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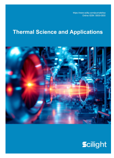

Article

A Comparative Study of B10 Biodiesel Blends and Its Performance and Combustion Characteristics

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Abstract: The primary objective of this work is to assess and examine the combustion properties of non-edible oil feedstock, specifically Azolla, in an Internal Combustion (IC) test Rig. First, a Soxhlet apparatus is used to extract oil from Azolla. This raw oil is then converted into Azolla biofuel. The comparison of Azolla biofuel with non-edible oils like Jatropha biodiesel, castor biodiesel, Neem oil biodiesel, and Karanja biodiesel takes place. In this study, we tested a 10% blend of biodiesel in a diesel engine, which included Azolla10, Jatropha10, Castor10, Neem10, and Karanja10. The researchers measured the physical properties of all fuels and conducted a comparison with American Society for Testing and Materials (ASTM) standards. An engine with one cylinder and water cooling was employed in the test setup. The diesel engine's emissions and performance were assessed under various load conditions. Results showed that the Azolla10 blend and diesel fuel delivered similar performance. However, for emissions and Combustion Characteristics like Oxides of Nitrogen (NO_x)-920 PPM, Hydrocarbon (HC)-52 PPM, Carbon Monoxide (CO)-0.085%, Carbon dioxide (CO_2)-7.38%, In-cylinder Pressure-79 bar at 10 °C, Heat release rate-58 Kw at 0 °C and Mean gas temperature-25 °C. Azolla demonstrated a significant reduction compared to diesel. Based on these experiments, Diesel engines may be able to run on the Azolla blend without any changes.

Keywords: non-edible feedstock; Azolla; trans-esterification; combustion ignition engine; performance parameters; emission parameters; combustion characteristics

1. Introduction

The present-day fossil fuel utilisation has increased, which is why the demand for fossil fuel increased. As fossil fuel costs rise, future production may drop. This is why researchers are studying alternative fuels for IC engines. Such changes could help reduce emissions. The use of algal oil in biodiesel blends has been the subject of numerous studies. In test rigs, these non-edible algae species perform admirably.

Paul Brouwer (2016) [1] noted that Azolla is one of the fastest-growing plants known for its ability to fix nitrogen. High-quality biodiesel can be produced from the lipids extracted from Azolla. Vinod et al. (2019) [2] the potential of Azolla through anaerobic digestion experiments. They concluded that energy recovery for biogas production depends significantly on both load and temperature. Plyushi et al. In 2019 [3], researchers looked into a new biodiesel made from algae. They discovered that performance and combustion parameters were significantly impacted by a shorter ignition delay interval. They observed a significant increase in NO_x emissions compared with overall emission parameters. Prabakaran et al. (2021) [4] A novel heterogeneous dolomite catalyst was investigated for its effectiveness in the trans-esterification process, achieving an azolla yield rate of 88.7%. They

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found that using a methanol-to-oil ratio of 30:1 can reduce the emission parameter at a compression ratio of 18:1. However, NO_x levels may increase. Under these conditions, the performance parameters show a reduction in BTE and an increase in BSFC when compared with diesel at peak load conditions. S I Hawash (2015) [5] conducted an experimental investigation on Jatropha biodiesel. They tested different blends and load conditions. The performance and emission parameters showed that B20 produced low CO emissions, while B50 resulted in high CO_2 emissions. All blends produced high levels of NO_x. They concluded that B20 is the optimum fuel blend.

Le De a Monteiro (2013) [6] investigated castor oil biodiesel. They tested different blends, including B10 and B20. These blends had a similar performance to diesel. However, they had lower brake torque than diesel. Specific fuel consumption might also be higher than that of diesel. Mathalai Sundaram C (2019) [7] found that neem biodiesel can significantly reduce HC emissions. However, it can also increase NO_x emissions compared to diesel. Adding DMC (Di-Methyl Carbonate) to neem biodiesel leads to better combustion and significantly lowers CO and NO_x levels. Y Rathore (2016) [8] Transesterification of non-edible Karanja seed oil is carried out using methanol and NaOH as a catalyst. The Karanja seed oil properties, as per the ASTM Standards, show that the biodiesel acid value is more than 3. The study found the physico-chemical properties of Karanja biodiesel comparable with diesel and Karanja seed oil is suitable for biodiesel purposes. Sandeep Yadav (2022) [9] found that the experimental investigation of Karanja biodiesel produced results showing higher BTE and BSFC than diesel, while the emission characteristics of CO and HC were significantly lower and NO_x was higher compared with diesel. Jayashri N Nair (2016) [10] presents the increasing usage of biodiesel. Biodiesel is an unconventional source; the studied neem biodiesel performance and emissions can be tested. The emission parameters CO, HC, and NO_x are those of thermal efficiency that can be increased. Mehmood Ali (2020) [11] investigated the production of biodiesel by mixing the oils of jatropha and neem. Jatropha & neem biodiesel (NJB10%). The emission parameter CO can be reduced compared with diesel and CO_2 can be increased, SO_2 can be reduced, and NO_x can be increased compared with diesel. Youssef A Attai (2020) [12] Castor biodiesel produced high-yield seeds; castor biodiesel was tested with different load conditions. Castor biodiesel may result in higher exhaust gas temperatures, specific fuel consumption, and HC, CO, and NO_x emissions. While thermal efficiency tended to decline, specific fuel consumption also rose; cylinder pressure and net heat release rate saw the worst declines.

B S Chauhan (2011) [13] evaluated in-cylinder pressure, pressure rise rate, and heat release rate while utilising Jatropha biodiesel to investigate engine performance and emissions. The findings showed that brake thermal efficiency may decrease. But, brake-specific fuel consumption (BSFC) can increase. Emissions of HC, CO, CO_2, and smoke are lower, while NO_x emissions can be higher. Nithyananda B S (2013) [14] experimented on neem biodiesel. They tested different blends. The results showed that the fuel properties and performance improved, especially with the B20 blend. Fangyuan Zheng (2023) [15] found that using different blends of castor biodiesel at a constant speed produced some key results. For blend B80, NO_x and CO_2 emissions increased. Additionally, the properties showed high velocity but a lower calorific value compared to diesel, which significantly reduced the performance parameters like BTE. Dewi harreh (2017) [16] studied Karanja biodiesel production. The process used transesterification with methanol and sodium hydroxide. This method led to successful biodiesel conversion. Following that, calculations were made for the physicochemical characteristics, including braking power, brake-specific fuel consumption (BSFC), and brake thermal efficiency.

Mohankumar Subramanium (2020) [17] The study looked at several volume ratios of diesel and algal fuel (A10, A20, A30, A40, and A100). A single-cylinder, direct-injection diesel engine was then used to test these mixtures. A20 was the blend that exhibited emission characteristics most similar to those of pure diesel, with large increases in NO_x and CO_2 levels but significant decreases in HC and CO emissions. S Thiruvenkatachari (2020) [18] The study discusses the Azolla microphylla plant, which grows on the surface of water bodies. Oil was extracted from Azolla using the solvent extraction method, and biodiesel was subsequently produced through transesterification. Results indicated that the B25 blend exhibited higher brake thermal efficiency. However, emissions of CO, HC, and smoke were notably higher for B25 compared to diesel, while NO_x emissions were significantly reduced due to the nature of the combustion process. D Kannan (2018) [19], the study's primary goal was to lower emission parameters. The study tested bio-nanoparticles and nanoparticles in biodiesel under various load conditions. The emission parameters CO and HC can be reduced. A golzary (2020) [20] Optimizing lipid extraction for the manufacture of biodiesel and the growth rate of Azolla were the main topics of the study. With a doubling time of 2.1 days, the highest growth rate was attained at 22 °C, 75% humidity, and pH 6.4. In the end, Azolla is a viable feedstock for the production of biodiesel due to its quick growth rate.

