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RESEARCH ARTICLE

Garcinia gummi-gutta biodiesel dipped with Fe_3O_4 immobilizer is a superior blend for a stationary diesel engine

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Abstract

This study investigates biodiesel blends made from Garcinia gummi-gutta in single-cylinder diesel engines. The research aims to test blends B10, B20, B30, B40, and B100 by conducting trials on constant-speed diesel engines running at 1500 rpm. A notable aspect of this work is the inclusion of Garcinia gummi-gutta biodiesel blends having immobilized Fe_3O_4 nanoparticles. Key findings show that the performance of blend B10 is 29.99%, which is very close to that of conventional diesel. The blends have specific 0.15 MJ/KWh for B10 and 0.16 MJ/KWh for B20, which are like the fuel consumption rate of diesel. B10 and B20 produce pressures of 56.98 bar and 54.42 bar, respectively. The B10 blend has the highest heat release rate of 71 J/^{o}CA, once again it is shown to be a favorable blend when compared to diesel. Emissions analysis has shown that the B20 and B30 blends have produced marked reductions in carbon monoxide (CO) emissions of 18.42% and 19.20%, respectively, compared with diesel. In addition, NOx emissions from the B10 blend are very low (700 ppm). The B40 blend proves the lowest hydrocarbon emissions at 58.1 ppm. Therefore, the use of Garcinia gummi-gutta biodiesel shows promising combustion performance and emissions characteristics comparable to those of diesel, thereby meeting sustainable energy goals.

Keywords: Garcinia, gummi, gutta, novel fuel, emissions, green energy, sustainable energy goals

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1. Introduction

An earlier summary of global energy consumption highlighted that the principal share of energy consumed derives from the combustion of petroleum-based fuels in internal combustion IC engines [1]. Worldwide consumption totals 86.5 million barrels per day of oil and 261 billion cubic feet per day of gasoline. Based on recent consumption rates, worldwide reserves of oil and natural gas will be depleted in 40 and 60 years, respectively. Hydrocarbon and liquid fuels account for a dominant share, attributable to their intrinsic physicochemical and oxidation characteristics [2]. Regrettably, stocks of non-renewable energy fuels have declined, and hence they might remain unused for a decade. An energy scheme for an emerging economy is crucial to the country's overall progress.

Compared with all the provinces, India is ranked as the world's sixth prime end user of energy drives [3]. Thus, annual claims are expected to increase by 1.5–4.5%, while overall energy demand is expected to increase eightfold by 2030. Annually, India loses a substantial amount of foreign exchange through imports of crude hydrocarbon fuels, which together total nearly 70% of the country's requirement. Currently, the fossil oil demand in India is estimated at 125 million tons, along with a yearly generation yield of 35 million tons [4-5]. Based on the cogent report, demand for crude oil will increase over the coming decades. This scenario has adverse consequences

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for the crude oil production sector, leading to severe fluctuations in petroleum prices and destabilization of continental, national, and global economies. If there is a superior directness compared to current renewable sources, it will provide impetus for expanding global trade in novel oil-producing crops. The Energy Division of the States forecasted that the unfair scenario would cause an ultimate demand of 92% at the time scale of 2035 [6].

Biodiesel is derived from Guar gummi-gutta methyl esters (GGME) and GGME–mineral diesel mixtures. Biofuel was derived from Garcinia gummi-gutta seed oils using an innovative adsorbed enzyme, yielding 93.08% after 76 hours of reaction. Raw GGME was blended with mineral-derived diesel at several percentage levels. The burning, achievement and environmental aspects of the GGME mixtures were assessed [7]. Garcinia is a widely recognized indigenous herbal medicine for weight loss, and many weight-loss supplements worldwide have it. Fruit peels are used as food-preserving agents because they have a high hydroxycitric acid content, which gives them a sour and tart taste; they are also used as a spice [8]. Garcinia kernels also have a great appeal and may be a suitable alternative to fuel and hence help to sustain the environment's position [9,10]. Numerous studies have examined various biodiesel fuels. Immobilized lipoprotein substrates are an interesting area of research, particularly for fuel synthesis. They offer several advantages over conventional organic catalysts, such as specificity, flexibility, and environmental sustainability. Below are a few of the most important reflections:

