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Impact of Compression Ratio on Combustion Characteristics of VCR-CRDI Type Diesel Engine Fueled with Moringa Oleifera Methyl Ester

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ABSTRACT

This study explores the impact of compression ratio (CR) and fuel blends on the combustion properties of a diesel engine fueled by conventional diesel and biodiesel derived from Moringa oleifera. The research was conducted on a single-cylinder diesel engine with variable compression ratio (VCR) and common rail direct injection (CRDI), utilizing diesel and Moringa oleifera biodiesel blends MB10, MB20, and MB30. The experimental conditions included varying the CR between 15:1 and 18:1, maintaining an injection timing of 23°before top dead center, injection pressure set at 600 bar, and an engine speed of 1500 rpm under 100% load. The findings revealed that increasing the CR raises cylinder pressure (CP), cumulative heat release rate (CHRR), and rate of pressure rise (ROPR) for all the tested fuel blends. Notably, the diesel exhibited the highest CP of 70.83 bar, CHRR of 1.36 kJ, and ROPR of 6.42 bar/°CA (degree per crack angle) at a CR of 18:1. Among the biodiesel blends, MB30 showed the highest CP of 69.21 bar, while MB10 displayed highest CHRR and ROPR of 1.5 kJ and 6.17 bar/°CA, respectively. Furthermore, the net heat release rate (NHRR) and mean gas temperature (MGT) decreased with rising CR for all tested fuels. At a lower CR of 15:1, the diesel showcased the highest NHRR and MGT of 69.75 J/°CA and 1303.69 °C, respectively, whereas, in the case of biodiesel blends, MB20 demonstrated the highest values of 67.53 J/°CA and 1287.39 °C, respectively, at the same CR. Meanwhile, the ignition delay (ID) and combustion period diminish with a rise in the CR for all tested fuel blends. At a higher CR of 18:1, the minimum ID and combustion duration for diesel were reported as 17°CA and 15°CA, respectively. For the biodiesel blends, MB10 and MB30 showed a minimum ID of 16°CA, while MB10 and MB20 exhibited minimum combustion duration of 15°CA at the same CR.

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Combustion duration

1. INTRODUCTION

A significant portion of the global energy needs is fulfilled by conventional energy resources, including coal, petroleum, and natural gas. However, petroleum-based fuel supplies are scarce and focused in specific regions. These resources are at risk of depletion. Consequently, renewable energy sources are appealing owing to a shortage of reserves of fossil fuels (Demirbas, 2010). In this regard, biodiesel, derived from a wide range of sources, such as edible and inedible vegetable oils, animal-based fats, and leftover cooking oil, can power diesel engines without requiring any modifications (Demirbas, 2007). In terms of thermal operation, diesel and biodiesel-fueled engines operate identically; however, biodiesel results in lower emissions compared to diesel fuel (Janaun & Ellis, 2010).

Plant-derived vegetable oils, animal fats, utilized cooking oil, and various other feedstocks can be converted into biodiesel through the transesterification process. This process turns the triglycerides in these feedstocks into diglycerides and monoglycerides, which are subsequently transformed into fatty acid esters. The transesterification reaction occurs in the presence of alcohol and is catalyzed by either KOH or NaOH (Ma & Hanna, 1999; Suresh et al., 2021). The use of biodiesel in diesel engines results in a reduced thermal performance and lower emissions of carbon monoxide (CO), hydrocarbons

NOMENCLATURE

aTDC	after top dead centre	MB10	90% diesel + 10% Moringa biodiesel
bTDC	before top dead centre	MB20	80% diesel + 20% Moringa biodiesel
CHRR	Cumulative Heat Release Rate	MB30	70% diesel + 30% Moringa biodiesel
CP	Cylinder Pressure	MGT	Mean Gas Temperature
CR	Compression Ratio	NHRR	Net Heat Release Rate
CRDI	Common Rail Direct Injection	ROPR	Rate of Pressure Rise
ID	Ignition Delay	VCR	Variable Compression Ratio
IP	Injection Pressure	°CA-	deggree of crank angle
IT	Injection Timing		

(HC), and smoke—with the exception of nitrogen oxide emissions (El-Kassaby & Nemit-Allah, 2013; Sanjid et al., 2016; Soudagar et al., 2021).