Vijayan Venkatraman (2018) [21] noted the rapid growth of populations and vehicles, the increase in energy demand, and how all researchers focused on biodiesel. They used Azolla algae as the biofuel, and they prepared the biodiesel blends (B20) with and without nano additives. The properties of the nano additives and emission parameters tested significantly reduced the emission parameters. Bose Narayanasamy (2018) [22] the high oil content of Azolla algae was the subject of the investigation. Soxhlet extraction was used to extract the oil from Azolla, and transesterification was then used to turn it into biodiesel. Next, titanium dioxide (TiO_2) nano additions were added to the biodiesel to improve it. Sudhakaran, R (2025) [23]. Azolla methyl ester (AME) blends (B20, B30, and B40) in CI engines at different compression ratios are examined in this investigation. Higher blend proportions and compression ratios significantly reduced CO emissions, significantly increased NO_x emissions, and improved brake thermal efficiency. KJ (2024) [24] In this study, waste dolomite catalyst is used in a 10-litre pilot reactor to produce biodiesel from Azolla pinnata oil, achieving a yield of 99.14% at 70 °C over four hours. Compared to diesel, engine tests with Azolla blends (A20, A40, and A60) show that the A20 blend reduces smoke by 10%, CO by 13.07%, and HC by 12.9%. The results confirm the process's technological feasibility, emission benefits, and socioeconomic potential as a sustainable alternative to fossil fuels. Kannan, T (2024) [25]. This study optimises Azolla biodiesel–diesel blends with SiO_2 nanoparticles (25–75 ppm), adjusting injection timing, pressure, and compression ratio to achieve the lowest emissions and optimal CI engine performance. At 18.5° b TDC timing, 238 bar pressure, 17.12 compression ratio, and 45.9 ppm SiO_2 with a desirability of 0.6180, bio-silica nanoparticles yield the best results, as confirmed by XRD, SEM, TEM, and EDS analyses. Add the SiO_2 Nano Particles, significantly reducing emissions without compromising performance. Mahgoub, B. K. (2023) [26] This review examines nano-biodiesel blends in diesel engines to improve fuel properties, combustion efficiency, and emissions in the context of oil shortages and increasing energy demands. Nano-additives such as Al_2O_3, CeO_2, CNTs, CuO, GO, and TiO_2 increase brake thermal efficiency by up to 24.7% (e.g., Jatropha B20 + 50 ppm Al_2O_3), reduce BSFC by 25%, and lower HC by 70.94%, CO by 80%, and NO_x by 30% across blends. Future research work every one focus on the hybrid nanoparticles.

Elsaid (2025) [27]. This study evaluates Azolla as a sustainable macroalga for second-generation biodiesel, thereby eliminating the deficiencies of first-generation fuels derived from food crops. According to GC-MS, FT-IR, and NMR spectroscopy, lipid extraction produces biodiesel with a kinematic viscosity of 4.32 mm^2/s at 40° C and a flash point of 165 °C, indicating no significant trace element issues. Azolla biodiesel shows promise as a locally produced alternative to diesel for utility vehicles. Senusi (2024) [28] In this study, third-generation biodiesel from Azolla filiculoides, Ulva lactuca, and residual frying oils (palm, sunflower, and corn) is evaluated using transesterification under optimum circumstances (methanol:oil 3:1–12:1, 0.5–3 percent by weight of catalyst, and 55–75 °C). High levels of unsaturated fatty acids (54–85.7%) are revealed by GC-FID, resulting in biodiesels that fulfil criteria for cetane numbers (44.4–57.9), densities (872–883 kg/m^3), and viscosities (3.52–5.3 mm^2/s). Azolla filiculoides thrives, encouraging the use of third-generation feedstocks in the production of sustainable biodiesel. Atmanli, A. (2020) [29] This study examines the biodiesel potential of freshwater Scenedesmus dimorphous and marine Isochrysis affix. galbana microalgae cultivated in Bristol/Erdschreiber media with 1.5% CO_2 and 16:8 light-dark cycles, including growth, harvesting, transesterification, and quality evaluation. With transesterification yields of 87.4% and 94.6%, respectively, the lipid contents of Scenedesmus and Isochrysis reached 15.87% and 42.65%, respectively; Isochrysis exhibited greater saturated fatty acids that improved fuel qualities. The preferred biodiesel feedstock is Isochrysis affix. Galbana because of its easier production and higher oil yield. Liu, H (2019) [30] This study investigates the combination of ethanol, diesel, and PODE in a six-cylinder heavy-duty diesel engine, making benefit of PODE's high cetane number and co-solvent function for steady ethanol miscibility. The findings show increased BSFC, decreased HC/soot (up to 86.9% weighted soot for DPE15), quicker late-stage combustion, equivalent BTE at low/medium loads, and increased NO_x under the WHSC cycle. By balancing soot/CO/HC reductions against NO_x/BSFC spikes at ideal ratios, blends improve greener combustion.

In order to enhance the performance of a compression ignition (CI) engine without necessitating any modifications, the performance and emission characteristics of the biodiesel containing these nano-additions were examined.

Therefore, based on the analysis, the main purpose of this study is to investigate the rapid growth of Azolla, its high yield, and the enzymatic transesterification process used to extract oil, as well as the use of the extracted oil for biodiesel preparation. The performance parameters and combustion characteristics of biodiesel blends, such as AME10 (10% Azolla oil + 90% pure diesel), were compared with those of pure diesel and various non-edible oils in a single-cylinder diesel engine.

2. Preparation of Materials and Fuels

2.1. Procedure for Extracting Azolla Oil

As seen in Figure 1, the plant species Azolla creates thick colonies. It is renowned for having a high lipid content, which can range from 30 to 44% and is mostly derived from free fatty acids. In (Bijoyet et al., 2017) [31]. Azolla is the fastest-growing plant on Earth (Paul Brouwer, 2016) [1]. The growth rate of Azolla allows it to double in weight every 2.1 days (Agolzay, 2020) [20]. We washed the azolla twice with water to remove impurities. Then, we dried it for 5 days to get rid of moisture. The Azolla was then pulverised with a mixer grinder, and a Soxhlet device was used to extract the solvent from the ground material. The flow chart for making biodiesel from Azolla algae (S. Thiruvenkatchari, 2020 [18]) shows that the powdered sample was weighed. Then, someone placed it in a thimble chamber. Someone put the methanol mixture at the bottom of the flask. A heated oil mantle was used to warm the solvent in the bottom flask, maintaining a temperature of 65 °C for 5 h.

