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SCIENTIFIC PAPER

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COMBUSTION, PERFORMANCE, AND EMISSION CHARACTERISTICS OF A CI ENGINE USING *BORASSUS FLABELLIFER* BIODIESEL BLENDS

Highlights

- Biodiesel is derived from *Borassus flabellifer*.
- Five biodiesel blends (B20, B40, B60, B80, and B100) are examined in a diesel engine.
- HC, CO, and smoke emissions were found to be lower, while NO_x emissions were observed to be higher.
- Performance of the biodiesel blends was comparable to that of the diesel fuel.

Abstract

Borassus flabellifer methyl esters (BFMEs) have a few attractive characteristics that make them a potential rival to diesel and other alternative fuels. This study presents the first comprehensive analysis of its performance, combustion, and emission characteristics in a diesel engine. In addition to a high calorific value, a high cetane number, and the availability of oxygen, constituting 10% of its total weight, it is also readily available. Experimental testing of BFMEs was conducted on a single-cylinder compression ignition (CI) engine in this stage. BFMEs were blended with diesel at various concentrations (20%, 40%, 60%, 80% and 100%). Blends of BFMEs were experimentally examined for their combustion properties, emissions, and performance. The CI engine was set to steady-state operation so that it would reach the optimum temperature for the conditions in which it was operating. Initially, it was found that neat BFMEs had the lowest thermal efficiency, while BFME20, BFME40, BFME60, and BFME80 all had a higher brake thermal efficiency (BTE) than BFME100 at rated load conditions (by 5.1%, 2.8%, 2.0%, and 1.4%, respectively). Compared to other blends, BFME20 and BFME40 have better fuel efficiency. Fuel efficiency was improved by a reasonable amount, and BFME20's consumption was reduced by 5.1% compared to BFME100. Compared to diesel, hydrocarbons, CO, and smoke emissions from BFME20 were reduced by 9.9%, 5.8%, and 3.71%, respectively. These results underscore the potential of low-ratio BFME blends as cleaner and more efficient biodiesel alternatives, highlighting BFME's practical applicability in existing diesel engines without major modifications.

Keywords: Biodiesel, Borassus flabellifer, Combustion, Performance and emission characteristics.

INTRODUCTION

Researchers are constantly investigating potential alternatives to the existing reliance on fossil fuels, which serve as the dominant energy source for industrial purposes. Nowadays, there is a significant focus on the study of combustion processes using alternative fuels, especially for diesel fuel, to bring about transformative changes in the transportation industry [1]. Owing to their various compositions and the lack of experimental response data in the literature, predicting the combustion behavior of these alternative fuels is difficult [2]. The current endeavor is made much more difficult by the presence of this obstacle. The reduction of exhaust emissions is the primary emphasis of research and development for alternative diesel fuels, which is in line with the goals of protecting the environment and saving energy [3]. Synthetic fuels, dimethyl ether, biodiesel, diethyl ether (DEE), methane, alcohols, and hydrogen are important alternatives to conventional fuels [4]. Decisions regarding future fuels are constrained by variables including fuel availability, production feasibility, and transportation logistics. The choice is