Sahoo and Das (2009) performed experiments under different loads using diesel, neat biodiesel from Jatropha, Karanja, and Polanga, as well as their blends. Several combustion parameters of the engine were analyzed, including ignition delay (ID), rate of heat release (HRR), and peak cylinder pressure (CP). The results indicated that the highest peak CP was observed with neat Polanga biodiesel. Additionally, the use of neat Jatropha biodiesel consistently resulted in shorter IDs, ranging from 5.9° to 4.2° lower crank angles (CA). In another study, Nagesh (2019) conducted experiments on a diesel engine, investigating compression ratios (CRs) of 14, 16, and 18, using different blends of Karanja biodiesel as fuel. The outcomes suggested that the Karanja blended biodiesel B60 demonstrated elevated CP, cumulative heat release rate (CHRR), and brake thermal efficiency (BTE). Furthermore, it exhibited reduced ID and lower emissions of pollutants such as CO and HC under conditions of a higher CR of 18:1, 42% load, and an engine speed of 1500 rpm. Similarly, Hwang et al. (2014) performed experiments on a diesel engine using two engine loads at varying injection pressures (IP) and injection timings (IT). The findings indicated that, across all operating conditions, the biodiesel blend resulted in a modest reduction in both peak CP and HRR, along with a slight increase in ID. In a related study, Balasubramanian and Subramanian (2021) investigated the impact of CR on combustion characteristics using Karanja biodiesel in a diesel engine. Their findings indicated that increasing the CR elevated CP while simultaneously reducing ID, combustion reaction time, and HRR.

Paul et al. (2017) examined the impact of engine load on the combustion properties using a Kirloskar-make TV-1 type diesel engine fueled with a blend of diesel-ethanol and biodiesel derived from Pongamia Pinata. Their results demonstrated that at full engine load, the fuel blend D35E15B50 achieved higher CP and CHRR. Similarly, Ramalingam and Mahalakshmi (2020) explored the combustion behavior of a Kirloskar-manufactured TAF-1 type diesel engine using diesel and Moringa oleifera biodiesel with hexanol and ethanol as fuels. Their findings revealed that the fuel blend B90-D5-H5 provided the highest CP and HRR, as well as the longest ID period. Furthermore, Teoh et al.(2019) studied a 4-cylinder turbocharged diesel engine powered by diesel and Moringa oleifera biodiesel at various engine speeds and biodiesel blends. Their results demonstrated that a higher percentage of biodiesel content in the fuel blend lowered the peak HRR and CP. Moreover, for all tested fuel blends, the CP and peak HRR increased with higher engine speeds. In a similar study, Hosamani & Katti (2018) investigated the effects of fuel blends and CR on the combustion characteristics of a variable compression ratio (VCR) diesel engine using dual biodiesel from Simarouba and Jatropha. The data revealed that an increase in CR led to higher CP, net heat release rate (NHRR), CHRR, and rate of pressure rise (ROPR). Additionally, it was observed that the ID and combustion reaction time decreased with increasing CR for all fuel blends. In addition, Dash et al. (2019) studied the combustion properties of a diesel engine using Nahar biodiesel as a fuel, examining the effects of different fuel blends. The results showed that a rise in the volume percentage of biodiesel within the fuel blend raised the peak CP while simultaneously reducing the HRR and ID. Sanjid et al. (2016) investigated the impact of fuel blends on engine combustion behavior using a multi-cylinder diesel engine powdered by Moringa and Kapok biodiesel. The experimental findings demonstrated shorter IDs for biodiesel blends, with peak CP and HRR occurring closer to the top dead center (TDC). Across all tested fuel blends, peak CP and HRR were consistently observed at 3−5° after TDC.

The reviewed literature illustrates that fuel blends and various other engine operating parameters, such as engine load, speed, CR, IP, and IT, significantly influence combustion characteristics such as CP, CHRR, NHRR, ROPR, ID, and combustion duration. However, there exists a gap in the literature highlighting the effect of CR specifically on the combustion characteristics of VCR-CRDI type diesel engines operating at higher IP of 600 bar, IT of 23° before TDC, and a fixed engine speed of 1500 rpm. Therefore, further research is imperative to evaluate the impact of CR on the combustion properties in engines running on various blends of Moringa oleifera biodiesel.

Thus, the key objective of this study is to assess the impact of CR on the combustion properties of diesel engines when fueled with diesel and various blends of Moringa oleifera biodiesel (MB10, MB20, and MB30) under an elevated IP of 600 bar, IT of 23°before TDC, and a constant engine speed of 1500 rpm.