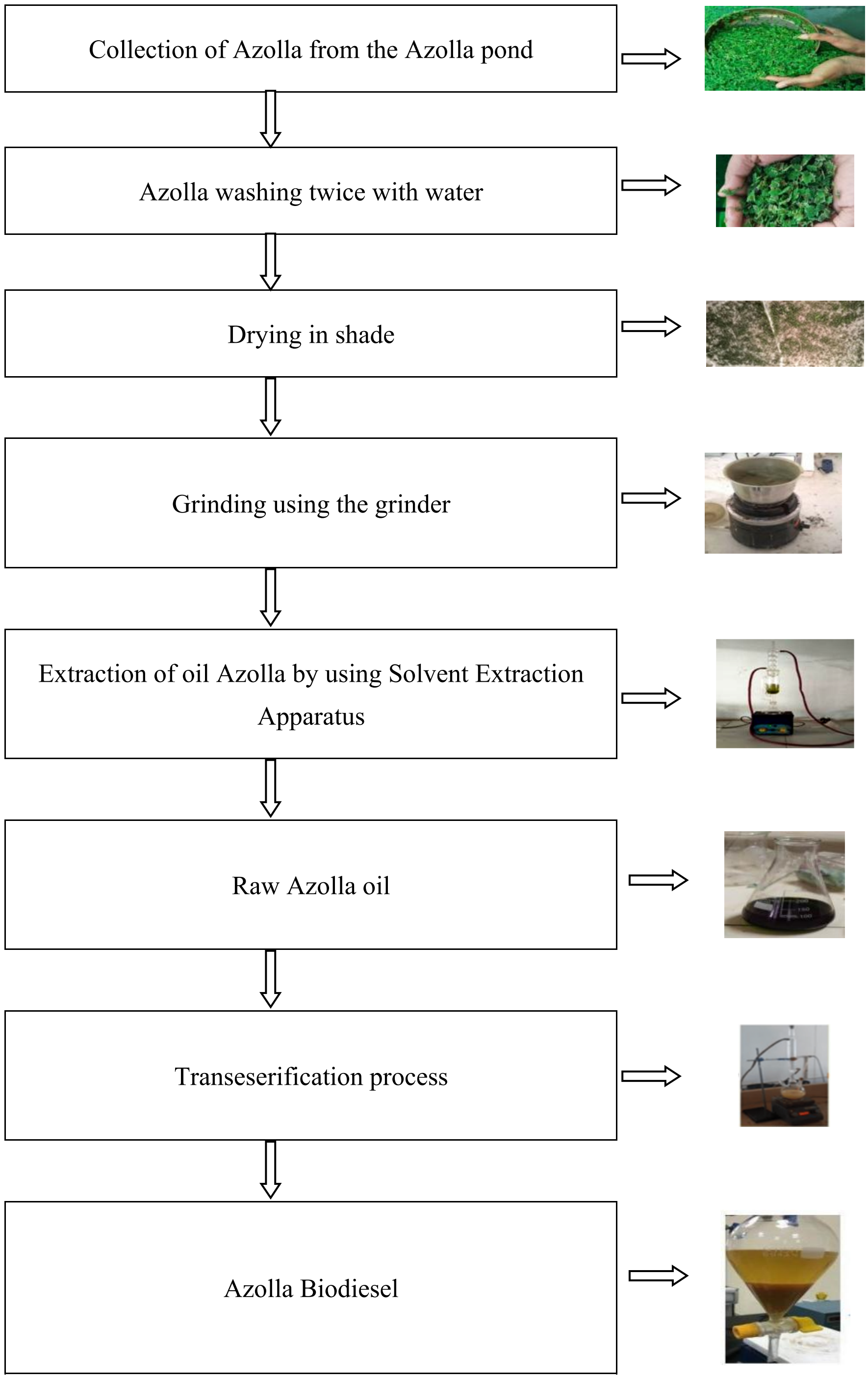

Figure 1. Flow chart of the production of Azolla biodiesel.

2.2. Trans-Esterification Procedure

This procedure's main objective is to make Azolla oil less viscous. Alcohols like methanol or ethanol react with the extracted raw oil when a base catalyst like NaOH or KOH is present. The procedure is to dissolve raw oil in methanol in a titration flask and then add NaOH or KOH at a rate of 17 g per liter in the list in Table 1. Methanol and extracted raw oil have a 5:1 ratio. In a vessel that is heated with a heater to 70 °C, the raw oil goes through the transesterification process. After that, the KOH and methanol mixture is added, and the temperature is kept at 65 °C while being agitated for two hours. The biodiesel is then collected at the bottom of a separating funnel once the processed oil has been moved there.

Table 1. Description of the Transestification Process utilized in the Production of Biodiesel.

Simple	Catalyst	Alohal	Temp	Molar Ratio	Yield%	References
Azolla	KOH (17 g per lit)	Methanol	70	05:01	88.7	Prabakaran S (2021) [4] S. Thiruvenkatachari (2020) [18]
Jatropha	KOH (0.55%W/W)	Methanol	60	05:01	99	Bryan R. Moser (2009) [32]
Castor	NI Dropped Zno Nano (11%W/W)	Methanol	55	08:01	95.2	G. Baskar (2018) [33]
Neem	KOH (0.5%W/W)	Methanol	70	09:01	94.9	H. Muthu (2010) [34]
Karanja	KOH (1%W/W)	Methanol	65	06:01	97	Rupesh L. Patel (2017) [35]

2.3. Blends Preparation

The team mixed the extracted azolla biodiesel with diesel in a 10 to 90% ratio (AME10). They tested this fuel blend and compared the results to various non-edible biodiesels.

2.4. Properties of Biodiesel

They measured the fuel chemical properties of AME10 bio-diesel. They compared these with various non-edible blends: Jatropha 10, Castor 10, Neem 10, Karanja 10, and pure diesel. See Table 2 for details.

Table 2. Features of biodiesel and diesel produced from different feedstocks.

Feedstock	Density	Calorofic Value (MJ/KG)	Viscocity at 40 °C (mm^2/s)	Flash Point	Centance Number	References
Azolla	837	43.24	2.7	67	45	Prabakaran S (2021) [4]
Karanja	930	39.12	5.52–5.59	230	39	Rupesh L. Patel (2017) [35]
Jatropha	879	39.2	4.8	135	51	Samiddha Palit (2011) [36]
Castor	959	37.20–39.5	15.17	145	48.9	Paula Berman (2011) [37] Vinay R. Patel (2016) [38] Volkhard Scholz (2007) [39]
Neem	863.8	43	3.8	150	48.9	Ismail J. Madai, (2020) [40]

3. **Experimental Configuration**

A four-stroke, single-cylinder, water-cooled diesel engine test apparatus was used for the studies. Table 3 contains the specifications of the engine test rig. Various load conditions were used to record performance and emission metrics, including brake mechanical and thermal efficiency, brake-specific fuel consumption, and emissions of carbon monoxide, nitrogen oxides, and hydrocarbons.

3.1. Test Rig Specifications

The experimental investigations were carried out on a single-cylinder, four-stroke, water-cooled diesel engine test rig Speciications of IC Engine in Table 3.

Table 3. Specifications of IC Engine.

Engine Model	Kirloskar Model
Power	5 HP
Speed	1500 rpm
Compression Ratio	16.5:1
Bore Diameter	18 mm
Type of ignition	Compression ignition
Stroke length	110 mm
Orifice diameter	20 mm
Applying load	Rope brake
Method of Starting	Crankshaft
Method of cooling	Water

3.2. Experimental Layout and Setup

The experimental layout consisted of a single-cylinder, four-stroke, water-cooled compression ignition engine mounted on a rigid test bed and coupled with the dynamometer, see on the Figures 2 and 3.

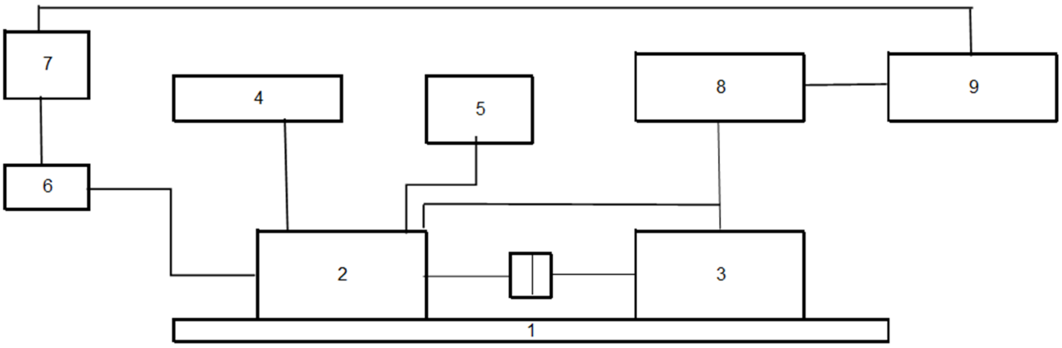

Figure 2. Line Diagram for Experimental Setup: 1. Engine Bed; 2. IC Engine; 3. Rope Type Dynamometer; 4. Air Tank; 5. Fuel tank; 6. Exhaust gas; 7. Exhaust gas analyser; 8. Display Panel; 9. Computer.

