https://doi.org/10.36296/1819-8058.2026.1(84).311-319

THE IMPACT OF DIESEL AND VARIOUS BLENDS OF BIODIESEL ON PERFORMANCE, EMISSIONS, AND COMBUSTION IN DI DIESEL ENGINES

Received May 07, 2025; accepted Mar. 23, 2026
Available online Mar. 31, 2026

Sekharraj K.[1], Balu P.[2], Giriprasath A.[3], Rathinasuriyan C.[4], Didkivska H.[5]

Author for correspondence: Balu Pandian
e-mail: balumitauto@gmail.com

[1] Research Scholar,
Department of Automobile Engineering
https://orcid.org/ 0009-0004-3562-9957

[2] Associate Professor,
Department of Automobile Engineering
https://orcid.org/ 0000-0003-3480-1116

[3] Associate Professor,
Department of Mechanical Engineering
https://orcid.org/0009-0004-9219-294X

[4] Associate Professor
Department of Mechanical Engineering
https://orcid.org/0000-0001-7380-3064

[5] PhD (Engin.)
https://orcid.org/0000-0002-8314-9606

[1, 2] Bharath Institute of Higher Education and Research, Chennai, Tamil Nadu, India

[3] Sri Manakula Vinayagar Engineering College, Puducherry, India

[4] Vel Tech Rangarajan Dr.Sagunthala R&D Institute of Science and Technology, Avadi, Chennai, India

[5] Institute of Renewable Energy, NAS of Ukraine, Kyiv, Ukraine

Abstract. *The increasing demands for sustainable energy and stringent emission regulations have prompted the exploration of alternative fuels in internal combustion engines. This study investigates the effects of conventional diesel and various biodiesel blends on the performance, emission, and combustion characteristics of direct injection (DI) diesel engines. The study aims to identify the most suitable biodiesel blend that can serve as a viable alternative to conventional diesel fuel, providing high engine efficiency with reduced environmental impact. The rise in consumption, environmental emissions, and the cost of petrol make the energy recovery from trash a top priority. Not only can biodiesel meet energy demands, but it can also reduce greenhouse gas emissions, making it an important source of renewable energy. An experimental study of diesel and many different biodiesel blends was conducted to analyse their performance, emissions, and combustion characteristics. To prepare the emulsified fuel and go on with further experimental work, this effort aimed to identify the optimal biodiesel blends. The results of this paper showed that among all other biodiesel blends with various compositions, Syzygy Cumini (SC) biodiesel 20% by volume with diesel (SC20) was the best mix. Based on the outcomes of performance, combustion, and emission metrics, it was selected. Overall, SC20 biodiesel was identified as the optimal blend, offering a promising balance between engine performance, combustion stability, and lower exhaust emissions, thus supporting its potential use in existing diesel engines without modifications.*

Key words: *diesel engine, biodiesels, performance, emissions, combustion, renewable energy.*

ВПЛИВ ДИЗЕЛЬНОГО ПАЛИВА ТА РІЗНИХ СУМІШЕЙ БІОДИЗЕЛЮ НА РОБОЧІ ХАРАКТЕРИСТИКИ, ОБСЯГИ ВИКИДІВ ТА ПРОЦЕС ЗГОРЯННЯ В ДИЗЕЛЬНИХ ДВИГУНАХ ІЗ БЕЗПОСЕРЕДНІМ УПОРСКУВАННЯМ ПАЛИВА

Отримано 07 трав. 2025 р.; рекомендовано до публікації 23 бер. 2026 р.
Доступно онлайн 31 бер. 2026 р.

Секхарradж К.[1], Балу П.[2], Гіріпрасат А.[3], Ратінасурія С.[4], Дідківська Г.[5]

Автор для кореспонденції: Балу Пандіан
e-mail: balumitauto@gmail.com

[1] наук. співроб. кафедри машинобудування
https://orcid.org/ 0009-0004-3562-9957

[2] доцент кафедри машинобудування
https://orcid.org/ 0000-0003-3480-1116

[3] асистент кафедри машинобудування
https://orcid.org/0009-0004-9219-294X

[4] доцент кафедри машинобудування
https://orcid.org/0000-0001-7380-3064

[5] канд. техн. наук
https://orcid.org/0000-0002-8314-9606

Анотація. *Зростання попиту на енергію зі сталих джерел та посилення вимог щодо обмеження викидів стимулюють пошук альтернативних видів палива для двигунів внутрішнього згоряння. У цій роботі досліджено вплив традиційного* *дизельного палива та різних сумішей біодизеля на робочі характеристики, обсяги викидів і процес згоряння палива в дизельних двигунах з безпосереднім упорскуванням. Метою дослідження є визначення найбільш придатної суміші біодизеля, яка може слугувати життєздатною альтернативою традиційному дизельному паливу, забезпечуючи високу ефективність роботи двигуна за одночасного зменшення негативного впливу на довкілля. Зростання обсягів споживання палива, обсягів шкідливих викидів та вартості бензину зумовлює актуальність генерації енергії з відходів. Біодизельне паливо здатне не лише задовольнити потреби в енергії, а й зменшити викиди парникових газів, що робить його важливим джерелом відновлюваної енергії. Експериментальне дослідження дизельного палива та різних сумішей біодизеля було проведено з метою аналізу їх експлуатаційних, екологічних характеристик та показників згоряння. У межах роботи також було визначено оптимальні суміші біодизеля для приготування емульсійного палива й подальших експериментальних досліджень. Результати дослідження доводять, що серед усіх досліджених сумішей біодизеля з різним складом найкращі показники продемонструвала суміш біодизеля Syzygy Cumini (SC) у кількості 20% за об'ємом з дизельним паливом (SC20). Саме її було обрано на основі комплексної оцінки показників роботи двигуна, процесу згоряння та викидів. Загалом біодизельна суміш SC20 визначена як оптимальна, оскільки забезпечує збалансоване поєднання високої ефективності роботи двигуна, стабільності згоряння та зниження рівню викидів відпрацьованих газів, що підтверджує можливість її використання в існуючих дизельних двигунах без конструктивних модифікацій.*