2. EXPERIMENT METHODOLOGY

2.1 Biodiesel Production

Biodiesel derived from Moringa oleifera was produced from the Moringa seed oil using the single-step

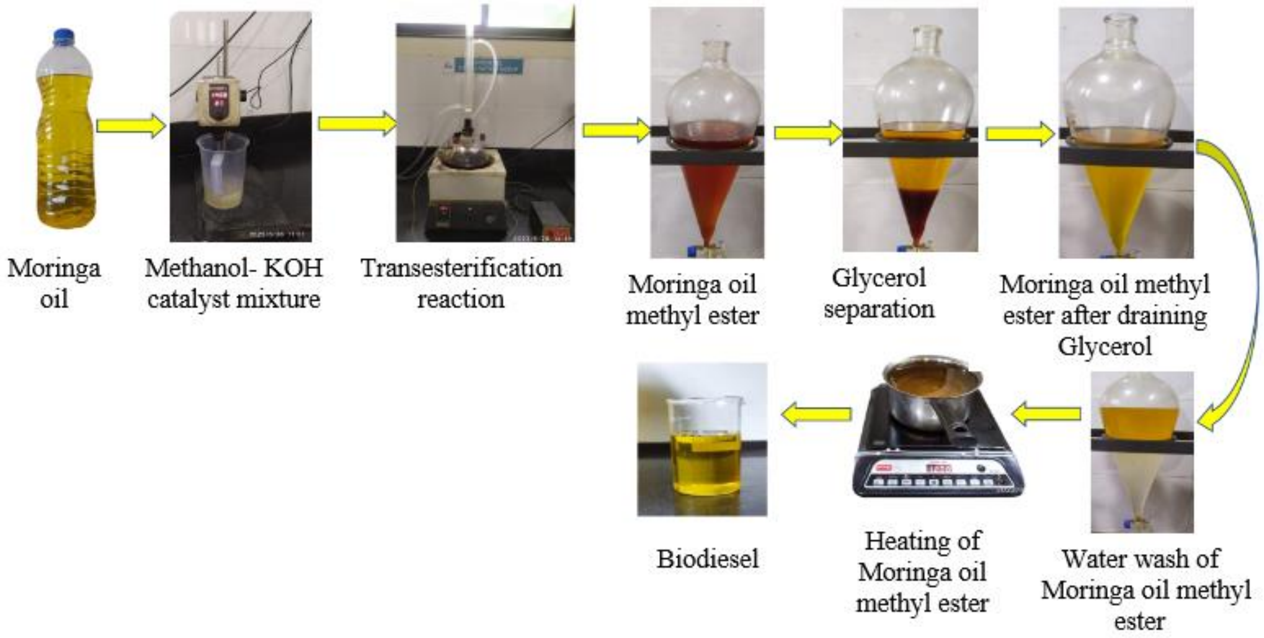


Fig. 1 Process of biodiesel production from Moringa oleifera oil

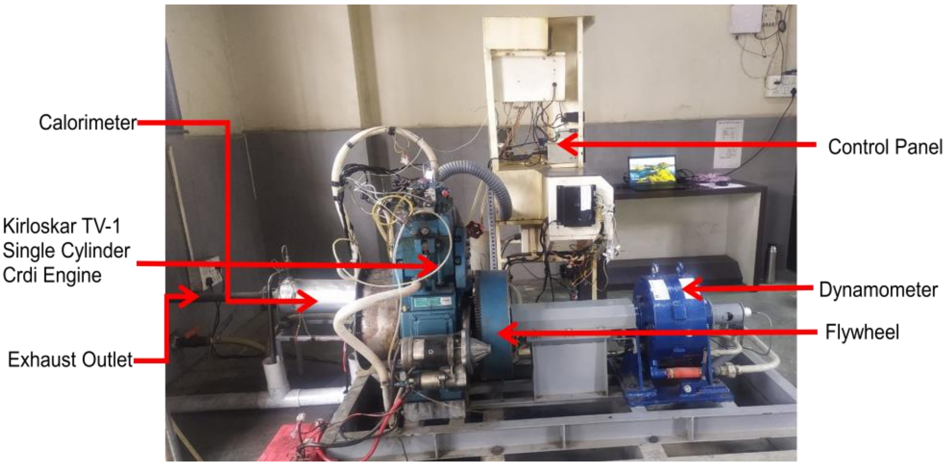


Fig. 2 Experiment setup

transesterification process. The reaction involved methanol and KOH as catalysts, with methanol to oil molar ratio of 5.5:1 and KOH added at 1% (w/w of oil). The reaction was performed in a three-neck flask equipped with a magnetic stirrer, maintained at 65°C for one hour at a stirring speed of 600 rpm. After completion of the transesterification reaction, the mixture containing glycerin and methyl esters was allowed to settle in a separation funnel for 12 hours to facilitate the separation of glycerin from methyl esters. Subsequently, the methyl esters underwent washing with heated mineral water to remove residual methanol from the solution, followed by a final heating step to remove any remaining water content. The process of Moringa oleifera biodiesel preparation is shown in Fig. 1.

