as fuel [3]. Many studies exist on the performance and emission characteristics of compression ignition (CI) engines fueled with biodiesel and biodiesel–diesel blends. Some representative studies include the works of [4], who examined the effect of cerium oxide ( $\text{CeO}_2$ ) and cerium composite oxide nanoparticles on exhaust emissions from a diesel engine fueled with waste cooking oil (WCO) biodiesel. The nano-additives were blended at low concentrations to improve combustion under full-load conditions. Results showed that both  $\text{CeO}_2$  and its composite oxide significantly reduced carbon monoxide (CO) and unburned hydrocarbons (HC) by catalyzing more complete combustion. The cerium composite oxide achieved slightly better emission reduction than pure  $\text{CeO}_2$ . However, nitrogen oxides ( $\text{NO}_x$ ) rose somewhat due to higher in-cylinder temperatures. Overall, cerium-based nano-additives enhance biodiesel combustion efficiency and reduce the emission of harmful exhaust gases.

The study of [5] investigated the effect of adding nanoparticles with dispersants to diesel-biodiesel blends on combustion, engine performance, and emissions in a direct-injection compression-ignition engine. Nanoparticles were dispersed to enhance fuel stability and promote better atomization and combustion. Engine tests measured cylinder pressure, heat release, brake thermal efficiency (BTE), fuel consumption, and exhaust emissions under varying load conditions. Results showed improved combustion with higher peak pressures and heat release, increased BTE, and reduced brake-specific fuel consumption.

Emissions of carbon monoxide (CO), hydrocarbons (HC), and smoke opacity decreased significantly, while nitrogen oxides ( $\text{NO}_x$ ) increased slightly due to higher combustion temperatures. Similarly, [6] examined the Cost, Emission, and Thermo-Physical Determination of Heterogeneous Biodiesel from Palm Kernel Shell Oil: Optimization of Tropical Egg Shell Catalyst and observed some similar trend in emission characteristics. The study [7] compared graphene oxide (GO) and graphene nanoplatelets (GNP) as fuel additives in a diesel engine fueled with a diesel biodiesel (B20) blend. Nanoparticles (25-75 ppm) were ultrasonically dispersed to enhance combustion. At 50 ppm GNP, the engine showed the highest improvement: brake thermal efficiency (BTE) increased by 5.8%, and **brake**-specific fuel consumption decreased by 6.4% compared to B20 alone. CO and HC emissions dropped by 21% and 27%, while smoke opacity decreased by 18%.  $\text{NO}_x$  emissions rose slightly (6%) due to higher combustion temperatures. GNP outperformed GO in combustion enhancement and emission reduction, demonstrating strong potential as a fuel additive.

Furthermore, the majority of reported processes still rely on homogeneous catalysts, which create downstream separation challenges, generate wastewater, and have limited reusability. Our study introduces a new feedstock pairing, *Mucuna pruriens* (velvet bean) and *Gmelina arborea* (white teak). These two hardies, non-edible tropical oilseeds are abundant in Nigeria but largely underutilized in biodiesel research. While *Mucuna* has shown promising yields

and nitrogen-fixing benefits for degraded soils, and Gmelina is a fast-growing and carbon-sequestering species, no previous work has systematically blended these two oils to exploit their complementary fatty acid profiles for improved fuel quality and process stability. The objective of this study is to produce biodiesel blends from *Mucuna pruriens* and *Gmelina arborea* oils and to assess their engine performance and exhaust emission characteristics in a compression ignition engine.