Immobilized lipases, which can run under a variety of conditions particularly at high temperatures and across a range of pH values, are more stable than free enzymes, which can be denatured by various factors. Reusability: These catalysts can be recycled with minimal loss of activity, making them more economical for industrial use. A new study investigated the use of electromagnetic reinforcements for limited motion, allowing easy separation and reconnection of the accelerator. For example, iron oxide showed favorable performance in compositions. Lipases are the backbone of environmentally friendly manufacturing, ensuring cleaner biodiesel production through reduced use of hazardous chemicals and reduced generation of waste. Unique Substances: Researchers are exploring different substances, including those extracted from oysters that immobilize lipases, making them more thermally stable and effective. The novelty of the present work is the use of Garcinia gummi-gutta as a biodiesel part combined with Fe3O4 (iron oxide magnetic nanoparticles) immobilized in the biodiesel formulation to predict the performance, combustion, and emission parameters in a single-cylinder diesel engine. Studies show that blending alcohol and diesel with Garcinia-derived biodiesel yields improved fuel properties and lower levels of pollutants.

However, slight increases in fuel use due to braking and increased NOx emissions should be examined. Economic Production: Garcinia fruit seeds are rich in oil and show high oil-conversion efficiency for biofuel production. Large-scale manufacturing processes and cost-minimizing strategies could make this biofuel profitable. Optimization of energy characteristics: Garcinia-blended exhibits characteristics like conventional diesel fuel, but further research is needed to perfect its energy efficiency and its compatibility with existing machinery. The use of Garcinia-derived biodiesel can significantly reduce CO and hydrocarbon emissions. However, its life-cycle assessment is needed to quantify its environmental footprint.

2. Material and methods

2.1. Materials

As noted above, improving lipase-immobilized transesterification activity was a prudent strategy that achieved a high yield and produced high-quality biodiesel. In this study, 30 to 70°C and 12 to 74 hrs were taken at the first stage of this procedure with TL immobilized Fe_3O_4 nanoparticles (1 to 6 per cent), raw Garcia fuel (1 Liter), and methanol (2 to 14 per cent). These optimized conditions for this lipase-catalyzed transesterification process are based on earlier research findings. The starting lipase-immobilized catalyst (Fe_3O_4 + Thermocycles lanuginose) transesterification activity was measured in a 500ml empty bottle with an airtight cap. Then, the bottle was loaded with 250 ml of raw Garcinia oil and 1 per cent of immobilized catalyst (Fe_3O_4), which was stirred manually to mix the two, with the bottle occasionally closed and opened to separate them. Pellets were placed in a magnetic stirrer, and the operating conditions were set up with a stirring rate of 800 to 1000 rpm. Typically, the temperature is set to 20°C and the magnetic stirrer runs for 12 h. The magnetic stirring process started in an airtight bottle. The lipase-immobilization transesterification process runs under favorable conditions. When stirring is complete, the immobilized lipase cleaves all the triglycerides in the raw Garcinia oil, converting them to FAME (Garcinia oil fatty acid methyl esters) and glycerol. In addition, the immobilized lipase promotes the reaction and aids in achieving an improved triglyceride ratio in raw Garcinia oil, thereby mitigating excess biodiesel output. The lipase-based reaction was ended, and the raw reaction mixtures were transferred to a separating funnel and stored under calm, equilibrated conditions. Figure 1 shows the preparation of a Garcinia biodiesel blend and the transesterification process. Processing of the trans ester of Garcinia requires specific conditions to maximize yield Temperature: Generally, about 55 to 60°C with homogeneous catalysts such as Hydroxide, while a little higher (about 60°C) with mixed catalysts such as calcium oxide. about 15 minutes of reaction time are needed when catalysts are evenly distributed, and up to an hour when various catalysts are used.

2.2. Methods

The fatty acid methyl esters were then separated, and the resulting extract was processed using a lipase-immobilized catalyst, resulting in increased production rates. Lipase-immobilized transesterification is shown in Figure 1. FAME GO was extracted into a beaker having no substance, and the glycerol content was then separated [11]. Table 1 shows the properties of biodiesel.