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primarily led by energy efficiency and emissions analyses [5] carried out to evaluate the engine characteristics of different alternative fuels (rice bran oil, mahua oil, linseed oil) in a single-cylinder, 4-stroke diesel engine. This study aimed to evaluate these options in comparison to conventional mineral diesel. As a result of their high viscosity, low volatility, and polyunsaturation, these oils blended with diesel revealed operational and durability concerns compared to plain vegetable oils. During blending with linseed oil methyl ester, the severity of these problems reduced. Economic analysis showed that vegetable oil derivatives could replace mineral diesel at a lower cost, eliminating fossil fuel dependence. The engine characteristics of a diesel engine running on poon oil in its purest form as well as in a variety of blends with diesel. Poon oil was blended with diesel to solve issues associated with carbon deposits and poor atomization, which come with vegetable oils [6]. Lower viscosity, enhanced volatility, enhanced combustion properties, less carbon deposits, and decreased nitrogen oxide (NO_x) emissions were among the favorable outcomes. The study revealed that combining poon oil with diesel could improve diesel engine performance and emissions while decreasing brake thermal efficiency (BTE). The experiment test was conducted on a single-cylinder, 4-stroke, variable compression ratio (VCR) multi-fuel engine was powered by waste cooking oil methyl ester and a variety of blends with regular diesel [7]. While comparing the biodiesel blends with diesel, it was found that biodiesel blends resulted in significant improvements in performance characteristics. These benefits included an increase in BTE as well as decreased emissions of hydrocarbons (HC), CO, and CO_2. However, there was a surge in NO_x emissions. An investigation of the karanja oil blends (20-50%) on emissions and performance in a DI-CI engine showed that the addition of karanja oil has resulted in improved combustion pressure (CP) and heat release rate (HRR) and decreased emissions of HC, CO, and smoke [8]. An exhaustive study on the performance and tailpipe emissions of a HINO H07C DDF engine powered by various fuels, including biodiesel. Compared to diesel, biodiesel showed better levels of torque and horsepower, indicating that it can serve as an ecologically aware alternative for heavy transportation fleets. As a result, CO_2 and NO_x emissions increased, which constituted a trade-off [9]. The combustion and thermal efficiency of a diesel engine fueled with diesel and linseed oil. The study found that the quantity of linseed oil had a non-monotonous effect on engine performance, with the best combustion characteristics obtained when using a blend containing 20% of linseed oil [10]. The efficiency and emissions of a single-cylinder, 4-stroke diesel engine powered by biodiesel generated from Euglena sanguinea algae. The findings demonstrated that emissions of HC and CO substantially decreased up to the ES30 blend ratio; however, emissions of NO_x were slightly increased [11]. The effectiveness and characteristics of pollutants in biodiesel sourced from rubber seed oil. The results demonstrated that the B10 blend displayed the most favorable brake-specific fuel consumption (BSFC) and BTE. A significant concern about biodiesel blends is the slight rise in NO_x emissions [12]. The effect of karanja biodiesel on the engine performance of a compression ignition engine has exhibited a slight decrease in BTE and an increase in BSFC. Additionally, there was a reduction in HC and CO emissions, alongside a slight increase in NO_x emissions [13]. The effects of neem biodiesel blended with diesel on the efficiency and exhaust emissions of a VCR engine. The study revealed that blends of biodiesel made primarily from neem oil, especially those with a higher compression ratio, may offer an eco-friendly substitute for regular diesel fuel while preserving or enhancing emissions and engine performance [14]. Compared to diesel, this technique reduces emissions of CO by 14% and NO_x by 3%. Emission data may be continuously and instantly monitored with the use of an Internet of Things emission monitoring kit [15]. The utilization of kapok oil methyl esters (KOMEs) as a biodiesel by blending it with conventional diesel fuel at volumetric ratios of 10%, 20%, and 30%, resulting in KOME10, KOME20, and KOME30 blends, respectively. The combustion analysis revealed that, during stationary engine operation, both the peak cylinder pressure (Pmax) and the maximum net heat release rate (HRRmax) were lower than those of pure diesel. In a common rail direct injection (CRDI) system, the Pmax increased by 13-15% and HRRmax by 16-32% compared to diesel. Examination of engine emissions revealed a reduction in carbon dioxide (CO_2), unburned hydrocarbons (UBHCs), and smoke concentrations in all KOME blends. Nitric oxide (NO) emissions showed a slight increase, rising around 0.7-1.5% in the stationary mode and 1.3-8% in the CRDI mode relative to diesel. The results suggest that KOME blends could be a viable alternative fuel for non-road direct injection diesel engine applications [16]. The performance of a 5-25% polanga biodiesel blend study found the B10 performance equivalent to diesel fuel and reduced emissions, suggesting that polanga biodiesel could be a promising future fuel with a focus on balancing the emissions and performance in the diesel engine [17]. There have been numerous studies conducted on plant-based oils; however, this particular study is among the first to methodically investigate the combustion, emission, and performance properties of BFME in a CI engine by utilizing a variety of blend ratios. Comparison study of a single-cylinder diesel engine operating at a constant speed using different fuel blends are displayed in Table 1. The upward direction represents an increase, while the downward direction represents a loss.

This study compares the performance of an engine with different biodiesel blends of *Borassus flabellifer* methyl esters (BFMEs) using a consistent experimental setup. *B. flabellifer* oil was used for the transesterification process of producing biodiesel. Each blend was compared with diesel fuel by using it in a diesel engine and obtaining engine performance values. All data were then compared graphically with each other and with diesel fuel to determine the most suitable blend.

Table 1. Comparison study of a single-cylinder diesel engine operating at a constant speed using different fuel blends.

Fuel type	Efficiency		Emission Characteristics				Reference
	BSFC	BTE	CO	NO_x	HC	Smoke	
Waste sunflower & kohlrabi grape seed oil	↓	↑	↓	↑	↓	↓	[18]
Poppy and Canola Oils	↓	↑	↓	↑	↓	↓	[19]
Waste sunflower and cotton oil	↓	↑	↓	↑	↓	↓	[20]
Kapok oil	↓	↑	↓	↑	↓	↓	[21]
Coconut waste cooking oil	↓	↑	↓	↓	↓	↓	[22]
Rice bran oil	↓	↑	↓	↓	↓	↓	[23]
Rapeseed oil	↑	↑	↓	↑	↓	↓	[24]
Juliflora seed oil	↓	↑	↓	↑	↓	↑	[25]
Borassus flabellifer oil	↓	↑	↓	↑	↓	↓	Present study

MATERIALS AND METHODS

B. flabellifer Biodiesel

The oil extracted from *B. flabellifer* was purchased in a local market in the Indian state of Tamil Nadu. From a chemical distributor, anhydrous methanol, acetic acid, and potassium hydroxide were obtained. The quality of the chemicals used in this process was suitable for analytical usage. The transesterification process (Figure 1) was carried out using a conical flask that was fitted with a thermometer, a magnetic stirrer, and a reflux condenser. *B. flabellifer* oil was added to the flask at first, and it was preheated to 65 °C. Methanol was used to dissolve potassium hydroxide, which was used as a catalyst. The solution obtained was then added to the shaking flask, and a 2h timer was used to monitor the reaction. After that, the mixture was allowed to sit in a separating funnel so that the glycerol layer was able to be extracted. After being rinsed twice with warm water containing 5% acetic acid, methyl esters were finally washed with water. Remaining methanol and water were removed from biodiesel using a rotating evaporator heated to 80 °C in a vacuum. The methyl esters of *B. flabellifer* oil were then dried at 100 °C. The properties of BFMEs are shown in Table 2. The production of the total cost of *Borassus* oil is Rs 36 per litre, which is considerably less than the cost of diesel, Rs 70 per litre. It is valuable to note that the cost will reduce with a rise in mass production and plant facilities.