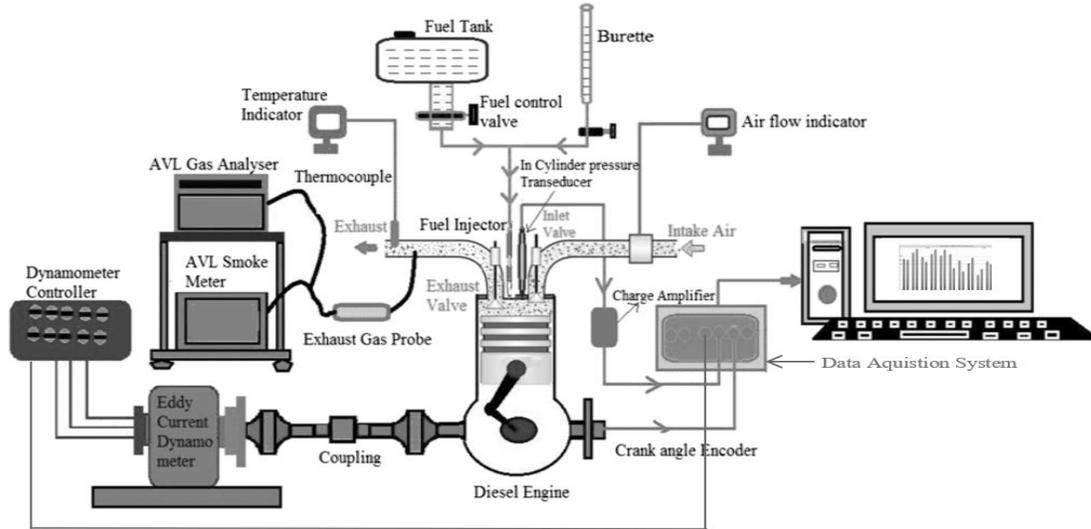
## 2.0 Materials and methods

Gmelina and mucuna were harvested from their parent fruits were air-dried and manually cleaned to eliminate foreign particles. The dried biomass was milled using an industrial grinder, after which 100 g of the pulverized material was placed inside a semi-permeable cotton pouch and loaded into the thimble of a 500 ml Soxhlet extractor. Subsequently, 400 ml of n-hexane was poured into a 500 mL round-bottom flask. The Soxhlet apparatus, containing the thimble-encased sample, was assembled and connected to a condenser fixed on the solvent flask. Heating was initiated on a controlled hot plate while cooling water circulated through the condenser jacket to maintain continuous solvent reflux. Extraction was allowed to proceed until no visible oil residue

remained in the extraction chamber. The spent biomass (defatted residue) in the membrane was discarded, and the solvent-oil mixture collected in the flask was subjected to distillation to recover n-hexane, leaving the extracted oil behind [8,9]. For performance and emission analysis, various biodiesel-diesel blend ratios were prepared and designated as B5, B10, B15, B20, B25, B30, B35, and B40, where the numeric value represents the percentage of biodiesel in the blend. B100 denotes pure biodiesel, while D100 refers to conventional petroleum diesel used as the baseline fuel

### 2.1 Engine characteristics

In this study, the environmental performance of the produced biodiesel was evaluated by analyzing its exhaust emission characteristics. A gas analyzer was employed to quantify the emission levels during combustion of the blends in a test engine. A single-cylinder diesel engine (Lombardini DIESEL 3LD 510), Figure 1 and fully with specifications in Table 1, was used for the experimental investigation. The gas analyzer was connected directly to the engine exhaust line to monitor real-time emissions. Pollutants such as carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), and exhaust smoke opacity were measured using an integrated exhaust gas analyzer and smoke meter to assess the combustion cleanliness and environmental impact of the biodiesel blend.



**Figure 1.** Schematic setup of diesel test bed.

**Table 1.** Engine specification

Parameter	Specification
Engine type	Single cylinder, four stroke, water cooled, compression ignition (CI) engine
Bore	82 mm
Stroke	110 mm
Compression ratio	16.5:1
Speed	1500 rpm
Rated Power	3.7 kW
Cubic capacity	556.24 cc

### 3.0 Results and discussion

Figure 2 compares diesel engine performance using biodiesel blends (B10-B100) and conventional diesel (D100) under varying loads, focusing on brake power (BP) and mechanical efficiency ( $\eta_m$ ). At low load (1.0 kW), D100 recorded the highest BP (58 kW) and efficiency (88%), while biodiesel blends exhibited progressively lower values with increasing biodiesel content due to lower

calorific value and higher viscosity affecting combustion [10]. As load increased to 2.5 kW, BP increased for all fuels, reaching 86 kW for D100 and 79, 74, 71, 67, and 56 kW for B10-B100, respectively, indicating partial compensation for biodiesel's lower energy density at higher combustion temperatures and pressures [11, 12]. Mechanical efficiency followed a similar trend, with D100

remaining highest (88-91%), B10-B20 showing comparable values (82-86%), and B100 recording the lowest (78-80%). Overall, moderate blends, particularly B20, provide a practical compromise between

engine performance, emission improvement, and sustainability, whereas higher blends favor environmental benefits at the expense of power output