[1, 2] Інститут вищої освіти та досліджень «Бхарат», м. Ченнаї, штат Тамілнад, Індія

[3] Технічний коледж «Шрі Манакула Вінаягар», м. Пудучеррі, Індія

[4] Науково-дослідний інститут науки й технології «Вел Тек Рангараджан» ім д-ра Сагунтала, м. Аваді, Ченнаї, Індія

[5] Інститут відновлюваної енергетики НАН України, Київ, Україна

Ключові слова: *дизельний двигун, біодизель, експлуатаційні характеристики, викиди, згоряння, відновлювана енергія.*

1. Introduction

As the average energy consumption of the transport sector rises by 2.0% annually, the operationalisation of a better transport system boosts the economy of any nation. Energy demand and consumption have grown as a result of industrialisation. In the beginning, crude oil was utilised as a substitute to supply the energy demand, and starting in 1970, there was a global scarcity of crude oil. Researchers and scientists have been working on creating alternative fuels to address this problem globally [1]. Increased use of vehicles as a result of population expansion has increased toxic petrol emissions into the atmosphere. Diesel engines are often used in transportation, industry, and agriculture due to their dependability, combustion efficiency, and power output [2]. In recent years, however, internal combustion engines have been subject to increasing pollution and emission concerns due to the development of low-emission and efficient engines. The most popular of these alternative fuels is biodiesel. The characteristics of biodiesel are similar to those of diesel since it is renewable, biodegradable, and non-toxic. This allows it to be blended with diesel [3]. At the same time, ternary blends may be created by combining biodiesel as a co-solvent with diesel and other fuels that include oxygen. However, because of its detrimental impact on engine performance, biodiesel cannot be utilised directly on diesel engines. Alcohol and diesel are encouraged to combine because the polar head of the biodiesel molecule is directed towards the alcohol, and the non-polar tail is directed towards the fuel. We all know that incomplete fuel combustion is the primary cause of soot, THC, and CO emissions. Due to its high oxygen concentration, biodiesel can solve the issues [4]. And other studies on these emissions have already shown encouraging findings. Numerous researchers have investigated the combustion and emission characteristics of diesel engines powered by different kinds of biodiesels using experimental and modelling methods [5]. By releasing oxygen atoms from its chemical structure, biodiesel boosts combustion efficiency and lowers air pollution by reducing particulate matter (PM), carbon monoxide (CO), and hydrocarbon (HC) emissions. In addition, diesel and biodiesel can be mixed in any ratio. The low calorific value and low volatility of biodiesel fuel, as well as its poor cold flow qualities, are just some of the disadvantages of the fuel. The emission of nitrogen oxides would also be higher with biodiesel fuel, according to several experts [6]. The combustion and emissions characteristics of diesel engines fuelled by biodiesel-diesel blends have been studied in order to enhance the quality of biodiesel [7]. The main aim of this paper is to compile experimental research on diesel-biodiesel blends in an effort to increase performance and reduce hazardous emissions.

2. Materials and Methods

2.1 Preparation of Citrullus Lanatus

The preparation of *Citrullus lanatus* (watermelon) biodiesel involves a series of steps beginning with the collection and processing of mature watermelon seeds. The seeds are extracted from the fruit, thoroughly washed to remove pulp residues, and sun-dried for several days to reduce moisture content. Once dried, the seeds are crushed and subjected to mechanical pressing using a screw-type expeller to extract the crude oil. The extracted oil is then filtered to remove solid impurities and stored in clean, airtight containers. Before transesterification, the physicochemical properties of the crude oil, such as acid value and free fatty acid (FFA) content, are determined. If the FFA level exceeds 2%, a two-step process is employed: initial acid esterification using methanol and sulfuric acid to reduce FFA, followed by base-catalyzed transesterification with methanol and sodium hydroxide (NaOH) as the catalyst. The reaction is maintained at around 60°C with continuous stirring, and after the completion of the process, the mixture is allowed to settle into two layers: crude glycerol and biodiesel. The biodiesel layer is then washed repeatedly with warm distilled water to remove impurities and dried to eliminate moisture and residual alcohol. The purified watermelon seed biodiesel is finally analyzed for its key fuel properties, ensuring it meets the ASTM D6751 or EN 14214 standards for biodiesel fuels (Fig. 1, Table 1).

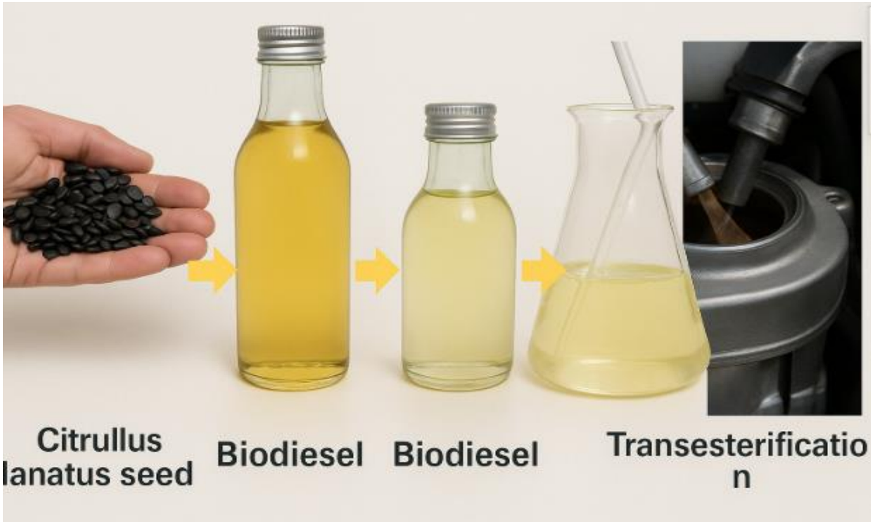

Fig. 1. Biodiesel preparation

Table 1. Fuel Characteristics of Citrullus Colocynthis, Syzygium Cumini (Jamun), and Diesel