Properties of Biodiesel

Following the production of the required amount of methyl esters of the oil, the required characteristics of the esters were determined using IS test techniques (IS: 1448). The sample was prepared and tested for physicochemical properties in the ITA lab, Chennai. The experimentation was presented based on various biofuel and basic properties, inclusive of density, calorific value, and cetane number, etc. The properties of all the fuels are tabulated by testing in a local chemical analysis laboratory, as shown in Table 2.

FTIR Analysis

Fourier transform infrared (FTIR) spectroscopy is effective and versatile in evaluating biodiesel quality [26,27]. Figure 2 illustrates that the FTIR spectra of both the raw oil and the produced biodiesel have notable similarities, indicating that the chemical structure and functional groups remained mostly unchanged during the process. Microwave irradiation for localized heating did not elicit any detrimental side reactions. The conversion of triacylglycerol molecules into fatty acid methyl esters and glycerol was successfully achieved. The FTIR spectra display distinct absorption peaks, notably the carbonyl (C=O) stretching at 1744 cm^{-1} and the C-O stretching at 1163 cm^{-1}, consistent with results from prior studies [28], thus confirming the retention of these functional groups in the biodiesel product. The spectra suggest stretching vibrations associated with CH, CH_2, and CH_3 groups at 3003, 2854, and 2922 cm^{-1}, respectively. Bending vibrations (ρCH_2) for these groups are seen at 1375, 1163, and 723 cm^{-1}. The spectral features confirm the structural integrity of the biodiesel and validate the effectiveness of FTIR spectroscopy in evaluating its content and quality.

Test Engine

A four-stroke, water-cooled, vertically mounted, single-cylinder diesel engine with DI was part of the experimental setup. An eddy current dynamometer was used in conjunction with this engine, which had a fixed compression ratio of 16.5 and operated constantly at 1500 rpm. Figure 3 shows the test engine for the experimental setup, and the specifications of the engine are mentioned in Table 3. The accuracy and uncertainty in the measurement of the engine and uncertainty are shown in Table 4. This engine type was selected due to its importance as a primary power source in a variety of Indian industries, including agriculture, construction, industry, and energy generation. The experimental setup includes all the necessary sensors for gauging variables, including air/fuel ratio, cylinder pressure (CP), crank angle (CA), temperature, and load. The engine fuel that was used for testing consisted of a number of different fuel mixes with different concentrations, including B20, B40, B60, B80, and B100. The dependability of the data, as well as its reproducibility, was enhanced by taking the average of the outcomes of each experiment, which was carried out three times. The accuracy of the experiments was checked using an uncertainty analysis that was carried out. To estimate the percentage uncertainties of essential parameters, such as braking thermal efficiency and load, a comparison was made between the percentage uncertainties of the measurement devices and those stated in Table 5. The experimental setup includes all the necessary sensors for gauging variables, including air/fuel ratio, CP, CA, tempera-ture, and load. A data acquisition system connects these instruments to a computer for real-time data collection and analysis.

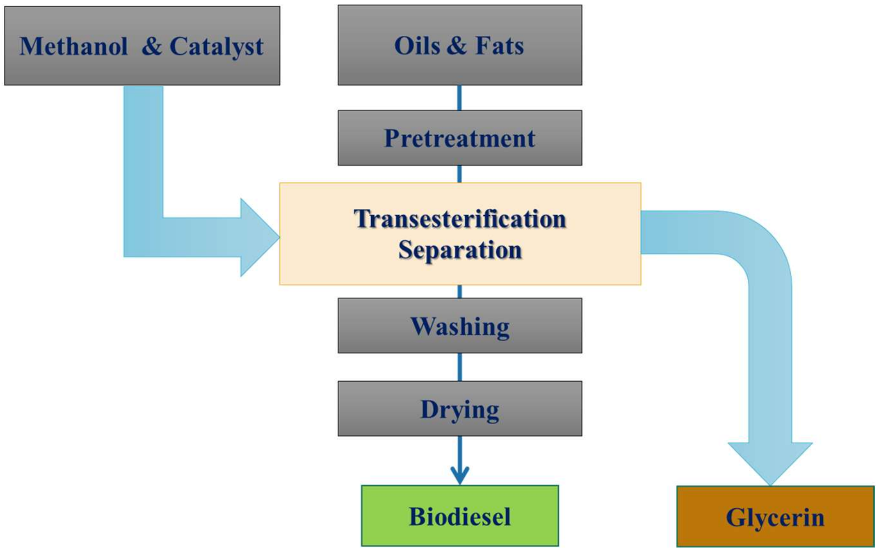

Fig. 1. Transesterification process.

Table 2. Properties of *Borassus flabellifer* biodiesel blends.