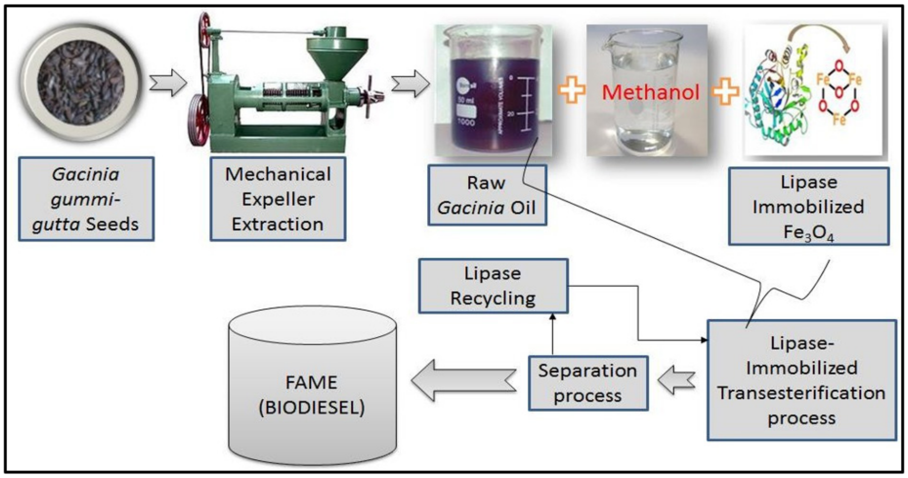

Figure 1. Garcinia biodiesel blend preparation and transesterification

Table 1. Properties of biodiesel

Property	units	ASTM D6751	ASTM D6751	Diesel	B10	B20	B30	B40	B100
Cetane number	-	D2699	55	48	43	40	39	36	34
Heating value	MJ/Kg	D 445	-	43.4	42.90	41.12	40.41	39.20	38.24
Air/fuel ratio	-	D 6751	15.5	14.2	13.4	12.9	12.8	11.1	10.2
Viscosity		D 93	1.8-5.9	2.9	1.8	1.9	1.4	1.3	1.2
Fire point (°C)	(°C)	D 613	89	84	74	72	68	65	55
Density	kg/m^3	D 5865	900	860	852	832	820	811	805
Flash Point	(°C)	D 92	60	55	57	64	62	64	67

The reaction mixture of FAME GO was then heated to 40 °C to remove added water and methanol, as well as impurities present in the biodiesel. This was reacted in different batch procedures for producing Garcinia biodiesel. The conditions found for FAME GO conversion were a reaction temperature of 440 °C, a 5% w/w O4 lipase-immobilised catalyst, a 62-74-hour reaction time, and 6% w/w methanol. In this case, the largest average biodiesel yield was 92.12. Methanol is used to accelerate the reaction and increase the biodiesel yield. After this, it was centrifuged for 12–15 minutes. To decide miscibility, biodiesel was mixed with raw diesel in various proportions, and the mixtures remained blended for 15 to 20 days, with no change saw.

3. Experimental setup

Experimental research was carried out using a Kirloskar DI diesel engine with a rated capacity of 5.2 kW, running under four-stroke conditions at 1500 rpm. The main instrument was mounted on the engine to decide performance under varying loads at a constant speed. Initially, the test engine was run on standard diesel fuel. The changes made to the fuel and the engine are presented in detail. This research focuses on industrial mobile generators and agricultural applications, both using the Kirloskar DI diesel engine. The stationary diesel engine was used to conduct experiments, during which adjustments to the injection timing were made. Figure 2 shows the actual experimental design, and Table 2 lists the engine specifications.

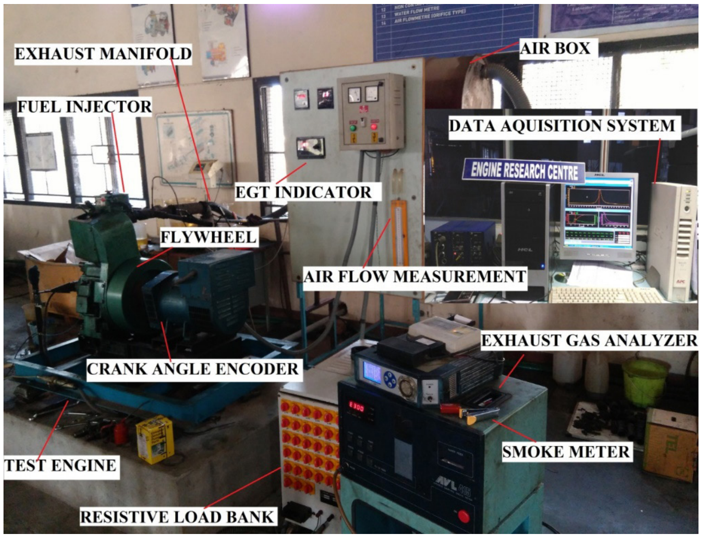

Figure 2. Actual experimental setup

Table 2. Engine specifications

Type	Description
Compression ratio	19:1
Injection timing	23 deg before Top Dead Center
Swept volume	661 cc
Number of nozzles and spray hole diameter	4 and 0.3 mm
Bore and Cooling type	90 mm and air-cooled engine
Rated power and speed	5.2 kW at 1500 rpm
Piston geometry	Hemispherical
Stroke	120 mm
Make	TAF – 1