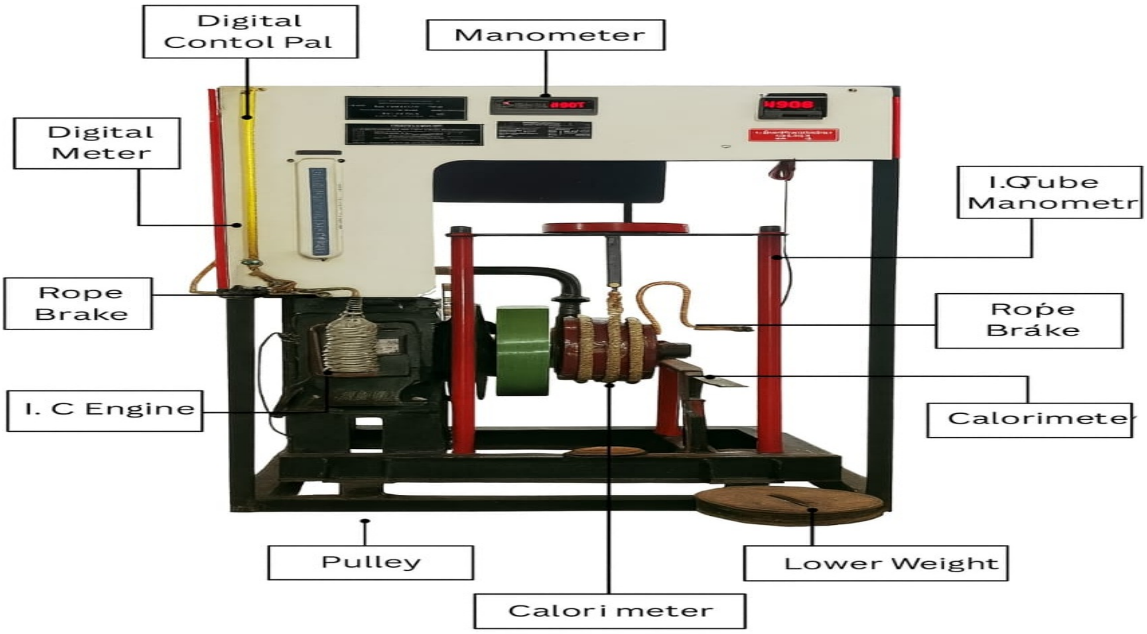

Figure 3. Experimental engine setup.

3.3. Fatty Acid Composition

Fatty acids for different Non-edible oils listed in the Table 4.

Table 4. The constituents of fatty acids in various non-edible oils.

Fatty Acid	xx:x	Azolla	Jatropha	Castor	Neem	Karanja
Myristic acid	C14:0	2.79	4.6	---	0.2–0.26	---
Palmitic acid	C16:0	37.6	4.2	1.2	136.-16.2	3.7–7.9
Palmitoleic acid	C16:1	6	1.4	---	---	---
Stearic acid	C18:0	3.9	6.9	1.2	14.4–24.1	2.4–8.9
Oleic acid	C18:1	---	43.1	19.2	49.1–61.9	44.5–71.3
Linoleic acid	C18:2	---	34.4	55.2	2.3–15.8	10.8–18.3
Linolemic acids	C18:3		13.2	0.6	---	16.3
References		Maryam Dohaei-2020 [41]	M. Rizwanul Fattah (2013) [42]	Esmat Maleki (2013) [43]	S.P. Singh (2010) [44]	M.R. Avhad (2015) [45]

XX: Total number of carbon atoms in the fatty acid chain; X: Number of double bonds in the chain.

4. Results and Discussions

The uncertainty analysis of the experimental measurements was conducted using the standard propagation of errors in Table 5. The team tested a diesel engine with a range of compression ratios to investigate differences in engine performance and combustion properties between diesel and biodiesel fuels.

Table 5. Percentage of Uncertainty.

S No.	Parameter	Uncertainty
1	Brake Thermal Efficiency	0.74
2	Mechanical Efficiency	0.6
3	Brake Specific Fuel Consumption	0.8
4	Carbon Monoxide	0.7
5	Hydrocarbon	0.5
6	Oxides of Nitrogen	0.8
7	Carbon dioxide	0.6
8	In-cylinder Pressure	0.7
9	Net Heat Release Rate	0.6
10	Mean Gas Temperature	0.7

4.1. Performance Characteristics

4.1.1. Indicated Power

Under any fuel blend, the representation demonstrates that the indicated power improves continuously as the load increases. The basic fuel exhibits a higher heating value, a higher calorific value, and a high degree of combustion efficiency when compared to all fuel blends. At peak load conditions, the assessment findings for the tested mixes (A10, J10, C10, N10, K10, and base fuel) are 6.43 kW, 4.4 kW, 4.25 kW, 4.35 kW, 4.3 kW, and 6.24 kW, respectively, as shown in Figure 4.

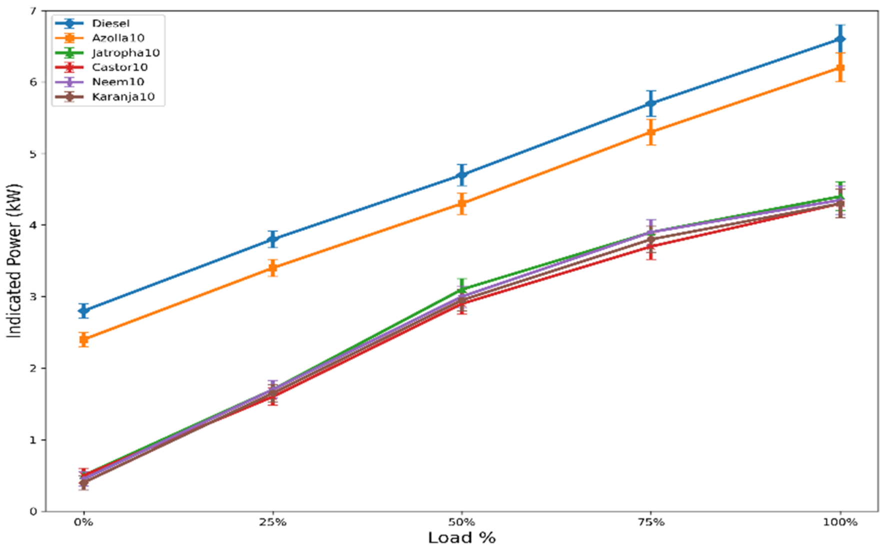

Figure 4. Load vs. Indicated Power.

4.1.2. Brake Power

The engine-generated power, which is comparable to braking power, is used to test various blends and load conditions. Peak loading conditions were brought on by the brake power. BP values from the A10 blend test are compared to various non-edible oils and base fuel under peak load circumstances. A10 is 3.84 kW, J10 is 3.8 kW, C10 is 3.6 kW, N10 is 3.75 kW, K10 is 3.7 kW, and base fuel is 3.95 kW, as shown in Figure 5. Compared to the diesel D100, the A10 provides more compressed action.