S.No	Property	Diesel	Citrullus Colocynthis	Syzygium Cumini (Jamun)
1	Molecular weight (gm/mol)	160	815.62	918.54
2	Stoichiometric air fuel ratio	33.5	N/A	N/A
3	Flame velocity (cm/s)	27	30	34
4	Auto-ignition temperature (K)	534	715	700-830
5	Heat of combustion (kJ/kg)	40.3	74	64
6	Density of gas at NTP (g/cm^3)	0.85	0.78	0.74
7	Octane number	-	84	55
8	Cetane number	45-55	40	45
9	Boiling point (K)	550-630	370	340 - 405
10	Specific gravity	0.78	0.845	0.918

3. Experimental Setup

The experimental investigation was carried out on a single-cylinder, four-stroke, direct-injection (DI) diesel engine coupled to an eddy-current dynamometer for applying controlled loads. Biodiesel was produced from *Citrullus lanatus* seed oil through an alkali-catalyzed transesterification process, and blends were prepared in predetermined proportions. The engine was equipped with a calibrated fuel measurement system, thermocouples for recording coolant, lubricating oil, exhaust, and inlet-air temperatures, and a piezoelectric in-cylinder pressure transducer synchronized with a high-resolution crank angle encoder to capture cycle-resolved combustion data. Exhaust emissions, including CO, HC, and NOx, were measured using an automotive gas analyzer, while smoke opacity was determined using a standard smoke meter. At each test point, the engine was stabilized at the rated speed and loads ranging from no-load to full load, and steady-state data were recorded for fuel consumption, brake power, emissions, and pressure traces (Fig. 2, Table 2). The heat release rate and ignition delay were computed from the averaged pressure-crank angle diagrams, enabling a comprehensive assessment of the influence of *Citrullus lanatus* biodiesel and its blends on engine performance, emissions, and combustion characteristics.

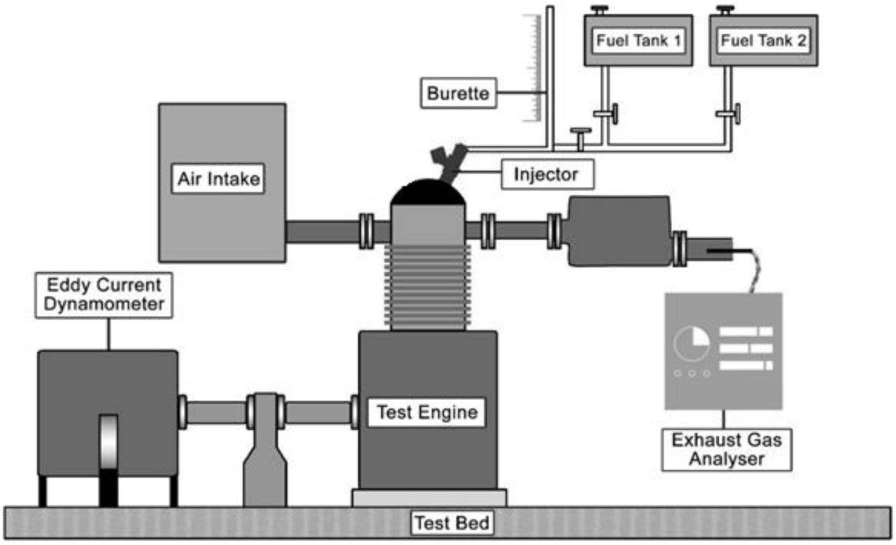

Fig. 2. Experiment setup

Table 2. Specifications of the Engine

Engine make	Kirloskar AV-1
Type	Single cylinder& water cooled
Bore × Stroke	80 × 110 mm
Displacement	550 CC
Max. power	3.7 kW at 1500 rpm
Fuel injection timing	23° bTDC
Compression ratio	16.5:1
Loading device	Electrical Dynamometer

4. Results and Discussion

4.1 Brake Thermal Efficiency (BTE)

A comparison in Fig. 3 is shown between the thermal performance of diesel brakes, Citrullus Colocynthis brakes, GGG20 brakes, Mordica Charantia brakes, and Syzygy Cumini brakes without changing the manufacturer's settings. The experimental results revealed that all fuels, including the reference diesel and the biodiesel blends, exhibited their maximum brake thermal efficiency at three-fourths of the full load. Among the tested blends, SC20 (20% *Syzygium cumini* biodiesel with 80% diesel) demonstrated the most favorable performance characteristics under this load condition. With increasing load, brake thermal efficiency increased. Diesel was found to have a braking thermal efficiency of 28.57% at 3/4 load. Comparing CC20, GGG20, MC20, and SC20 to diesel, the brake thermal efficiency decreased by 3.6%, 4.5%, 5.5%, and 3.0%, respectively. A number of variables affect an engine's brake thermal efficiency, but the heating value and specific gravity are the most important ones. The lower calorific value and higher viscosity of biodiesel fuels compared to diesel fuel may be the cause of the decline. Because SC20 has a little lower viscosity than other biodiesel fuels and hence better atomization than the other biodiesel blends, it marginally reduces brake thermal efficiency when compared to diesel. Additionally, it was discovered that its calorific value was larger than that of other biodiesel fuels [8].