Fuel Blends	Diesel	BFME	BFME 20	BFME 40	BFME 60	BFME 80	Test Standard
Viscosity at 30 °C (mm^2/s)	3.3	4.5	3.63	3.82	4.18	4.31	ASTM D 445-04e
Energy content (kJ/kg)	43300	40250	42153	41895	41350	40860	ASTM D5865
Cetane no.	54	57	55	56	56	57	ASTM D 613-05
Density (kg/m^3)	835	870	849	852	860	866	ASTM D7371-12
Flash point (°C)	50	128	69	86	105	122	EN ISO 2719

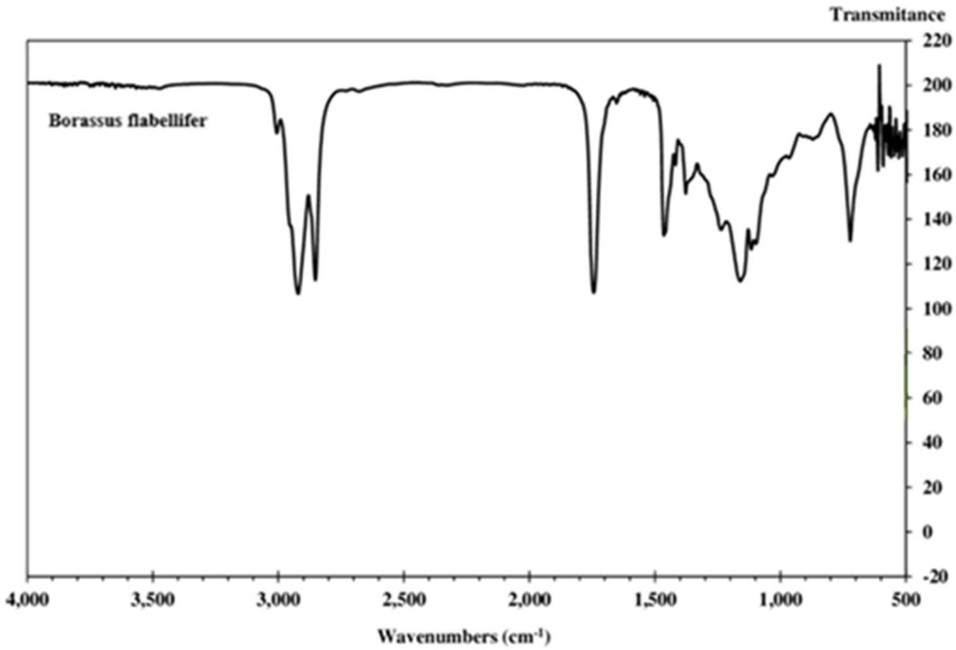

Fig. 2. Borassus flabellifer oil FTIR spectra.

Fig. 3. Experimental setup.

Table 3. Specification of the engine.

Details	Data
Manufacturing	Kirloskar
Model	TV1
Type of engine	Naturally aspirated diesel engine
Max. Brake power at rated speed	5.1 kW at a rated constant speed
Bore/stroke	88/110 mm
Engine CR	17.1:1
Injection mode and timing	Direct and 23° before TDC
Type of lubrication	Forced feed system
Oil tank capacity	6 liters

Table 4. Accuracy and uncertainty of the measurements.

Measurements	Accuracy	Uncertainty (%)
Temperatures	±1 ˚C	-
Engine speed	± rpm	-
Time	±0.5%	-
Power	±1%	1.5
SFC	±2%	1.4
CA encoder	±0.5˚ CA	1.5
CO	±0.02%	±1
HC	±10 ppm	±1
CO_2	±0.5%	±2
NO_x	±15 ppm	±2

RESULTS AND DISCUSSION

Experimental analysis of CO, HC, NO_x, and smoke opacity was conducted, along with the performance characteristics of BTE and brake specific energy consumption (BSEC), for both BFME blends and diesel. For combustion analysis, the CP and HRR were evaluated.

Performance Characteristics

Various blends of *B. flabellifer* and diesel at varying peak CP are shown in Figure 4(a), along with the corresponding BTE in relation to brake power (BP). The graph shows that the raw *B. flabellifer* biodiesel has a lower BTE than diesel because of its higher viscosity and lower heat content. When compared to diesel, BFMEs have a higher viscosity and a lower heating value, leading to a lower BTE of 10.9% at full load. Therefore, *B. flabellifer* fuel was combined with diesel at varying concentrations (BFME20, BFME40, BFME60, BFME80, and BFME), increasing its viscosity and calorific value. When the diesel concentration in biofuel is raised, the viscosity gradually decreases, and the heating value steadily improves in comparison to BFME. Compared to BFMEs at full load conditions, BFME20, BFME40, BFME60, and BFME80 each showed a 5.1%, 2.8%, 2.0%, and 1.4% increase in BTE, respectively. Higher oxygen concentration, together with improved viscosity and heating value, could contribute to these findings regarding the complete combustion of *B. flabellifer* blends. These results align with those of a previous study [29]. According to the results, BFME20 and