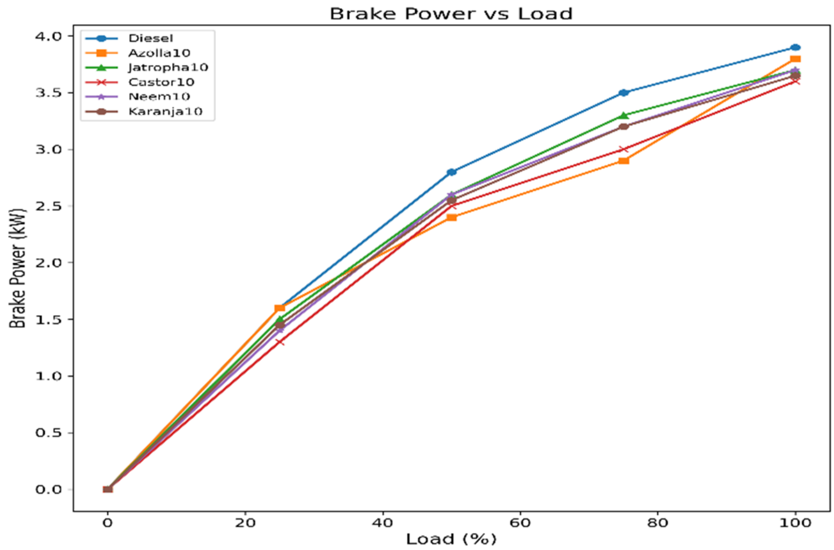

Figure 5. Load vs. Brake Power.

4.1.3. Brake Thermal Efficiency

Figure 6 demonstrates that the BTE of test fuel blends differs from that of pure diesel fuel and non-edible oil under different load conditions. It can be a result of BTE compared with the different non-edible oils and Pure Diesel. The BTE significantly decreased compared with other non-edible oil blends. As a result, the BTE values of test fuel blends are marginally lower than those of the base fuel. The A10 blend test results BTE values compared with different non-edible oils, base fuel is 1.17% less, J10 is 4.56% less, C10 is 05.18% less, N10 is 6.12% less, and K10 is 3.3% less, respectively. The results of A10 closer action, in contrast to the diesel D100.

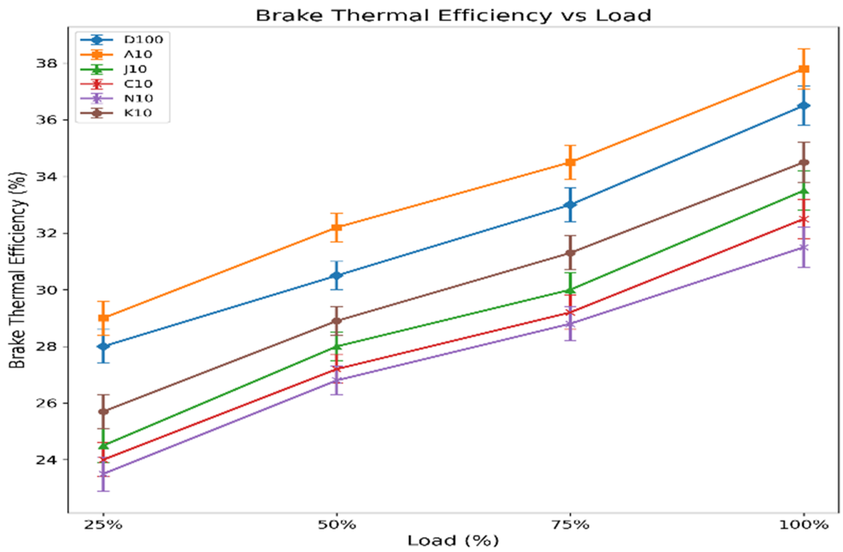

Figure 6. Comparison of Brake Thermal Efficiency with Load.

4.1.4. Mechanical Efficiency

The results showing the mechanical efficiency (ME) of all tested fuel blends, compared to various non-edible oil blends, are clearly presented in Figure 7, illustrating the impact of test fuel mixtures on pure diesel fuel. Inside the combustion chamber, electricity is generated, while brake power is produced via the crankcase chamber. The highest mechanical efficiency achieved is referred to as the peak load condition. The findings for A10, compared with several non-edible oil blends, indicate that it is 2.04% higher than pure diesel, while J10 is 23.45% lower, C10 is 14.77% lower, N10 is 16.81% lower, and K10 is 5.45% lower. The mechanical efficiency of A10 is close to that of the base fuel. The high viscosity of the other fuel blends may be the primary cause of their lower efficiency.

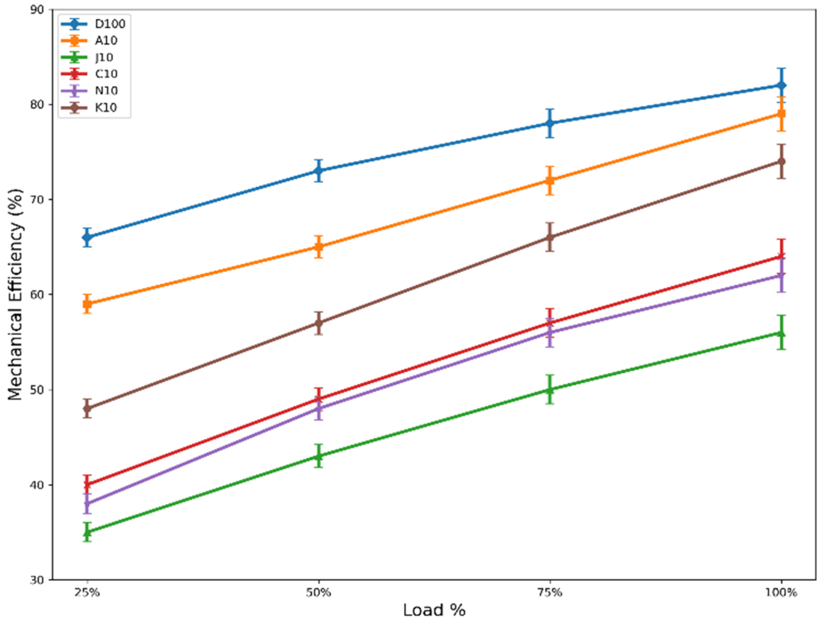

Figure 7. Mechanical Efficiency and Load Comparison.

4.1.5. Brake Specific Fuel Consumption

In contrast to the various non-edible oil blends and base fuel, the role of BSFC under changing load conditions in the tested fuels is demonstrated by the analysed data with different parameters (D100, A10, J10, C10, N10, K10) and increasing load levels (25%, 50%, 75%, 100%). The blend's BSFC increased continuously as the blending percentage increased, as shown in Figure 8. Compared to non-edible oil blends and base fuels, the combustion rate of the A10 blend decreased by 0.24 kg/kWh, J10 by 0.31 kg/kWh, C10 by 0.265 kg/kWh, N10 by 0.3 kg/kWh, K10 by 0.27 kg/kWh, and pure diesel by 0.23 kg/kWh at peak load conditions. This higher BSFC rate contrasts with other non-edible fuels. Among these, the A10 blend values are very close to those of the base fuel.