2.2 Experiment Setup and Test Procedure

As illustrated in Fig. 2, the experiment utilized a single-cylinder, VCR-CRDI type diesel engine capable of generating 3.5 kW of power at 1500 rpm. The CR of the engine was adjusted without interrupting its operation or modifying the combustion chamber geometry, facilitated by a uniquely designed tilting cylinder block arrangement. An eddy current-type dynamometer was coupled to the test engine, and the applied load was measured using a Sensotronics "S" beam-type universal load cell (Model-60001). K-type thermocouples were employed to record the exhaust gas temperature. PT100 RTD-type temperature sensors were utilized to measure the water temperature at both the inlet and outlet of the engine jacket and calorimeter. For precise measurement of the crankshaft's rotational position and determination of TDC, a Kubler CA sensor (Model-8.3700.1321.0360) with a resolution of 1 degree was utilized. The CP was measured using a dynamic pressure transducer (Model-M111A22) manufactured by PCB piezotronics and installed on the cylinder head. This transducer featured a resolution of 0.1 psi and an integrated amplifier.

Table 1 Main specification of the test setup

Engine type	Kirloskar make, Model type: TV-1, Mono cylinder, 4-stroke, and Water-cooled.
Dynamometer	Model type: AG 10, Eddy current type, Manufacturer: Saj test Plant Pvt. Ltd.
Load cell	“S” beam universal type, Capacity: 0-50 Kg.
Crank angle encoder	Manufacturer: Kubler, Model type:8.3700.1321.0360, supply voltage 5-30 V DC.
Piezo sensor	Manufacturer: PCB piezotronics, Model:M111A22, resolution: 0.1 psi
Data acquisition system	NI Instrument make, Model type: NI USB-6210, 16-bit, 250kS/s.
Load indicator	Digital, range 0-50kg, Supply: 85- 260 V AC/DC, Accuracy: 0.2% FS
Fuel flow transmitter	Yokogawa, Model type: EJA110-EMS-5A-92NN, Supply: 10 to 24 V DC, Calibration range 0-500 mm H_2O.
Airflow transmitter	Wika make, Model type: SL-1, Range (-) 250 mm WC.

To measure the air and fuel flow supplied to the engine, two types of pressure transmitters were utilized: differential pressure transmitters and pressure transmitters. Performance and combustion characteristics were tracked, gathered, and analyzed using "Enginesoft," LabVIEW-based software.

The main specifications of the test setup are represented in Table 1.

2.3 Uncertainty Analysis

To ensure the accuracy of experimental results, it is essential to analyze the uncertainty associated with each study. Measurement errors are inherent in experimental data, and the uncertainties of each measurement must be considered in order to calculate the overall uncertainties. Table 2 provides a comprehensive list of the percentage uncertainties for the instruments used in the experiment. The approach suggested by Moffat (1998) is utilized to calculate and present these uncertainties (Moffat, 1988).

Uncertainty in experiment=

$$\sqrt{\begin{matrix}(\text{Uncertainty of cylinder pressure})^2 + \\ (\text{Uncertainty of crank angle encoder})^2 + \\ (\text{Uncertainty of engine load})^2 + \\ (\text{Uncertainty of gas temperature})^2 + \\ (\text{Uncertainty of engine speed})^2\end{matrix}} \quad (1)$$

$$= \sqrt{\begin{matrix}(0.00002)^2 + (0.00278)^2 + (0.5)^2 + (0.004)^2 \\ +(0.004)^2\end{matrix}}$$

$= \pm 0.5$ %

The experiment was conducted on a diesel engine to examine the influence of CR and fuel blends on the combustion properties of an engine. The CR was varied from 15:1 to 18:1 in increments of one, using diesel fuel and blends of Moringa oleifera biodiesel (MB10, MB20, and MB30). The engine operated at full load and a constant speed of 1500 rpm, with an IP of 600 bar and an IT of 23°before TDC. The study aimed to provide insights on the influence of CR and fuel blends on combustion properties, including CP, CHRR, NHRR, RPR, mean gas temperature (MGT), ID, and combustion time period.