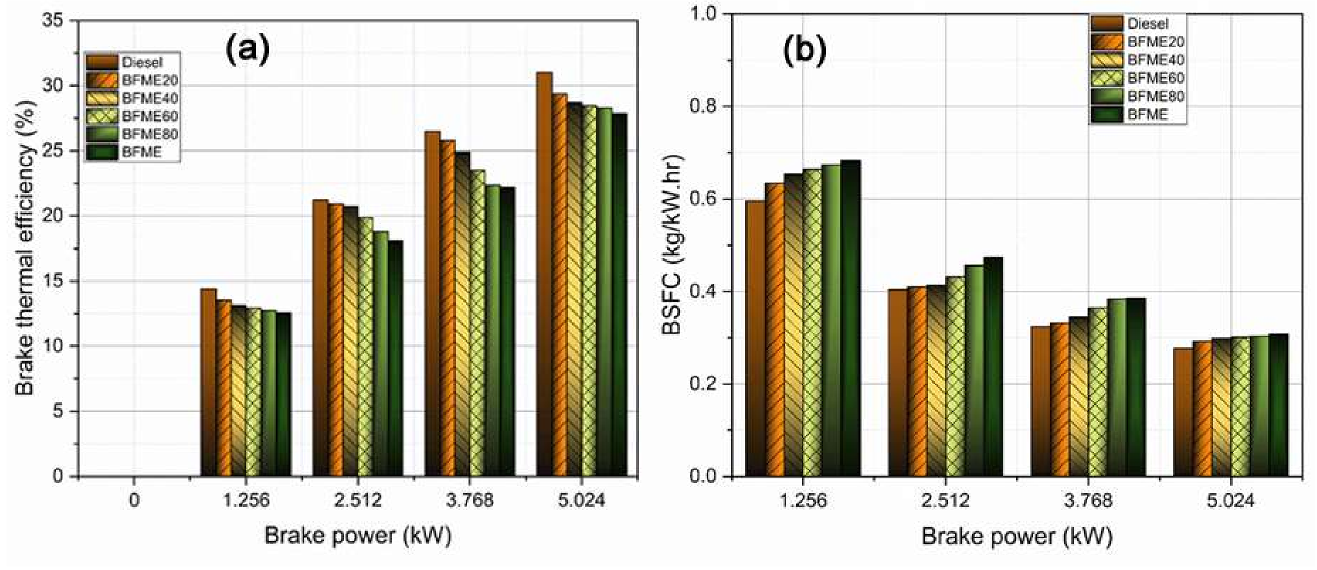

Fig. 4. Variation of engine parameters at different BPs for various blends: (a) brake thermal efficiency and (b) brake specific fuel consumption.