4. Uncertainity analysis

Various factors can cause errors and ambiguities, including device choice and calibration, environmental conditions, and testing and observation procedures. All these uncertainties can typically be divided into two broad categories: organized errors and random errors. Organized errors affect reliability, while randomness affects quantitative measurements. The different tools employed in this field study are noted, and any variation in the values saw is recorded. The present study considers the uncertainty of the tracked variable within its faithful measurement range. The range of standard deviations denotes the mean range of the results, within which ninety-five per cent of the results fall. Table 3 lists the instruments used and their associated uncertainties. Table 4 presents the measured uncertainty parameters.

Table 3. Instruments uncertainty analysis

S NO	Assessing Instruments	Instrument Range	Reliability	Uncertainty
1	Stop watch	-	± 0.9 s	1.2
2	Transducer	0-200 bar	±0.5 bar	1.6
3	Manometer	0-220 mm	± 10mm	2.2
4	Sensors	1000°C	±0.91	1.6
5	Smoke Meter	25 BSU	±0.4	2.1
6	Tachometer	0-7100 rev/min	± 12 rpm	1.9

Table 4. Measured uncertainty parameters

S NO	Parameters Measured	Percentage in Uncertainty
1	Speed	0.11
2	NOx	0.22
3	Load	0.41
4	BSFC	0.24
5	BTE	0.19
6	CO_2	0.31
7	CO	0.90
8	Fuel flow	0.40
9	HC	1.11
10	Smoke Opacity	1.22

5. Results and discussion

5.1 Brake thermal efficiency

Figure 3 shows the correlation among the thermal efficiencies of all GGME-diesel fuel mixtures. The BTE plots show that the mineral diesel blend has a higher BTE at peak load than other GGME fuel blends do. This can be explained by the influence of the fuel spray properties on the combustion process in the test engine and the viscosity ratios in the mixtures, which results in a drop in BTE [12,13]. The decrease in biodiesel BTE is influenced by the lower energy ratio of GGME biodiesel. The B10 and B20 blends show higher BTE than other blends because their lower viscosity promotes vaporization, fuel atomization, and droplet formation [14].

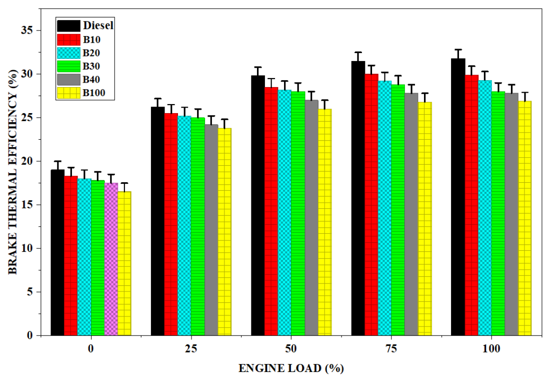

Figure 3. Brake thermal efficiency

As the plot shows, B10 and B20 blends can achieve as much as 75 per cent of the load and can perform similarly to mineral diesel when compared with other fuel combinations. As shown in the thermal efficiency plot, mineral diesel has a BTE of 31.6% at peak load conditions, and BTEs of 29.9%, 28.09%, 27.87%, and 26.9% at B10, B20, B30, and B40, respectively. GGME blend is less effective thermally than the other fuel blends [15]. The same trend is evident across the different biodiesel blends relative to the GGME blend. This can be attributed to friction in the engine, pumping losses, and inefficient work as indicated by the engine [16]. The test results are compared with those of conventional diesel. The test readings showed that the B25 blend can be utilised in diesel engines without any alterations, and the mixture can still provide sufficient heat transfer and reduce emissions during combustion [17].