4.2 Specific Energy Consumption (SEC)

Fig. 4 depict the precise energy consumption of several biodiesel blends (test fuels) and diesel (the reference fuel). At part load, it was discovered that the specific energy consumption was decreasing, but at full load, it rose for both the reference fuel and the test fuel. Figure 4 shows that diesel has a lower specific energy consumption when compared to other biodiesel mixes. It can be because biodiesel fuel has a lower heating value than diesel. Diesel was determined to have a maximum specific energy consumption of 16020.4 kJ/kWh at full load conditions. For CC20, GGG20, MC20, and SC20, the increases in specific energy consumption were determined to be 16.57%, 19.53%, 21.79%, and 7.58%, respectively. The engine used more fuel than diesel to produce the same amount of power since biodiesel fuel has a lower calorific value. Compared to other biodiesel blends, Syzygy Cumini's fuel has the lowest specific energy usage. Syzygy Cumini biodiesel's lower specific energy consumption may be due to its increased calorific value [9].

4.3 Unburnt Hydrocarbon (HC) Emission

Fig. 5 shows that hydrocarbon emission reduced until it reached the third-fourths load condition before increasing once more until the maximum condition was attained. The hydrocarbon might be present because of inefficient combustion brought on by a rich fuel mixture or a lack of oxygen for efficient combustion. At maximum load, diesel's hydrocarbon emission was determined to be 75 ppm. When using CC20, GGG20, MC20, and SC20 biodiesel fuels, respectively, the decrease in hydrocarbon emissions were determined to be 6.257%, 5.423%, 3.257%, and 7.564%. All biodiesel blends were shown to emit less hydrocarbons than diesel, according to research. Compared to diesel, biodiesel fuels produced fewer hydrocarbon emissions because the oxygen presence accelerated the combustion process. With SC20 biodiesel fuel, hydrocarbon emissions were reduced the most among all biodiesel fuels [10].