Table 2 Uncertainty of different parameters

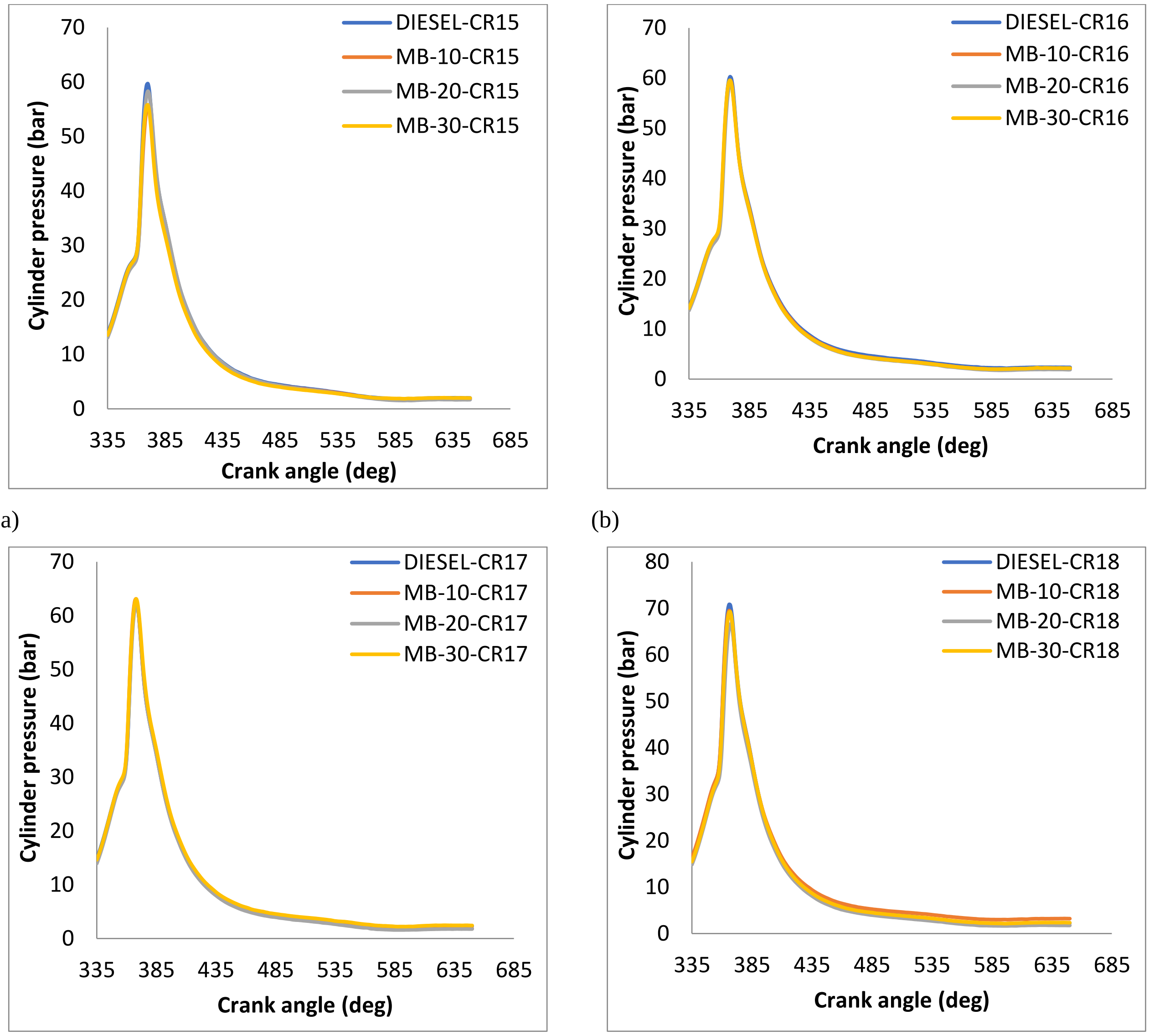
Equipment	Unit	Uncertainty (%)
Piezo Sensor	Psi	± 0.00002
Crank angle encoder	°CA	±0.00278
Temperature sensor	°C	±0.004
Load cell	kg	±0.5
Engine speed sensor	rpm	±0.004

3. RESULTS AND DISCUSSION

3.1 Cylinder Pressure

For compression ignition engines, the CPis determined by the amount of fuel burned during the pre-mixed combustion stage.