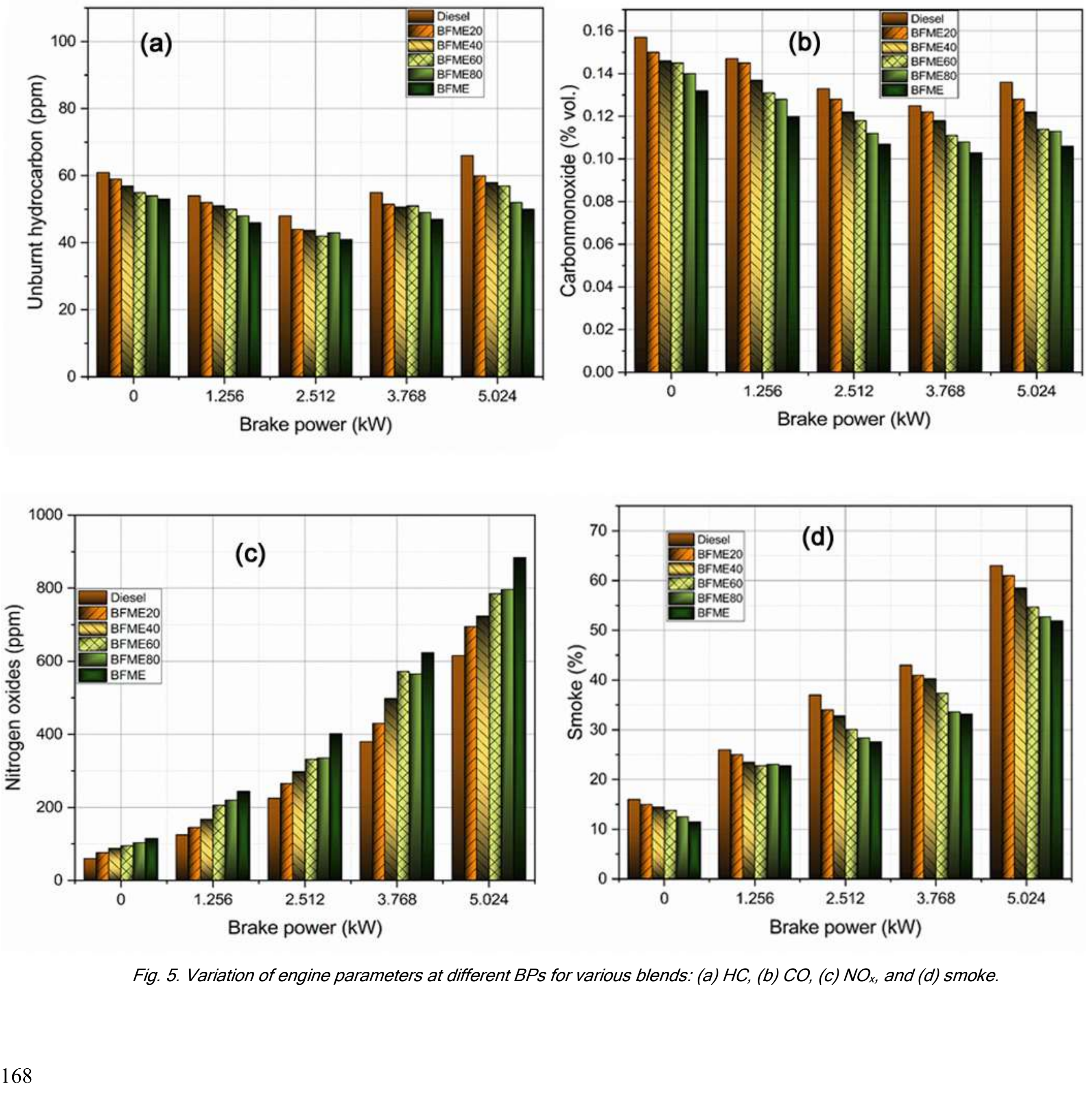

Fig. 5. Variation of engine parameters at different BPs for various blends: (a) HC, (b) CO, (c) NO_x, and (d) smoke.

BFME40 are superior to other blends in terms of performance. Owing to concerns regarding diesel substitution, further research was conducted on BFME20. All things considered, BFME20 was found to be the best blend, so it can be used for future experiments.

Variation in BSFC relative to BP at a steady state for various blends of *Borassus* biodiesel and diesel is shown in Figure 4(b). Use of raw *Borassus* biodiesel, as seen in the graph, increases fuel usage. Compared to diesel, BFMEs have a lower heating value. It is also clear from the results of BTE, which are a reflection of the amount of energy used. As a result of its high viscosity and low calorific value, BFMEs may not be atomized or evaporated efficiently, leading to this effect. From B100, *Borassus* biodiesel shows a gradual BSFC enhancement when the diesel concentration is increased. Improved BSFC values were measured for BFME20 (0.291 kg/kWh), BFME40 (0.298 kg/kWh), BFME60 (0.304 kg/kWh), and BFME80 (0.303 kg/kWh) at full load. Enhanced combustion in lower BFME blends is responsible for the reduced fuel required for the engine. It has been shown that fuel efficiency improves when the heating value of the fuel is increased. According to researchers, these explanations are reliable [30]. Because of a lack of calorific value, the BSFC of diesel blends with lower concentrations of BFMEs was better than those with greater concentrations of BFMEs. Overall, it was found that the BFME20 blend performed similarly to diesel fuel.

Emission Characteristics

The impact of HC formation on *B.* biodiesel-diesel blends and diesel fuel is shown in Figure 5(a). Compared to diesel fuel, the graph demonstrates significantly lower HC emissions for BFMEs. This could be because of the low levels of hydrogen and carbon present, in addition to the abundance of oxygen. HC emission for BFMEs is recorded at 50 ppm, which is 24.2% lower than diesel fuel. As a result of the beneficial effect of the integrated O_2, the CO emission profile was also observed in the HC emission. For all the test fuels, HC emission formation tended to rise with increasing engine load because a greater proportion of A/F mixture was admitted to the combustion zone under higher loads. Maximum engine load causes increased HC emissions from all test fuels because of the shorter combustion time required to maintain a constant engine speed. Diesel, BFME20, BFME40, BFME60, BFME80, and BFME all had HC emission results of 66, 58, 52, and 50 ppm at a peak load, respectively. Because of the enhanced combustion and increased oxygen content in biodiesel blends, HC emissions are reduced. As the concentration of *Borassus* in diesel is lowered from BFME80 to BFME20, the HC emission increases steadily due to the absence of O_2 content in lower blends. Although BFME80 had lower HC emissions than BFME20, the BFME20 blend was the best option due to its higher combustion efficiency and lower emission rate.

The CO emission variance for various BP, including *Borassus* biodiesel-diesel blends, and diesel fuel under standard conditions, is depicted in Figure 5(b). Based on the analysis recorded in the graph, raw *Borassus* biodiesel has a lower CO content than diesel. There is a significant concentration of internal O_2 in BFMEs, which may justify this production. In comparison to diesel, the generation of CO emissions is reduced by 21.9% for BFMEs at full load. *Borassus*'s ability to convert CO_2 to CO more efficiently is evidenced by the presence of built-in O_2 atoms. *Borassus*'s abundant supply of oxygen molecules also speeds up the combustion process, resulting in more efficient burning and fewer emissions. Comparable results are available [31]. As the *Borassus* concentration in diesel was lowered from BFME80 to BFME20, the CO emission rose progressively due to the decreasing O_2 level in the blend. Engine running on BFME20, BFME40, BFME60, BFME80, and BFME had CO emissions of 0.128%, 0.122%, 0.114%, 0.113%, and 0.106% vol., respectively. Compared to diesel, the CO emission was reduced by 17.1% for BFME20, 13.1% for BFME40, 7% for BFME60, and 6.1% for BFME80. The graph shows that the CO emission decreases for all the considered fuels as the load percentage rises from 20% to 70%. In contrast, at peak load situations, CO generation increased dramatically for all test fuels due to shorter residential combustion times and higher fuel consumption to maintain a steady-state condition [32]. Overall, the *Borassus* fuel blend had less carbon monoxide than diesel, and the BFME20 was chosen as the best blend because of its improved combustion and reduced emission formation.