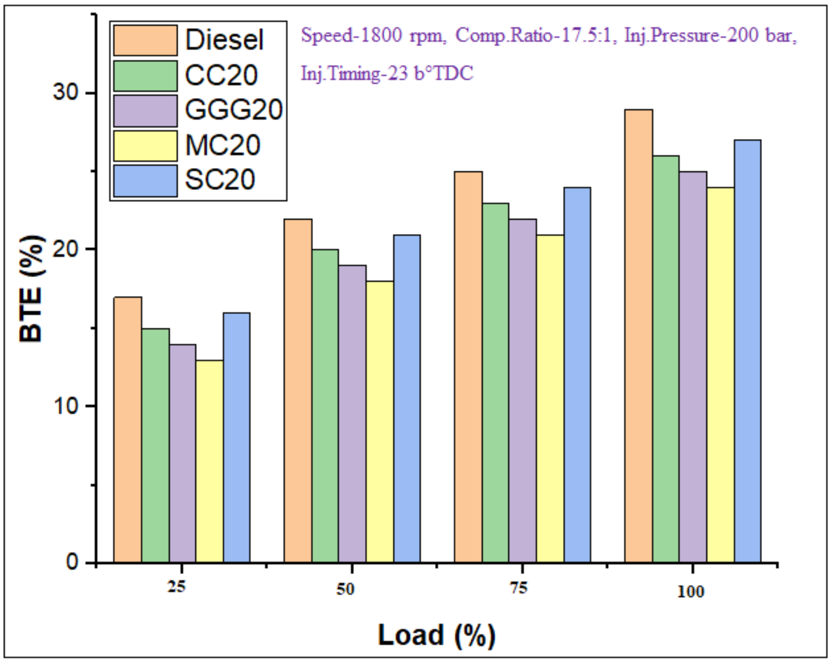

Fig. 3. Brake thermal efficiency vs load

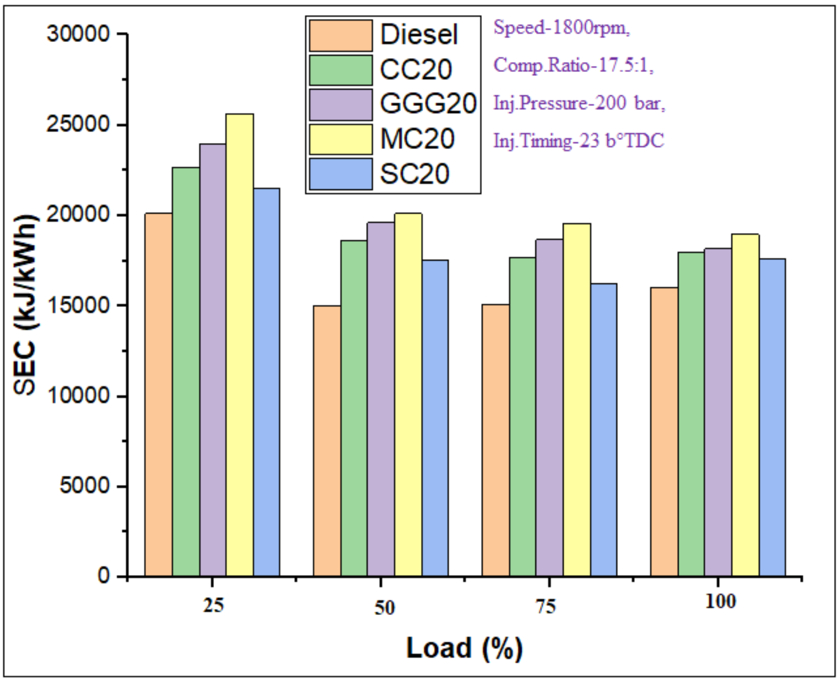

Fig. 4. Specific energy consumption vs load

4.4 Carbon Monoxide (CO) Emission

It can be seen from Fig. 6 that as the braking power increased, carbon monoxide emissions dropped. A maximum CO emission of 0.099% was determined for diesel, but 0.088%, 0.075%, 0.063%, and 0.053% were reduced for CC20, GGG20, MC20, and SC20, respectively. The carbon monoxide (CO) emissions for all biodiesel blends were observed to be slightly higher than those of diesel at lower load conditions, as shown in the figure. However, at higher loads (particularly at three-fourths of the load), CO emissions gradually decreased due to improved combustion efficiency. Contrary to the general expectation that biodiesel blends reduce CO emissions due to their inherent oxygen content, the figure shows that SC20 emitted marginally higher CO than diesel at part load, possibly due to incomplete combustion under suboptimal air–fuel mixing. These variations highlight the influence of load conditions and combustion characteristics on emission behavior and emphasize the need to interpret biodiesel emissions data in context with engine operating parameters [11].

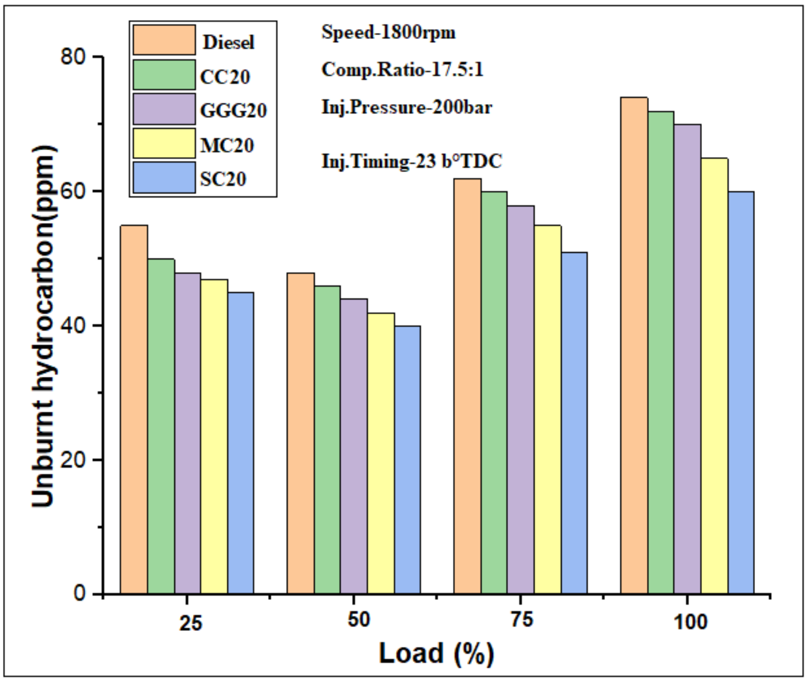

Fig. 5. Unburnt hydrocarbon vs load

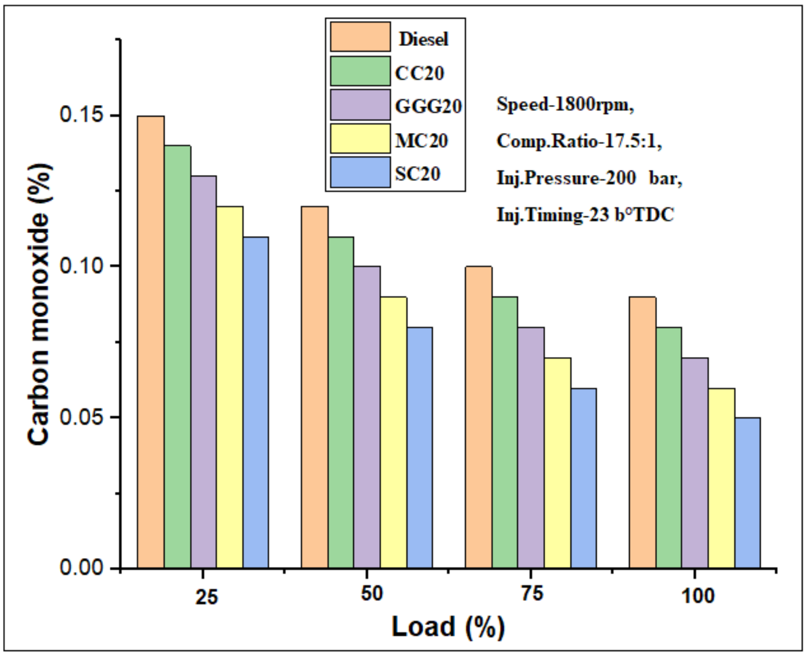

Fig. 6. Carbon monoxide vs load

4.5 Smoke Opacity

Fig. 7 shows that when the load increased, the smoke opacity rose for both the test fuels (biodiesel blends) and the reference fuel (diesel). Diesel fuel was found to emit 38.98 HSU of smoke opacity at maximum load. For CC20, GGG20, MC20, and SC20, the corresponding increases in smoke opacity were determined to be 6.2 HSU, 7.6 HSU, 8.1 HSU, and 4.2 HSU. The larger molecules in biodiesel may have produced poor atomization at greater loads, which further contributed to incomplete combustion. The slower combustion response may be caused by the higher viscosity of biodiesel fuels. However, when compared to other Syzygy Cumini and other biodiesel blend ratios, SC20 biodiesel produced the least amount of smoke opacity emissions. Lower smoke emissions may be caused by SC20 biodiesel's lower viscosity compared to other biodiesel blends [12].