Figure 3 (a)−(d) depicts the changes in CP with CA for various CR and fuel mixtures. The data demonstrates that increasing the CR leads to a corresponding rise in CP across all tested fuel mixtures. Specifically, the highest CP values are reported for the diesel and biodiesel blends MB10, MB20, and MB30, measuring 70.83, 60.5, 66.6, and 69.21 bar at a CR of 18:1 and CA of 366°, 366°, 367°, and 367°, respectively. The increase in the peak CP for diesel at a higher compression ratio (CR) of 18:1, compared to a lower CR of 15:1, is reported to be 18.64%. For the biodiesel blends MB10, MB20, and MB30, the increases in CP at a higher CR of 18:1, compared to a lower CR of 15:1, are 24.52%, 14.21%, and 24.05% respectively. This increase is attributed to the higher CR compressing the air-fuel mixture into a smaller volume prior to ignition. Consequently, the higher density of the blend leads to a larger quantity of fuel and air molecules within the combustion chamber, resulting in elevated CP upon ignition (Hosamani & Katti, 2018). Additionally, biodiesel blends are observed to exhibit a lower CP



(a) (b)

(c) (d)

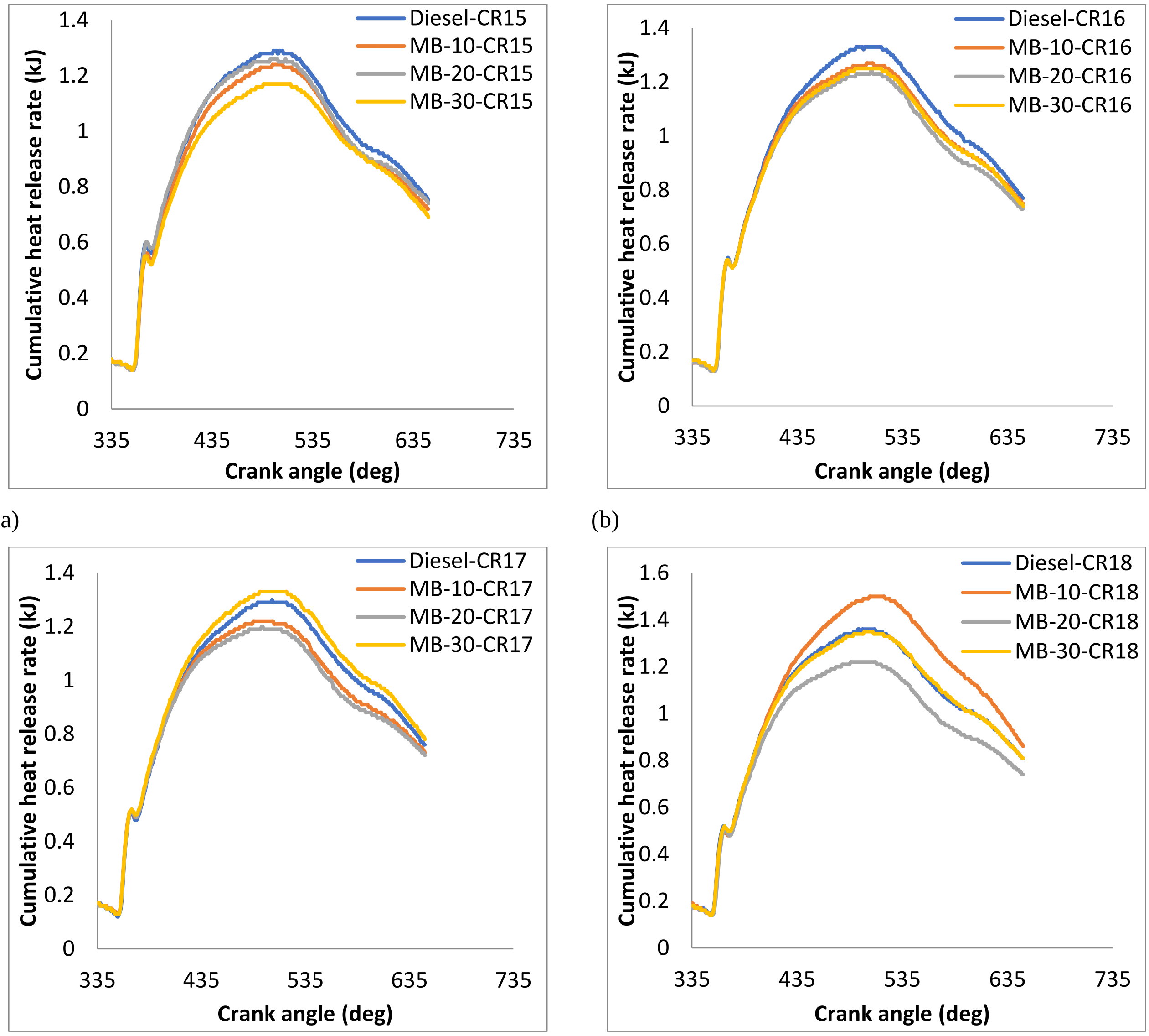
Fig. 3 Variation in CP for different fuel bends at (a) CR-15, (b) CR-16, (c) CR-17, and (d) CR-18