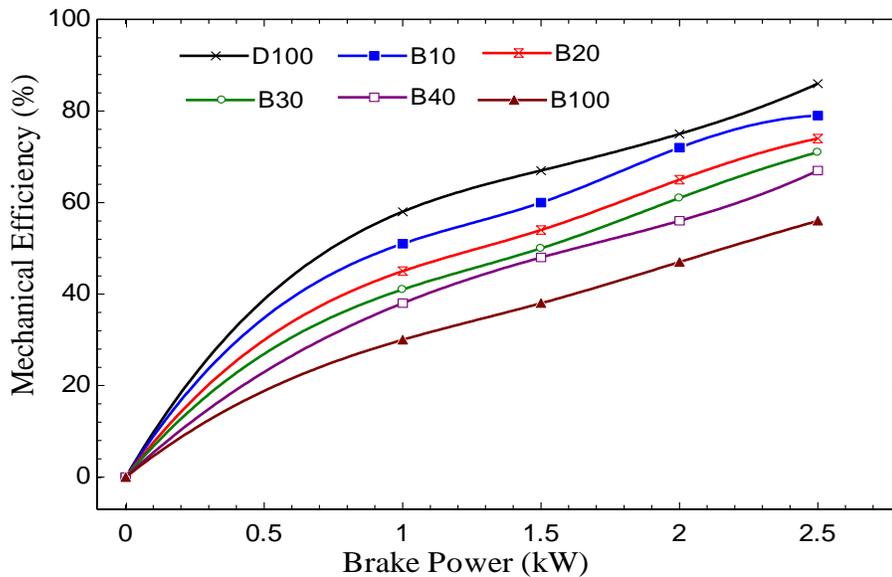


Figure 2. Effect of brake power on mechanical efficiency

Figure 3 shows the variation of specific fuel consumption (SFC) with brake power (BP) for biodiesel blends (B10–B100) compared with diesel (D100). At low BP (1.0 kW), all fuels exhibited high SFC due to poor combustion efficiency, with D100 at 0.42 kg/kWh and higher values for biodiesel blends, increasing with biodiesel content [13]. As BP increased to 2.0-2.5 kW, SFC decreased for all fuels, reaching about 0.30

kg/kWh for D100 and 0.33-0.46 kg/kWh for B10–B100, owing to improved combustion at higher temperatures and pressures. Although biodiesel blends consistently showed higher SFC due to lower energy content, the difference reduced at higher loads. Among the blends, B20 performed best, combining acceptable fuel economy with sustainability benefits.

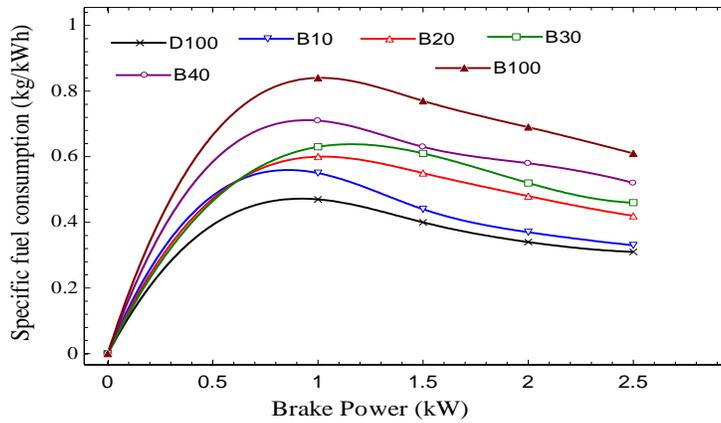


Figure 3. Effect of brake power on specific fuel consumption

Figure 4 illustrates that exhaust smoke intensity decreases with increasing brake power for all fuels, reflecting improved combustion at higher engine loads. At 1.0 kW, D100 produced the highest smoke opacity (58%), while biodiesel blends showed progressively lower values, decreasing to 39% for B100. As brake power increased to 2.5 kW, smoke levels dropped to

41% for D100 and 24% for B100. This trend indicates enhanced combustion temperature and turbulence at higher loads [14, 15]. The consistently lower smoke emissions of biodiesel blends are attributed to their inherent oxygen content, which promotes more complete oxidation of hydrocarbons and particulates.