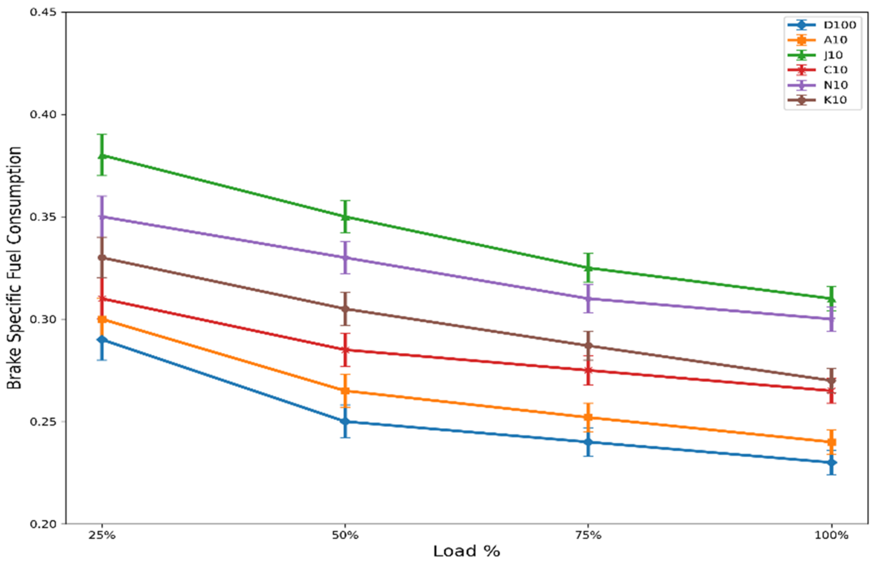

Figure 8. BSFC variability with load.

4.2. Emission Characteristics

4.2.1. CO (%)

The rate of CO emissions for the tested fuel blend, various non-edible oil blends, and diesel under different load conditions is shown in Figure 9. The air-fuel mixture ratio and in-cylinder temperature have the greatest effect on this emission parameter. Incomplete fuel combustion during the combustion process results in CO emissions. The significant amount of CO emissions produced during peak load conditions is primarily due to insufficient combustion chamber temperature, which prevents the conversion of CO to carbon dioxide. Under maximum load conditions, the CO emission levels generated by pure diesel, several non-edible oils, and A10 are as follows: pure diesel, 0.14%; A10, 0.085%; J10, 0.122%; C10, 0.13%; N10, 0.105%; and K10, 0.095%.

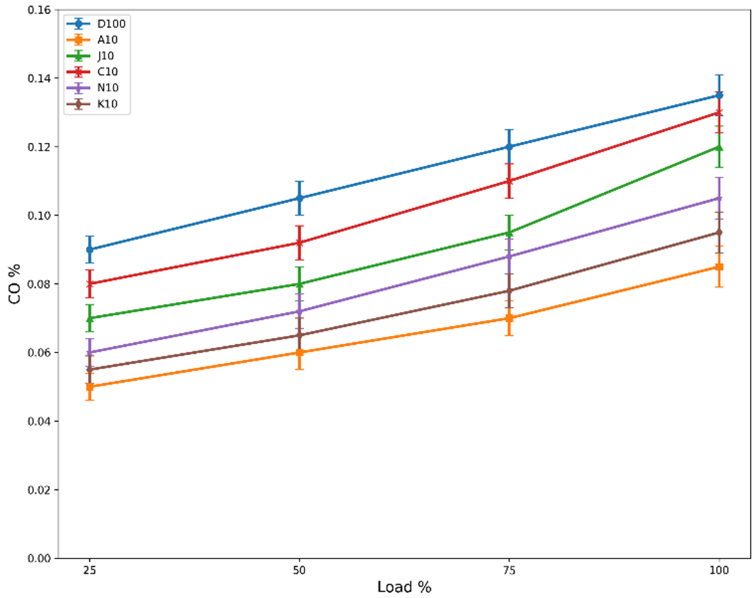

Figure 9. Carbon Monoxide Emissions According to Load.

4.2.2. HC (PPM)

This illustrates how the HC rates of various non-edible blends—J10, C10, N10, K10, A10, and pure diesel—vary with load conditions. The primary cause of these emission parameters is insufficient oxygen supplied for complete combustion. When comparing the test fuel blend A10 with other non-edible oils and pure diesel, it is evident from Figure 10 that the HC emission rate increased. Incomplete combustion occurs due to the fuel's low temperature inside the combustion chamber. At full load, the HC emission rates for A10, J10, C10, N10, K10, and D100 are 52 ppm, 54 ppm, 55 ppm, 50 ppm, 49 ppm, and 58 ppm, respectively. High levels of HC emissions were observed for A10 when comparing all HC emission measurements at peak load conditions.

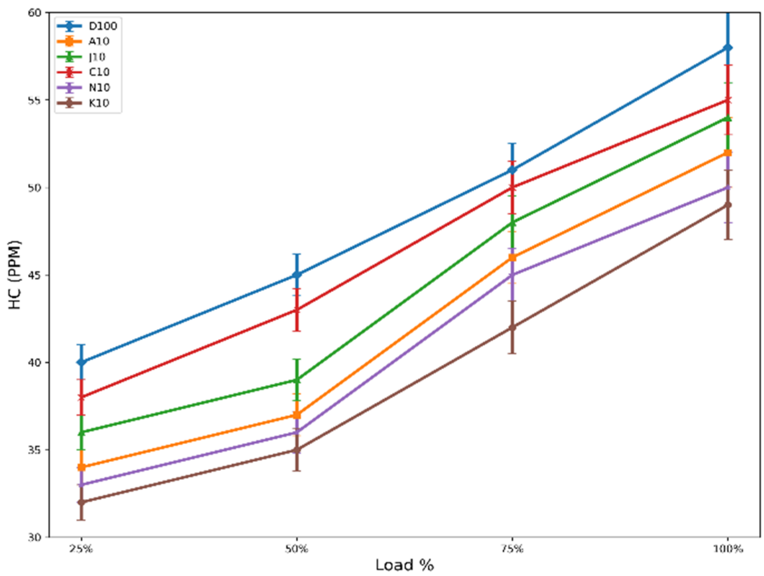

Figure 10. Hydrocarbon Emissions Concerning Load.

4.2.3. NO_x (PPM)

The chart (Figure 11) illustrates the difference in NO_x emission rates between pure diesel fuel and various non-edible oils in test fuel blends under various load situations. The NO_x emission rate is mostly influenced by the temperature of the cylinder and the amount of oxygen present. It can increase the load, the maximum amount of NO_x produced. NO_x compared with the different non-edible oils. The high amount of oxygen to be supplied combustion rate increased. So, this improved combustion process eventually leading to an increase in the rate of NO_x emissions. Higher NO_x emission rates are also correlated with higher Certance no values of the test blend. The emission rates of A10, J10, C10, N10, K10 and D100 at the maximum load condition are 920 ppm, 1000 ppm, 1100 ppm, 1080 ppm, 950 ppm and 1264 ppm, respectively.

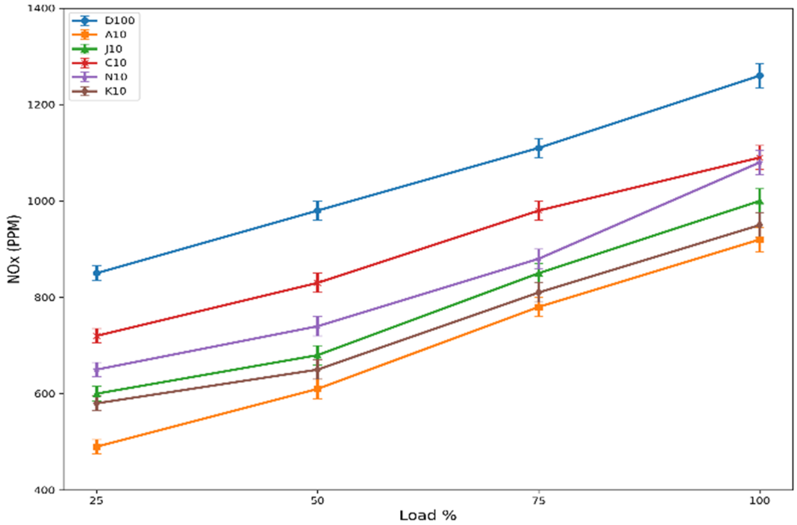

Figure 11. Nitrogen Oxide Emissions and Load Comparison.