4.6 Oxides of Nitrogen (NOx) Emission

Fig. 8 compares the nitrogen oxides (NOx) produced by diesel and different biodiesel blends. At low start load conditions, the NOx emission was shown to be high, and it rose with increasing load. The explanations for the increased NOx emission at higher loads were greater fuel intake and rich combustion. The NOx emissions from diesel fuel with 426 ppm were lower than those from other biodiesel blends. All other biodiesel mixes were likewise shown to have higher NOx emissions. When compared to diesel, the increase in NOx emission for CC20, GGG20, MC20, and SC20 was determined to be 14.56%, 8.59%, 4.63%, and 20.27%, respectively. The SC20 biodiesel mix was determined to have the highest oxides of nitrogen emission out of all biodiesel fuels. At peak flame temperatures, oxygen interacts with nitrogen, leading to combustion [13].

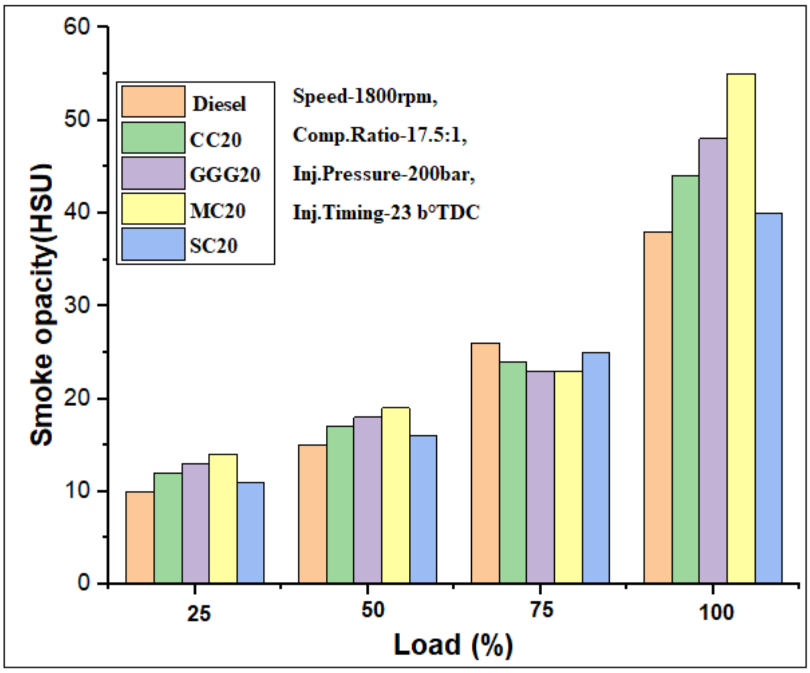

Fig. 7. Smoke opacity vs load

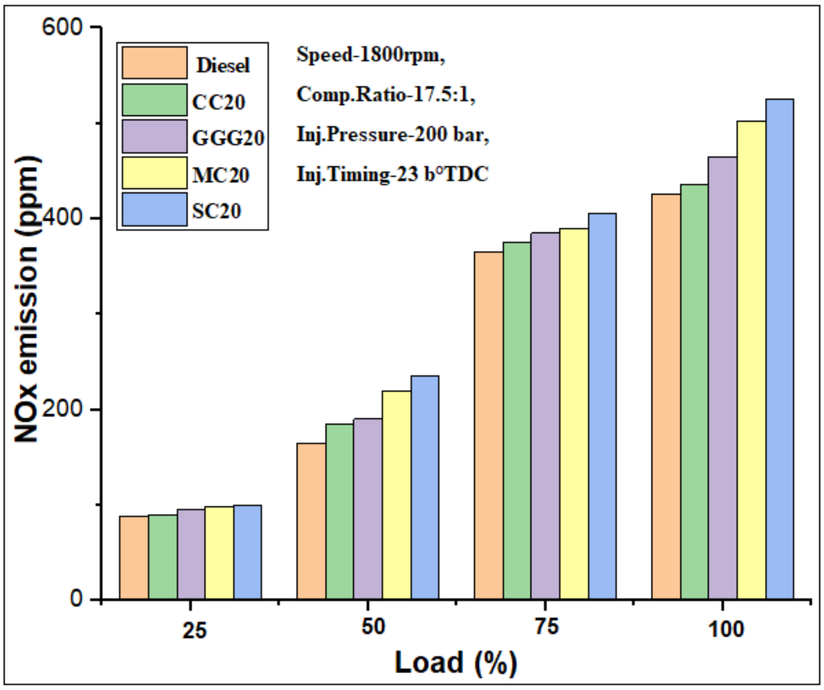

Fig. 8. Oxides of nitrogen vs load

4.7 Cylinder Pressure

Fig. 9 compares the cylinder pressures of the diesel, CC20, GGG20, MC20, and SC20 engines without altering the manufacturer's specifications. Diesel was discovered to have a 74 bar peak pressure. Comparing CC20, GGG20, MC20, and SC20 to diesel, the peak pressure was reduced by 8.54%, 9.34%, 12.55%, and 3.27%, respectively. The SC20 biodiesel was determined to have the least peak pressure reduction. Syzygy Cumini biodiesel's higher calorific value and lower viscosity than the other biodiesel blends might be to blame for this. Syzygy Cumini biodiesel has lower viscosity than other biodiesel blends because its molecules are smaller than those of other biodiesel blends, which improves atomization [14]. With better air and fuel mixing than the other biodiesel fuels and lower viscosity than the other biodiesel blends, it can be said that there was improved combustion. Therefore, it may be deduced that the combustion was superior to that of the other biodiesel fuels due to greater air and fuel mixing [15].