5.2. Brake specific energy consumption

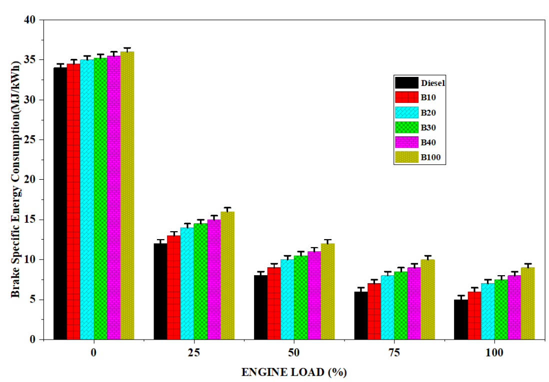

Figure 4. Brake specific energy consumption

Figure 4 shows the differences in brake-specific energy consumption and engine load between Garcinia blends and diesel. The plot shows that the BSEC of GGME diesel blends is larger at lower loads and smaller at higher loads. These blends include B100, which has a higher BSEC than other fuel blends, including mineral diesel, across all peak levels. During peak loading, mineral diesel consumes less energy, but the energy consumption range for both B10 and B20 is minimal owing to their characteristics, including calorific value and viscosity [18]. Moreover, all fuel blends showed a decrease in BSEC values with increasing uniformity and an increase with increasing load conditions, depending on the fuels viscosities, low heating values, and high mass flow rates [19]. Compared with diesel, the B10 blend attains a lower brake-specific energy consumption by 6 MJ/kWh. The B100 fuel blend at 100 per cent load has a fuel consumption of 11 MJ/kWh, which is 22.1 per cent greater than that of diesel, a difference that could be attributed to its (i.e., diesel's) higher Brake Thermal Efficiency and lower density. This is due to an increase in the density of the raw GGME blends, which enables greater fuel discharge during plunger movement and fuel pumping [20,21].

6. Combustion characteristics

6.1. Inline cylinder pressure

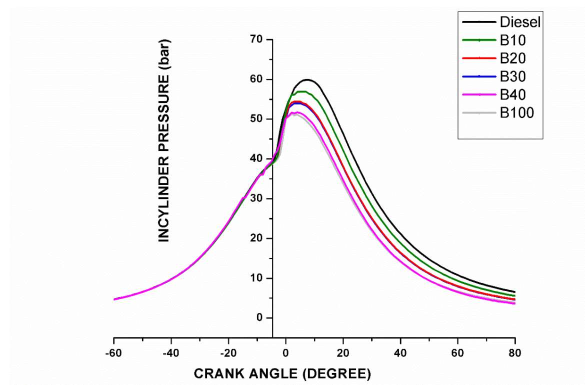

Figure 5. Cylinder pressure vs crank angle

Figure 5 shows the variation of in-cylinder pressure with crank angle for all GGME and diesel blends. Mineral diesel had a wider pressure range in the cylinder than the GGME blends [22]. The plot shows that the B10 (56.98 bar) and B20 (54.42 bar) blends have lower pressure than diesel. The B100 blend had the lowest peak pressure among the fuels. It may be related to high fuel evaporation, which could be associated with increased fuel density, inadequate atomization, and lower calorific values of the raw GGME blend [23]. These factors could also influence the air-fuel ratios and the performance of fuel vaporization. Overall, GGME blends showed a smaller pressure range than diesel, which might be explained by the lower fuel volume during the combustion stroke and the shorter ignition delay [23].

6.2. Heat release rate

Diesel engines release heat at a rate that is critical to combustion dynamics and efficiency. It is defined as the rate of heat production by the engine. This rate may affect the timing of fuel injection and engine horsepower. The attached figure shows the heat release at this stage of testing. Figure 6 shows that the highest heat release rate is obtained with blend B10, at 71 J/^{o}CA. This increase is due to the peak surface-tension level reached by the blend B10 under peak loads, which leads to an increase in heat-release rates. The refined evaporation of the fuel under high pressure and temperature is caused by the unique spray characteristics, including the elevated chamber temperatures and the increased oxidizing ability of the air [24].