compared to diesel mixes. This difference may be due to the higher viscosity and reduced volatility of biodiesel, which adversely affect atomization and mixture formulation, thereby causing lower CP values than diesel (Enweremadu & Rutto, 2010; Balasubramanian & Subramanian, 2021).

3.2 Cumulative Heat Release Rate

The CHRR refers to the total amount of heat generated from the fuel burned throughout the combustion process.

Figure 4 (a)−(d) illustrates the variations in the CHRR with CA at various CRs for the different fuel blends. It is observed that the CHRR increases with higher CR for all fuel mixtures. The maximum CHRR reported for the diesel and biodiesel blends MB10, MB20, and MB30 are 1.36, 1.5, 1.22, and 1.35 kJ at a higher CR of 18:1, corresponding to 499, 508, 502, and 505°CA, respectively. At a higher CR of 18:1 compared to a lower CR of 15:1, the increase in highest recorded CHRR for the diesel and biodiesel blends MB10, MB30 is 5.42, 20.96, and 15.38 % respectively. The CHRR decreases by 3.18% for the biodiesel blend MB20 at higher CR of 18:1 than lower CR of 15:1. This is ascribed to the improved combustion efficiency achieved by increasing the CR. Compressing the fuel-air mixture to a smaller volume prior to ignition raises the temperature and pressure during combustion. This higher initial temperature and pressure enhance combustion efficiency, resulting in a more complete fuel burning and a higher HRR (Mattarelli, et al. 2015). Moreover, it is observed that the Moringa biodiesel blends exhibit higher CHRR compared to diesel during the early phases of combustion. This can be attributed to the higher oxygen content inherent in biodiesel, typically comprising approximately 10−12% oxygen by weight. This elevated oxygen level enables more efficient and rapid combustion in the initial stages, thereby resulting in an accelerated HRR. In contrast, diesel, known for its superior ignition properties, such as a higher heating



(a) (b) (c) (d)

Fig. 4 Variation in CHRR for different fuel bends at (a) CR-15, (b) CR-16, (c) CR-17, and (d) CR-18

value and lower viscosity, experiences an increasing CHRR as combustion progresses (Onuh et al., 2021).