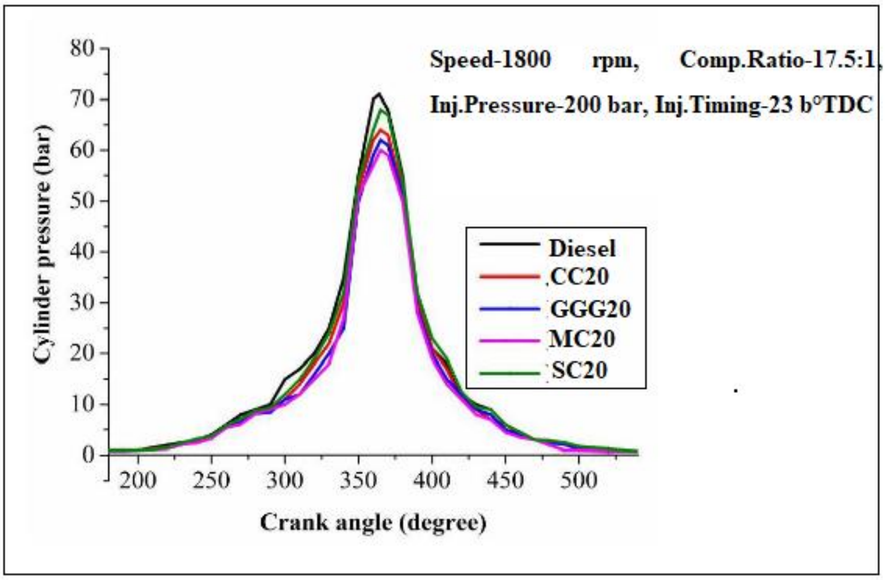

Fig. 9. Cylinder pressure vs crank angle

4.8 Heat Release Rate (HRR)

The rate of heat loss for diesel and different biodiesel mixes is shown in Fig. 10. By 85.6 J/deg CA, diesel fuel was shown to have the lowest peak heat release. For CC20, GGG20, MC20, and SC20, respectively, the maximal heat release rates were determined to be 84.5 J/deg CA, 83.2 J/deg CA, 85.6 J/deg CA, and 81.5 J/deg CA. All biodiesel fuels were found to have longer ignition delays than diesel. It could be because they have a lower cetane value than diesel. A lower cetane value lengthened the ignition delay period, causing more fuel to accumulate and, as a result, more heat to be released than with diesel fuel. It was discovered that the heat release rate of SC20 biodiesel fuel was virtually as fast as that of diesel. The fuel molecules' inability to reach the self-ignition temperature right away after absorbing heat may be the cause of the negative heat release [16].

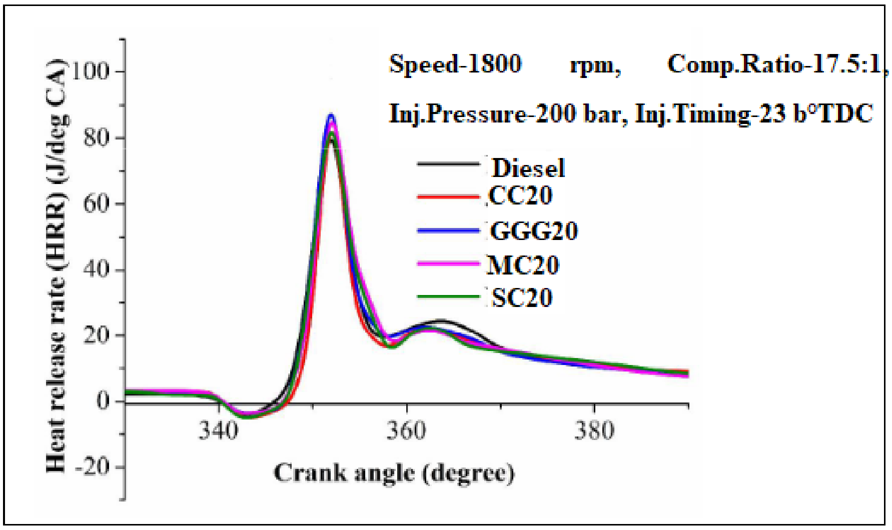

Fig. 10. Heat Release Rate vs crank angle

Conclusion

This study comprehensively evaluated the performance, combustion, and emission characteristics of a direct injection (DI) diesel engine fueled with diesel and various biodiesel blends derived from Syzygium cumini (SC20), Citrullus colocynthis (CC20), Garcinia gummi-gutta (GGG20), and Mordica charantia (MC20). The experimental results demonstrated that the maximum brake thermal efficiency for all fuels was achieved at three-fourths of full load, with SC20 showing an efficiency nearly equal to that of pure diesel. Combustion analysis indicated smoother heat release and shorter ignition delays for biodiesel blends, particularly SC20, due to its higher cetane number and oxygen content. Emission analysis revealed that while most biodiesel blends reduced smoke, unburned hydrocarbons (UHC), and carbon dioxide (CO_2), CO emissions were slightly higher for SC20 compared to diesel under part-load conditions, as indicated in the emission plots. Nitrogen oxide (NOx) emissions showed a moderate increase with all biodiesel blends due to enhanced combustion temperatures. Among all tested blends, SC20 emerged as the most balanced fuel, offering diesel-comparable performance with significant environmental benefits, especially under partial load. These findings support the feasibility of using Syzygium cumini biodiesel in existing diesel engines with minimal modifications, contributing to cleaner and more sustainable engine operation.The best biodiesel tested was Syzygy Cumini (SC) biodiesel (20% by volume with diesel). The enhanced performance and reduced hazardous emissions observed with the diesel–biodiesel blends result from the oxygenated nature of biodiesel, which improves the completeness of combustion. This leads to higher heat-release rates and more stable combustion, thereby contributing to marginal increases in brake thermal efficiency. Simultaneously, the improved oxidation process reduces the formation of CO, HC, and smoke due to lower carbon content and better fuel–air mixing. Across all tested blends, these mechanisms collectively demonstrate that biodiesel contributes to cleaner combustion without compromising overall engine performance, confirming its suitability as a partial substitute for conventional diesel in practical applications. Furthermore, higher proportions of water and secondary biodiesel fuels with water content might be investigated. Moreover, endurance tests as a continuous part of this experimental investigation would provide insight into engine wear and tear.