Results of NO_x emission testing under varying loads for *Borassus* biodiesel-diesel blends and diesel fuel are shown in Figure 5(c). Because the presence of O_2 in it caused the cylinder temperature to increase, the NO_x emission for all Borassus blends was higher than diesel. In all, the engine's NO_x emissions were 695, 724, 785, and 796 ppm when it was run on blends of BFME20, BFME40, BFME60, and BFME80. Compared to BFME, the NO_x levels dropped by 22.0% for BFME40, 12.6% for BFME60, and 11.05% for BFME80. Also, compared to diesel, NO_x emissions from CI engines running on BFME20, BFME40, BFME60, BFME80, and BFME were 13%, 17%, 27%, 29%, and 43% higher, respectively. Complete combustion caused by the presence of O_2 in *Borassus* biodiesel likely accounts for the higher peak combustion temperature observed. The greater combustion temperature of *Borassus* biodiesel may potentially contribute to these results. The graph demonstrates that NO_x emissions rise sharply with increasing load and *Borassus* biodiesel content. Reasons for this improvement in in-cylinder temperature may include a rise in the concentration of *Borassus* fuel, which increased the availability of heat in combustion from the previous cycle, and the presence of more O_2 molecules [33]. In addition, the peak in the cylinder temperature caused by the biodiesel's greater ignition delay resulted in higher NO_x emissions.

Smoke emissions from diesel and various Borassus biodiesel blends are presented in Figure 5(d). The graph shows that when *Borassus* fuel is blended with diesel, smoke emissions decrease. In the case of BFME, the resultant smoke emission is approximately 48.9% at maximum load. Incomplete combustion due to a rich or low mixture is typically responsible for the release of smoke during combustion. Owing to the abundance of oxygen molecules, which improve combustion, the issue was addressed. It has been found that increasing the *Borassus* concentration in diesel fuel exerts a negative effect on smoke emissions. When operating on BFME20, BFME40, BFME60 and BFME80, the engine's smoke emissions were 61.7%, 58.5%, 54.8%, and 52.7%, respectively. Smoke levels rose by 16.4% for BFME40, 10.2% for BFME60, and 7.2% for BFME80 compared to BFME. Smoke emissions from CI engines operating on BFME20, BFME40, BFME60, BFME80, and BFME were 3%, 1%, 13%, 16%, and 22% lower, respectively, compared to diesel. When the A/F ratio allowed into the combustion zone, or the amount of charge mixture present in the crevice volume, increases with engine load, smoke pollution generation also increases for all test fuels. Lower smoke emission was observed for blend concentrations of *Borassus* with diesel up to 80%, after which smoke emission marginally increased due to the larger droplet size of BFME resulting from higher viscosity. Owing to the presence of oxygen in biodiesel, which may have improved combustion, the biodiesel blends produce less smoke than diesel [34].

During the maximum load condition of a diesel engine, the HRR varies in relation to the CA, as shown in Figure 6(b). This study examined the effectiveness of HRR using various diesel and *Borassus* fuel blends. In the graph, diesel fuel was observed to have a greater HRR than the other fuels used in the experiment. The increased energy content and reduced viciousness of diesel fuel may be responsible for these outcomes. This is because the BFME blend has a lower heat content and a higher viscosity than other blends, hence the HRR is lower. HRR values of 67.9, 66.9, 62.8, 62.5, and 57.5 J/CA were achieved by the engine operating on BFME20, BFME40, BFME60, and BFME80, respectively. There was a 2.3% decrease in HRR generation for BFME20, 3.8% for BFME40, 9.7% for BFME60, and 10.2% for BFME80 compared to diesel. It may be because *Borassus* and its blends have a higher viscosity than diesel, which slows the rate at which they vaporize. Compared to diesel, *Borassus* blends with a higher cetane number begin their peak HRR curve and dominate the diffusion combustion phase much earlier. The results showed that when the *Borassus* concentration was diluted, the HRR output increased. The oxygen molecules in the fuel are the most important players during the combustion process, especially during the diffusion stage [34]. It's possible that the increased combustion and the existing O_2 content together produced these results.

CONCLUSION

In this study, the physical and chemical properties of *Borassus* biodiesel were evaluated. It could be used as a renewable fuel in a conventional internal combustion engine. The performance began to decrease with pure *Borassus* biodiesel, and it was closest to diesel with the BFME20 and BFME40 blends. Compared to other blends, BFME20 and BFME40 had lower energy consumption and higher thermal efficiency. In addition, compared to pure *Borassus* biodiesel, BFME20 was shown to reduce fuel consumption by 5.2% and to increase thermal efficiency by a respectable amount. Compared to diesel, HC and CO emissions from the BFME20 blend were lower. To compare, the reductions in BFME20 caused by HC, CO, and smoke were 9.9%, 5.8% and 3.1%, respectively. In the presence of sufficient oxygen and at the peak of the cycle's heat, *Borassus* blends significantly raise NO_x generation. Moreover, BFME20 had a slightly greater BTE than the other biodiesel blends. According to the parameters for higher diesel replacement and lower emissions, BFME20 was determined to be the best alternative energy source for the CI engine. As a result, it is necessary to improve its performance qualities and minimize harmful exhaust emissions before considering it as a replacement energy source.