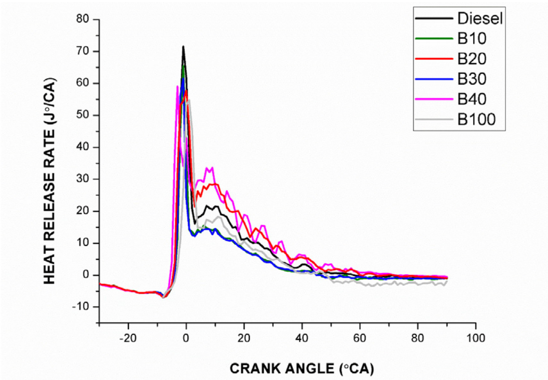

Figure 6. Heat release vs crank angle

7. Emissions

7.1. Carbon dioxide emissions

Figure 7 shows the variation in carbon monoxide emissions from the GGME mixtures. The findings show a slight rise in CO emissions up to 75 per cent load, after which emissions increase steeply under peak-load conditions. This increase has been caused by the pronounced effect of lean combustion mixtures with excess air in the engine. Increased rates of CO combustion are achieved by higher oxygen content in the fuel. As Figure 7 proves, all GGME fuel blends and mineral diesel showed higher CO emissions at peak load than previously. This was because the test fuels formed more homogeneous mixtures, resulting in fewer rich fuel zones and favoring complete combustion. Also, this was accompanied by reduced ID and changes in performance attributed to the increased cetane index of the fuel blends. Mineral diesel produced more CO at peak load than any of the fuel blends. B40 and B100 blends showed much lower CO emissions, of 0.08 per cent and 0.07 per cent, respectively. This is explained by the longer carbon chains of GGME fuels, the lower viscosity and density, and the enhanced atomization of the fuel blends, leading to greater fuel saturation [25].

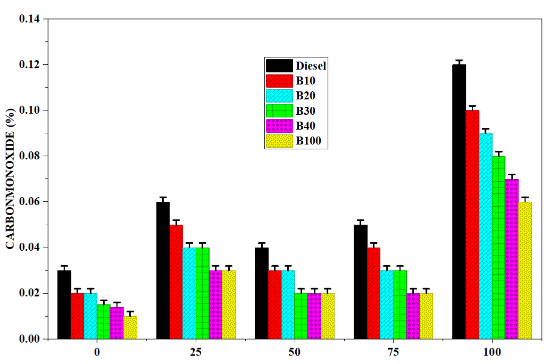

Figure 7. CO emissions

7.2. Unburnt hydrocarbons

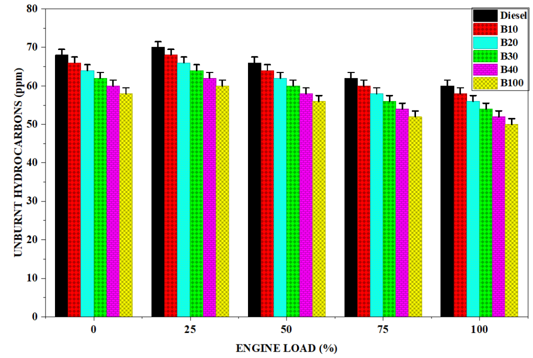

Figure 8. UBHC Emissions

The unburned hydrocarbon emissions from biodiesel are mainly due to its slow combustion. Several factors decide emissions of these pollutants, including fuel mixture, engine operating state, and cylinder design. Biodiesel, also known as biofuel, is a distinctive fuel that is typically oxygenated and is likely to produce fewer unburnt hydrocarbons than conventional diesel. Nevertheless, certain conditions may give rise to related emissions. Poor gas fragmentation, a normal combustion environment, and poor timing of fuel injection [26]. Figure 8 shows unburnt hydrocarbon emissions measured for the various test fuels used in this experiment. Figure 8 shows that certain factors, including fuel flame speed, post-flame oxidized conditions, and fuel-air ratio, positively affect the performance of some blends compared with conventional diesel, but not others. Regions with abundant fuel have the potential to increase the oxidation of unburnt hydrocarbons, thereby decreasing emissions. Emissions from GGME, its mixtures, and diesel show a downward trend under peak-load conditions. The levels of emissions for diesel, B10, B30, and B40 were 66.1 ppm, 60.98 ppm, 59.2 ppm, and 58.1 ppm, respectively. The B100 blend has consistently shown the lowest emissions, at 56.8 ppm. Because the blends offer lower viscosity [27].