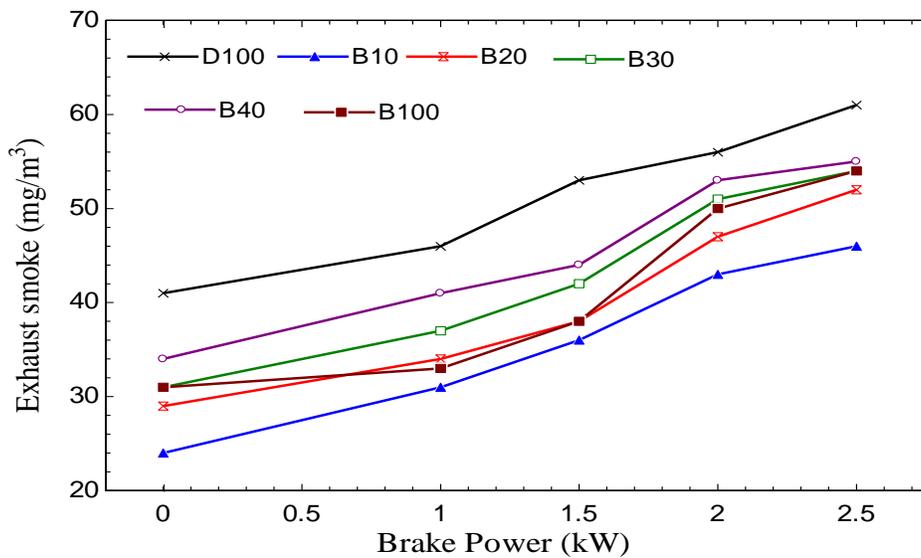


Figure 5. Effect of brake power on exhaust smoke

Figure 6 shows that CO<sub>2</sub> emissions increase with brake power for diesel and biodiesel blends, indicating more complete combustion at higher loads. At 1.0 kW, CO<sub>2</sub> concentration ranged from 3.2% for D100 to 4.6% for B100, while at 2.5 kW it increased to 4.8% and 6.5%, respectively. The higher CO<sub>2</sub> emissions from biodiesel blends are attributed to their oxygenated nature, which promotes complete oxidation of carbon and

reduces incomplete combustion products such as CO and unburnt hydrocarbons. Although B100 produced the highest CO<sub>2</sub> levels, this reflects improved combustion efficiency rather than adverse emission performance [16-18]. Overall, biodiesel blends recorded 10-25% higher CO<sub>2</sub> emissions than diesel, confirming cleaner and more efficient combustion.

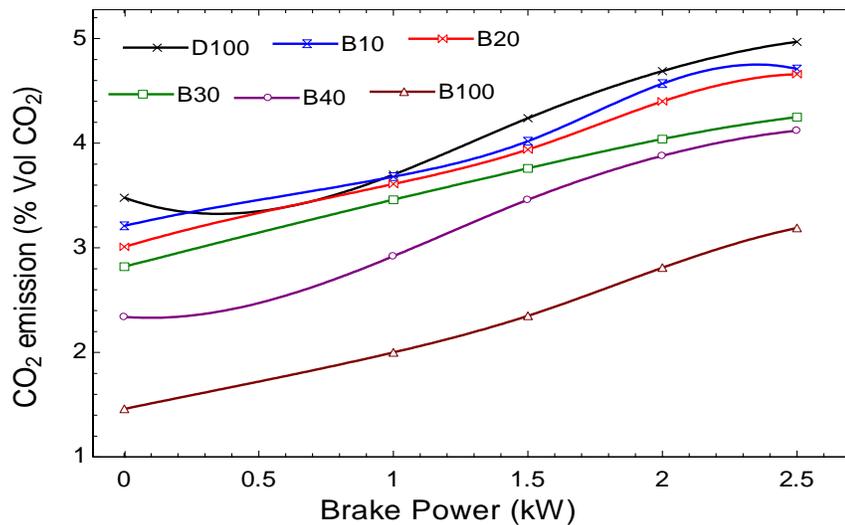


Figure 6. Effect of brake power on CO<sub>2</sub> emissions

#### 4.0 Conclusion

The present study demonstrates the technical feasibility and environmental advantages of biodiesel produced from blended *Mucuna pruriens* and *Gmelina arborea* oils in compression ignition engines. Engine performance analysis showed that brake power and mechanical efficiency increased with increasing load for all fuels, although higher biodiesel fractions resulted in reduced power output due to lower calorific value and increased viscosity. However, moderate blends, particularly B10 and B20, delivered

performance levels close to conventional diesel, confirming their suitability for practical engine operation without modification. Specific fuel consumption was consistently higher for biodiesel blends, especially at low loads, but the disparity reduced significantly at higher brake power, indicating improved combustion efficiency under increased temperature and pressure conditions. Emission analysis revealed a substantial reduction in exhaust smoke opacity with biodiesel use, attributable to the inherent oxygen content of biodiesel that

promotes complete oxidation of hydrocarbons. Although CO<sub>2</sub> emissions increased with biodiesel concentration and load, this trend reflects more complete combustion rather than adverse environmental impact, as it coincides with reduced toxic emissions such as CO and unburnt hydrocarbons. Overall, the study confirms that Mucuna–Gmelina biodiesel blends, particularly B20, offer a viable, sustainable alternative to fossil diesel, balancing engine performance, emission reduction, and renewable energy utilization in line with clean energy transition goals.

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