4.2.4. CO_2 (%)

The test (Figure 12) fuel blend's rate of CO_2 emissions under various load scenarios. The evaluation of the tested fuel combination in comparison to pure diesel and other non-edible oils. Under conditions of peak load and high CO_2 production, the emission rates for pure diesel are 5.2%, A10 is 7.38%, J10 is 8.5%, C10 is 6.69%, N10 is 9.5%, and K10 is 7.3% respectively. The primary cause of the combustion chamber's excessive production of carbon atoms. Carbon dioxide is created when, in the combustion chamber, the fuel and oxygen mix.

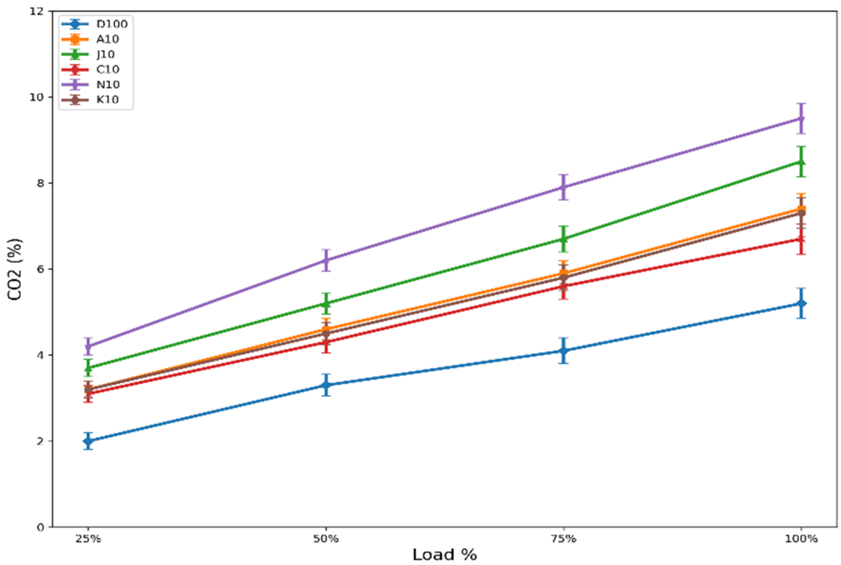

Figure 12. Comparison of Carbon Dioxide Emission with Load.

4.3. Combustion Characteristics

4.3.1. In-Cylinder Pressure

Varying crank angles result in changes in cylinder pressure within the combustion chamber. From +40° to −40°, the crank angle produces variations in cylinder pressure under engine-rated conditions, as shown in the figure. Figure 13 illustrates the changes in cylinder pressure as a function of crank angle at engine-rated conditions. This figure demonstrates that, depending on the measured load conditions, the main combustion period—also known as the ignition delay period—between the start of injection and combustion varies. Although the peak pressure readings differed, all tested biodiesel blends exhibited similar cylinder pressure profiles. To improve the combustion rate, the injected fuel is atomised and spontaneously mixed in the combustion chamber during the delay period. The fuel is then automatically ignited at the appropriate ignition temperature. However, the addition of 10% biodiesel causes a slight fluctuation in peak pressure. This minor decrease is attributed to the physical properties of biodiesel blends, such as higher viscosity and lower calorific value, which slow the rate of combustion within the combustion chamber. It has been observed that peak pressure indicates reduced engine efficiency as the blending ratio increases.

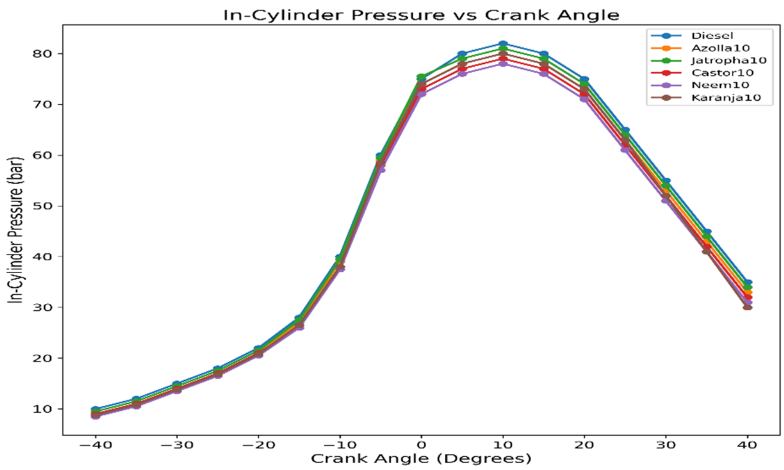

Figure 13. Comparison of In-cylinder Pressure with Crank angle (degrees).

4.3.2. Net Heat Release Rate

Figure 14 shows how the heat release rate of the VCR engine varies with crank angle when using different B10 blends and diesel fuel. Compared to the blended fuels, diesel fuel exhibited a higher heat release rate due to its higher calorific value, lower viscosity, lower density, and improved atomisation. Jatropha10, Neem10, and Karanja10 showed a substantial difference in heat release rate (HRR) compared to the base fuel, while Azolla10 and Castor10 did not show much change. The heat release rate was negative at the start of combustion and then steadily increased. This was due to the presence of oxygen-containing B10 blends introduced into the combustion chamber, which increased the heat release rate. Although the combustion process started and ended at nearly the same crank angles, the addition of biodiesel caused combustion to end earlier, indicating a shorter combustion duration for biodiesel. The results showed that the rate of heat emission decreased as the blend percentage in the fuel mix increased.

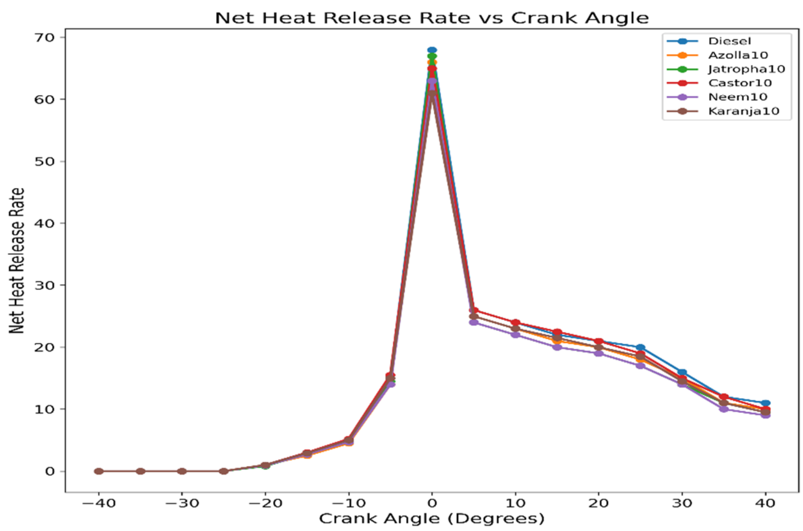

Figure 14. shows the relationship between the net heat release rate and the crank angle in degrees.

4.3.3. Mean Gas Temperature

Figure 15 above shows how crank angle and mean gas temperature are related. It has been established that base fuel has a higher mean gas temperature than all other blends, and the injection timing is shorter. At 20° crank angles, the mean petrol temperature of the Azolla10 is 1700 k, and at the same angle, the base fuel is 1750 k. The two main causes of blends with lower calorific values are the mean petrol temperature declines. Azolla10's average gas temperature values are close to Karanja10. For every blend, the mean gas temperature climbed gradually with crank angle, reaching a maximum value of 15° to 20° after the top dead centre. demonstrated that a larger oxygen supply to the combustion chamber led to a more thorough combustion and smoother temperature profiles.