7.3. NOx Emissions

Nitrogen oxides (NOx) are released during the combustion of fuel in biofuel engines and are also referred to as nitrogenous pollutants. Interactions of nitrogen in the atmosphere under high-energy conditions lead to the formation of several chemicals, including nitric oxide and nitrogen dioxide. Figure 9 shows the nitrogen emissions from diesel and the various test fuels used in this process. According to the test results, the lowest emissions were seen for B10 at 700 ppm. This is because the cetane number of the B10 blend is higher, and hence the ignition delay is minimal, thus producing very low emissions compared with other blends. The effective and prompt combustion of oxygen and nitrogen molecules within a shorter duration of time also adds to the less emission of the B10 blend compared to others [28].

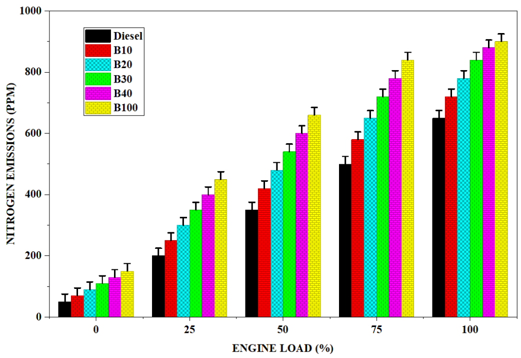

Figure 9. NO_X emissions

7.4. Smoke opacity

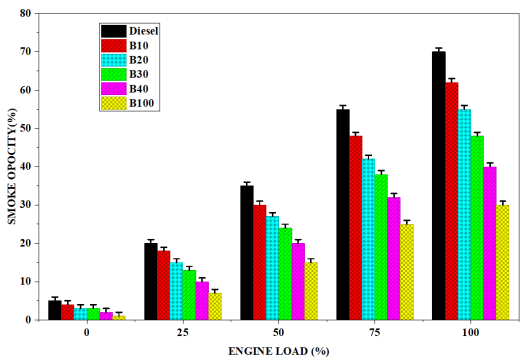

Figure 10. Smoke opacity

Smoke transparency measures the volume of smoke emitted from a diesel engine's tailpipe and shows the level of particulates discharged by the engine, along with fuel efficiency [29]. Smoke from the exhaust system is measured by light obstruction and quantified by a smoke transparency meter, which assesses combustion clarity; high smoke transparency shows insufficient combustion and formation of fine particles. Figure 10 shows the smoke levels during these tests. It proves that minimal smoke formation occurred during the B100 fuel test, reaching 35%. The two fuels produced substantially less smoke than traditional diesel and other blends. This is explained by the fact that pure biodiesel evaporates faster, reacts more readily with oxygen, and releases smoke particles more quickly than diesel fuel [30].

8. Conclusion

The present experimental study investigates the production of biodiesel using a novel immobilized lipase catalyst. The transesterification reaction for biodiesel synthesis was successfully carried out. The resulting biodiesel, termed GGME, was evaluated for its physical and chemical properties, and the findings were compared.

- This study found that GGME fuel and its blends showed low brake thermal efficiency. In particular, the B10 mix achieves a performance of 29.9%.
- Next to diesel, the B10 blend reaches the lowest brake-specific energy consumption by 6 MJ/kWh. The highest fuel consumption for the B100 blend at 100 per cent load was 11 MJ/kWh, 22.1% higher than that of diesel.
- In-cylinder pressure and heat release rate were further analyzed; both properties were low in all GGME blends and in mixtures of GGME blends with diesel. Low calorific value of the fuels, inadequate evaporation rates, and slow fuel atomization caused this.
- The inline cylinder pressure plot shows that the B10 (56.98 bar) and B20 (54.42 bar) blends have lower pressure than diesel. It is worth noting that the B100 blend had the lowest peak pressure among the fuels.
- The highest heat release rate is obtained with blend B10, at 71 J/^{o}CA. This rise occurs because blend B10 achieves a peak surface tension under peak load, which, in turn, results in increased heat discharge rates.
- All GGME blends and mixtures produced reductions in CO, UBHC, and smoke; the more oxygen in the fuel mixture, the less CO was produced, and the leaner the mixture, the fewer UBHC were produced.
- B40 and B100 blends showed much lower CO emissions: 0.08 per cent and 0.07 per cent, respectively. Longer carbon chains of GGME fuels, the fuels' lower viscosity and density, and the enhanced atomization of the fuel blends lead to greater fuel saturation.
- The levels of UBHC emissions are 66.1 ppm for diesel, 60.98 ppm for B10, 59.2 ppm for B30, and 58.1 ppm for B40. The B100 blend has consistently shown the lowest emission level of 56.8 ppm. This is because the blends are less viscous.
- UBHC and smoke emissions because of more complete combustion, which resulted from an increased oxygen ratio and a reduced ignition delay and led to earlier combustion timing and higher cylinder temperatures.
- NOx concentrations were lowest for B10, at around 700 ppm. The B10 blend has a higher cetane number, which implies reduced ignition delay and significantly lower emissions compared with other similar blends.
- The lowest soot was seen during a test of fuel mixture B100 (35%). Rapid evaporation, high reactivity with ozone, and more rapid emission of particulate matter have been cited as reasons for the phenomenon saw for both pure biodiesel and conventional diesel fuel.