REFERENCES

1. Uyumaz, A, Combustion, performance and emission characteristics of a DI diesel engine fueled with mustard oil biodiesel fuel blends at different engine loads, Fuel, 2018, 212, 256–267, http://dx.doi.org/10.1016/j.fuel.2017.09.005.
2. Ashok, B., K. Nanthagopal, B. Saravanan, K. Azad, D. Deepam Patel, B. Sudarshan, and R. Aaditya Ramasamy, Study on isobutanol and Calophyllum inophyllum biodiesel as a partial replacement in CI engine applications, 2019, Fuel, 235, 984–94. doi:10.1016/j.fuel.2018.08.087.
3. Harigaran A., & Pandian Balu, An experimental study on the performance and emission characteristics of a single-cylinder diesel engine running on biodiesel made from palm oil and antioxidant additive, International Journal of Ambient Energy, 2023, DOI: 10.1080/01430750.2022.2162577.
4. Rosha, P., S. Kumar, S. Kumar., H. Cho, B. Singh, and A. Dhir, Effect of compression ratio on combustion, performance, and emission characteristics of compression ignition engine fueled with palm (B20) biodiesel blend, Energy, 2019, 178, 676–84. doi:10.1016/j.energy.2019.04.185.
5. Rajayokkiam Manimaran., & K Murugu Mohan Kumar, Experimental analysis on unmodified diesel engine characterization with novel biodiesel blends extracted from waste Trichosanthescucumerina seeds, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, DOI: 10.1080/15567036.2021.1905110
6. Valencia G., C. Acevedo., and J. Duarte, Combustion and performance study of low-displacement compression ignition engines operating with diesel–biodiesel blends, Applied Science, 2020, 10 (3) 907. DOI:10.3390/app10030907
7. Mejía A., M. Leiva A., Rincon A., Gonzalez., and J., Duarte, Experimental assessment of emissions maps of a single-cylinder compression ignition engine powered by diesel and palm oil biodiesel-diesel fuel blends, Case Studies Thermal Engineering, 2020, 19, 100163, 1–13, https://doi.org/10.1016/j.csite.2020.100613.
8. Venkatesan Balaji., Kaliappan Seeniappan., Ezhumalai Shanmugam., Socrates Subramanian., and Jayaseelan Veerasundaram, Characterization and effect of the use of safflower methyl ester and diesel blends in the compression ignition engine, Oil & Gas Science and Technology–Revue d'IFP Energies nouvelles, 2021, 76 (29), doi.org/10.2516/ogst/2021011.
9. Balu P., Vasanthkumar P., Govindan P., Sathish T, An experimental investigation on ceramic coating with retarded injection timing on diesel engine using Karanja oil methyl ester, International Journal of Ambient Energy, 2023, DOI: 10.1080/01430750.2022.2161632.
10. Datta A., Mandal BK., 2017. An experimental investigation on the performance, combustion and emission characteristics of a variable compression ratio diesel engine using diesel and palm stearin methyl ester. Clean Technol Environ Policy 19:1297–1312. https://doi.org/10.1007/s10098-016-1328-3.
11. Balasubramanian R., Subramanian KA, Experimental investigation on the effects of compression ratio on performance, emissions and combustion characteristics of a biodiesel-fueled automotive diesel engine, Biofuels, 2019, https://doi.org/10.1080/17597269.2018.1558840.
12. Shrivastava P., Verma TN., David Samuel O., Pugazhendhi A, An experimental investigation on engine characteristics, cost and energy analysis of CI engine fuelled with Roselle. Karanja biodiesel and its blends Fuel. 2020, https://doi.org/10.1016/j.fuel. 2020.117891.
13. Örs İ., Sarıkoç S., Atabani AE., Ünalan S, Experimental investigation of effects on performance, emissions and combustion parameters of biodiesel–diesel–butanol blends in a direct-injection CI engine, Biofuels. 2019, 1608682, https://doi.org/10.1080/17597269.
14. Maawa., Wan Nor., Rizalman Mamat., Gholamhassan Najafi., and L. P. H. De Goey, Performance, combustion, and emission characteristics of a CI engine fueled with emulsified diesel-biodiesel blends at different water contents, Fuel, 2020, 267, 117265.
15. Nayak, Biswajeet., Thingujam Jackson Singh., and Anh Tuan Hoang, Experimental analysis of performance and emission of a turbocharged diesel engine operated in dual-fuel mode fueled with bamboo leaf-generated gaseous and waste palm oil biodiesel/diesel fuel blends, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 1-19.
16. Raja. KS, Sridhar, Senthil Kumar Srinivasan, K., Yoganandam, and Mahalingam Ravi, "Emissions and performance investigation on the effect of dual fuel injection in biodiesel driven diesel engine, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects , 2021, 1-11.