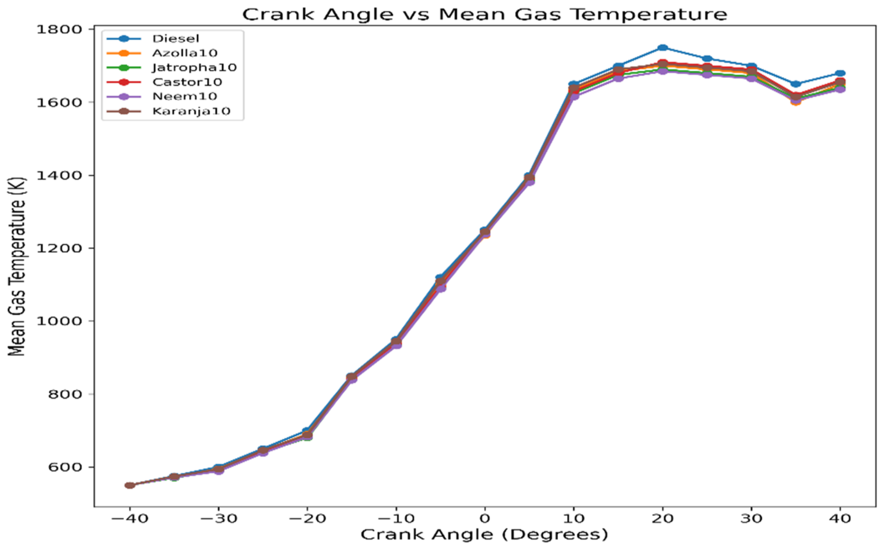

Figure 15. Variation of Mean gas temperature with Crank angle (degrees).

5. Conclusions

In a four-stroke, single-cylinder diesel engine test rig, the performance and emission parameters of diesel and A10 fuel blend are assessed under various load conditions. The following conclusions are reached after comparing the results with those of the other non-edible oils, J10, C10, N10, K10, and pure diesel.

Physical characteristics of the evaluated fuel blend showed a drop in density, an increase in calorific value, and a decrease in viscosity value. In comparison to the various non-edible oils, the cetane valve has a high value and the flash point value is also low.

- The indicated power at peak load conditions, the assessment findings for the tested mixes (A10, J10, C10, N10, K10, and base fuel) are 6.43 kW, 4.4 kW, 4.25 kW, 4.35 kW, 4.3 kW, and 6.24 kW. Respectively
- The peak load conditions evaluation values A10 is 3.84 kW, J10 is 3.8 kW, C10 is 3.6 kW, N10 is 3.75 kW, K10 is 3.7 kW, and Base fuel is 3.95 kW, in that order. Compared to the diesel D100, the A10 provides more compressed action.
- The A10 blend test results BTE values compared with different non-edible oils, base fuel is 1.17% less, J10 is 4.56% less, C10 is 05.18% less, N10 is 6.12% less, and K10 is 3.3% less, respectively. The test fuel blend A10 exhibits more intimate behavior in contrast to the diesel D100.
- Under conditions of maximum load, test the fuel blend A10 shows a significant reduction& increased compared to the non-edible oils and diesel. The ME reduction rate Diesel is 2.04% higher, J10 is 23.45% less, C10 is 14.77% less, N10 is 16.81% less, and K10 is 5.45% less. The tested blend A10 closer action in contrast to the diesel D100.
- Test fuel mixtures showed a notable decrease in fuel combustion rate compared to non-edible oil and pure diesel. The BSFC values were as follows: A10 at 0.24 kg/kWh, J10 at 0.31 kg/kWh, C10 at 0.265 kg/kWh, N10 at 0.3 kg/kWh, K10 at 0.27 kg/kWh, and pure diesel at 0.23 kg/kWh under peak load conditions. The combustion rate of A10 is closer to that of diesel D100.
- At maximal load circumstances, CO emission levels were generated by pure diesel, several non-edible oils, and A10. Pure diesel is 0.14%, A10 is 0.085%, J10 is 0.122%, C10 is 0.13%, N10 is 0.105%, and K10 is 0.095% respectively. The tested blend significantly increased compared to the D100.

- At full load, the HC emission rates for A10, J10, C10, N10, K10, and D100 are 52 ppm, 54 ppm, 55 ppm, 50 ppm, 49 ppm, and 58 ppm, respectively. High levels of HC emissions were produced when comparing all HC emission measurements at peak load conditions (A10).
- The rates of emission of NO_x from the tested fuel blend and other non-edible oils when the load is at its highest, using just diesel A10, J10, C10, N10, K10 and D100 at the maximum load condition are 920 ppm, 1000 ppm, 1100 ppm, 1080 ppm, 950 ppm and 1264 ppm, respectively.
- Under conditions of peak load and high CO_2 production, the emission rates for pure diesel are 5.2%, A10 is 7.38%, J10 is 8.5%, C10 is 6.69%, N10 is 9.5%, and K10 is 7.3%, respectively.
- The level of CO_2 emissions rates tests fuel blend and other non-edible oil with Diesel at peak load conditions, pure diesel is 5.2%, A10 is 7.38%, J10 is 8.5%, C10 is 6.69%, N10 is 9.5%, and K10 is 7.3% respectively. The tested blend CO_2 emission value is near the D100.
- Biodiesel blends Neem10 and Jatropha10 recorded the highest cylinder pressure in comparison to Azolla10, Castor10, and Karanja10, while diesel showed the highest peak pressure, suggesting somewhat improved combustion due to its high calorific value.
- In comparison to other blended fuels, diesel fuel demonstrated a higher heat release rate due to its higher calorific value, reduced viscosity, density, and improved atomisation. Jatropha10, Neem10, and Karanja10 demonstrated a substantial difference in heat release rate (HRR) with regard to base fuel, but Azolla10 and Castor10 did not exhibit much change.
- It has been established that base fuel has a higher mean gas temperature than all other blends, and the injection timing is shorter. At 20° crank angles, the mean petrol temperature of the Azolla10 is 1700 k, and at the same angle, the base fuel is 1750 k.

According to the findings outlined previously mentioned, A10 evaluation mixes may be used to serve as are replaced source of energy in combustion engines without much modification to enhance engine performance and emission levels.

6. Future Work

Research and use of biodiesels are progressing rapidly. The use of these biodiesels offers the potential to reduce pollution and provide a better alternative for the automotive industry. In future, blends will be prepared to assess performance and emission characteristics. Emission data in this study are considered under normal operating conditions. Azolla algae show promise, and with the addition of certain additives, there may be potential for improved efficiency and lower emissions compared to diesel.

Author Contributions

K.G.: conceptualization, methodology, investigation, data curation, formal analysis, software, visualization, writing—original draft preparation, writing—review and editing; N.S.K.: visualization, investigation, supervision, writing—original draft preparation, writing—review and editing; B.B.K.: visualization, supervision writing—review and editing. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement

Not applicable.

Data Availability Statement

All data used is presented in the paper.

Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper

Nomenclature

A10—Azolla (10%) + Diesel (90%)
J10—Jatropha (10%) + Diesel (90%)
C10—Castor (10%) + Diesel (90%)
N10—Neem (10%) + Diesel (90%)
K10—Karanja (10%) + Diesel (90%)
D100—Pure diesel
IC—Internal Combustion
ASTM—American Society for Testing and Materials
PPM—Parts Per Million
CV—Calorific value
BSFC—Brake Specific Fuel Consumption
BTE—Brake Thermal Efficiency
CI—Compression Ignition
CO—Carbon Monoxide
CO_2—Carbon dioxide
ME—Mechanical Efficiency
NO—Nitric Oxide
NO_x—Oxides of Nitrogen
HC—Hydrocarbon
VCR—Variable Compression Ratio
FAME—Fatty Acid Methylester

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