8.1. Environmental impact and future scope

Garcinia gummi-gutta biofuels are environmentally friendly, making them proper alternatives to conventional energy sources. Compared with diesel, Garcinia biodiesel blends emit substantially lower amounts of carbon dioxide and heterocyclic pollutants. Mixed blends have shown reductions in carbon monoxide and hydrocarbon emissions. Garcinia seeds are non-edible livestock feedstuffs grown in forested regions, thereby reducing competition with food crops and encouraging biodiversity. Biodiesel derived from Garcinia have low levels of Sulphur, thereby reducing nitrogen oxide pollution, which is a major cause of acid precipitation. Environmental Equality: Garcinia biodiesel is a vegetable-based energy source and is associated with carbon dioxide uptake during feedstock growth, thereby offsetting pollutants generated during combustion. Garcinia biodiesel causes combustion to be more complete, thereby reducing particulates and unrefined molecules. The possible restrictions on Garcinia gummi-gutta biodiesel are extremely high due to high pollutant levels when blended with an immobilizer, such as Fe_3O_2. In future work, the authors plan to include nanomaterials, such as titanium oxide and aluminum oxide.

8.2. Economic and logistical barriers

Garcinia gummi-gutta biofuels also have potential as a clean energy source, but large-scale deployment is hampered by financial and technical hurdles. Gummi-gutta oil processing, along with other steps used to extract oil from Garcinia, is a very costly process, particularly compared with conventional oils. Availability of the materials: Garcinia gummi-gutta trees are widespread in some areas, but occur at low density, which increases the cost of collecting pollen. In the market, it is difficult to compete with established biofuel feedstocks such as maize and rapeseed because they have more efficient supply chains. Administrative capability and technology. There are no specialized facilities for bioenergy retrieval and processing to support the development of this industry. Transferring materials from remote areas to processing facilities presents a significant challenge. Although mixtures of Garcinia gummi-gutta with biodiesel show promising efficacy, engine adjustments are necessary to achieve satisfactory results.

Author contributions statement

K. Sunil Kumar – conceptualization and writing - original draft. T. Sathish – method, software. Premalatha Munuswamy- Formal analysis. J. Jeha - Review & editing, supervision.

Declaration of interests

The authors have any competing financial or personal interests related to this work.

Data availability statement

The datasets used and or analyzed during the current study are available from the corresponding author on reasonable request.

Declaration of generative AI and AI-assisted technologies in the writing process

The authors would like to thank AI-powered writing tools, such as Grammarly, for their aid in enhancing the linguistic precision, correctness of grammatical structures, and the overall coherence of this article. All content, analysis and conclusions contained in this work are the author's own and are not in any way the work of AI. All content, analytical discussion and conclusions presented in this work are the sole work of the author and have not been generated using AI tools for any purpose other than to enhance the presentation and clarity of the text. The use of AI is aligned with the journal's standards of transparency and ethical guidelines in the authoring process.

Appendices

ASTM	American Society for Testing and Materials.
B10	10% Garcina biodiesel + 90% diesel
B20	20% Garcina biodiesel +80% diesel
B30	30% Garcina biodiesel+ 70% diesel.
B40	40 % Garcina biodiesel +60% diesel.
B100	100% Garcina biodiesel
IC	Internal Combustion Engines
CO	Carbon Monoxide
CO2	Carbon dioxide
DI	Direct Ignition
UBHC	Unburnt hydrocarbons
kW	Kilowatts.
Ppm	Parts Per minute
DI	Direct Ignition
ID	Ignition delay
Rpm	Revolutions Per minute
HRR	Heat Release Rate
BTE	Brake thermal efficiency
BSFC	Brake specific fuel consumption
GGME	Garcinia Gummi Methyl Ester

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