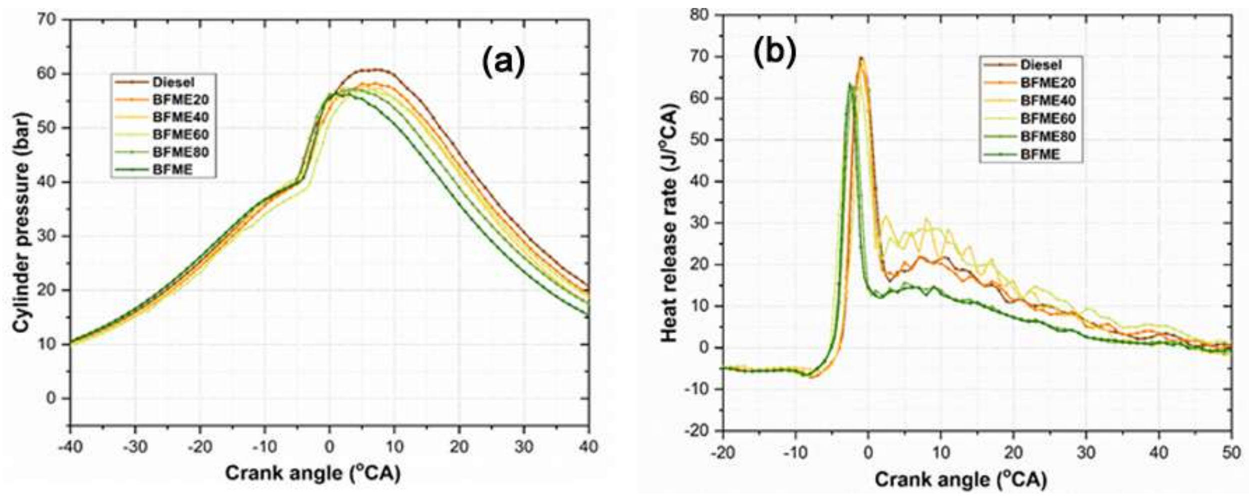

Fig. 6. Comparison of combustion characteristics for various blends of biodiesel: (a) cylinder pressure and (b) heat release rate.

NOMENCLATURE

bTDC - Before top dead center
BFME - Neat *B. flabellifer* methyl esters 100%
BFME 20 - 20% *B. flabellifer* methyl esters +80% diesel
BFME 40 - 40% *B. flabellifer* methyl esters +60% diesel
BFME 60 - 60% *B. flabellifer* methyl esters +40% diesel
BFME 80 - 80% *B. flabellifer* methyl esters +20% diesel
BP - Brake power
BSEC - Brake specific energy consumption
BSFC - Brake specific fuel consumption
BTE - Brake thermal efficiency
CA - Crank angle
CI - Compression ignition
CNG - Compressed natural gas
CP - Cylinder pressure
CRDI - Common rail direct injection
FTIR - Fourier transform infrared spectroscopy
HC – Hydrocarbon
HRR - Heat release rate
HRRmax - Maximum net heat release rate
KOME - Kapok oil methyl ester
UBHC - Unburned hydrocarbon

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KARAKTERISTIKE SAGREVANJA, PERFORMANSI I EMISIJE MOTORA SA KOMPRESIONIM PALJENJEM PRI KORIŠĆENJU MEŠAVINA BIODIZELA OD ULJA *BORASSUS FLABELLIFER*

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NAUČNI RAD

Metil estri Borassus flabellifer (BFME) imaju nekoliko atraktivnih karakteristika koje ih čine potencijalnim rivalom dizelu i drugim alternativnim gorivima. Ovaj rad predstavlja prvu sveobuhvatnu analizu njegovih performansi, sagorevanja i emisija u dizel motoru. Pored visoke kalorijske vrednosti, visokog cetanskog broja i dostupnosti kiseonika, koji čini 10% njegove ukupne mase, takođe je lako dostupan. Eksperimentalno testiranje BFME je sprovedeno na jednocilindričnom motoru sa kompresionim paljenjem (CI) u ovoj fazi. BFME su mešani sa dizelom u različitim koncentracijama (20%, 40%, 60%, 80% i 100%). Mešavine BFME su eksperimentalno ispitane na njihova svojstva sagorevanja, emisije i performanse. CI motor je podešen na rad u stacionarnom stanju kako bi dostigao optimalnu temperaturu za uslove u kojima je radio. U početku je utvrđeno da čisti BFME imaju najnižu termičku efikasnost, dok su BFME20, BFME40, BFME60 i BFME80 imali veću termičku efikasnost kočenja (BTE) od BFME100 pri nominalnim uslovima opterećenja (za 5,1%, 2,8%, 2,0% i 1,4%, redom). U poređenju sa drugim mešavinama, BFME20 i BFME40 imaju bolju efikasnost goriva. Efikasnost goriva je značajno poboljšana, a potrošnja BFME20 je smanjena za 5,1% u poređenju sa BFME100. U poređenju sa dizelom, emisije ugljovodonika, CO i dima iz BFME20 su smanjene za 9,9%, 5,8% i 3,71%, redom. Ovi rezultati naglašavaju potencijal BFME mešavina sa niskim odnosom kao čistijih i efikasnijih alternativa biodizelu, ističući praktičnu primenljivost BFME u postojećim dizel motorima bez većih modifikacija.

Ključne reči: Biodizel, Borassus flabellifer, sagorevanje, performanse i karakteristike emisije.