3.3 Net Heat Release Rate

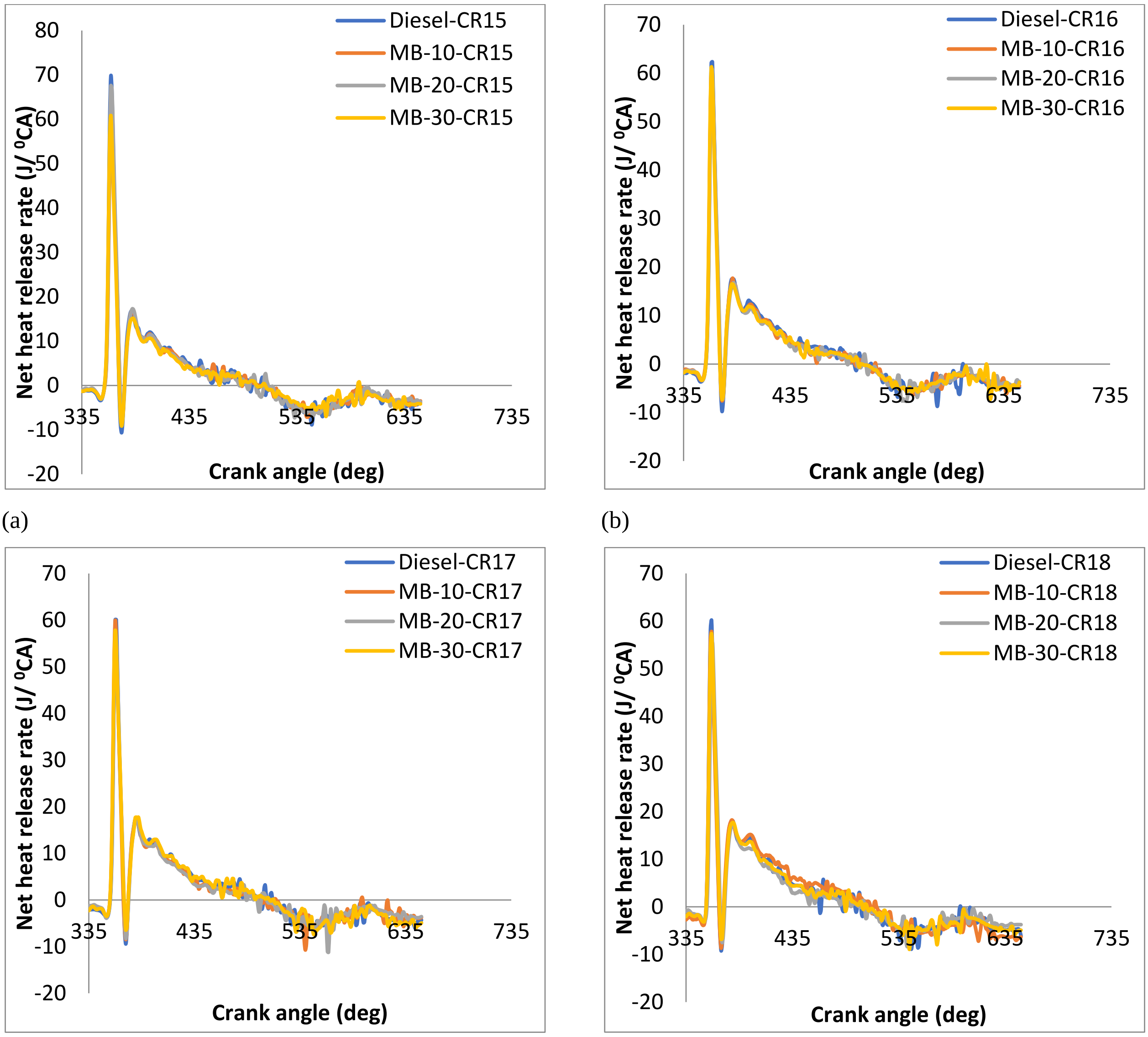
The NHRR results from the instantaneous burning of the fuel-air mixture during the ID period.

Figure 5 (a)−(d) demonstrates the variation in the NHRR across different CAs for various CRs and fuel blends. Initially, a negative NHRR is observed as the fuel entering the cylinder absorbs heat for the vaporization. The highest NHRR values noted for the diesel and biodiesel blends MB10, MB20, and MB30 are 69.75, 59.62, 67.53, and 60.86 J/°CA, respectively, at a lower CR of 15:1 and 362°CA for all fuel blends. The reported highest NHRR reduced by 13.74, 3.09, 8.04, and 5.74 % for diesel and biodiesel blends MB10, MB20, MB30 respectively at higher CR of 18:1. This is due to a longer ID observed at lower CR, which allows for more fuel to accumulate before the onset of combustion, resulting in a higher NHRR (El-Kassaby & Nemit-Allah, 2013). Furthermore, it is observed that Moringa biodiesel blends exhibit a lower NHRR in comparison to diesel, owing to their higher cetane number and inherent oxygen content. These characteristics of biodiesel blends minimize the ID, thereby reducing the accumulation of fuel before combustion and ultimately yielding a lower NHRR relative to diesel.

3.4 Rate of Pressure Rise

The pressure exerted on the piston and cylinder surface at the onset of combustion is represented by the maximum ROPR. As a result, the ROPR serves as an indicator of the noise level generated during engine operation. The ROPR is influenced by several factors, including ID, cetane number, rate of vaporization, combustion duration, IT, and fuel heating value (Dash et al., 2019).

As displayed in Fig. 6 (a)−(d), the ROPR was higher at a CR of 18:1 compared to a lower CR of 15:1 for all tested fuels. The maximum ROPR values reported are 6.42bar/°CA for diesel and 6.17, 5.82, and 6.12 bar/°CA



(a) (b)

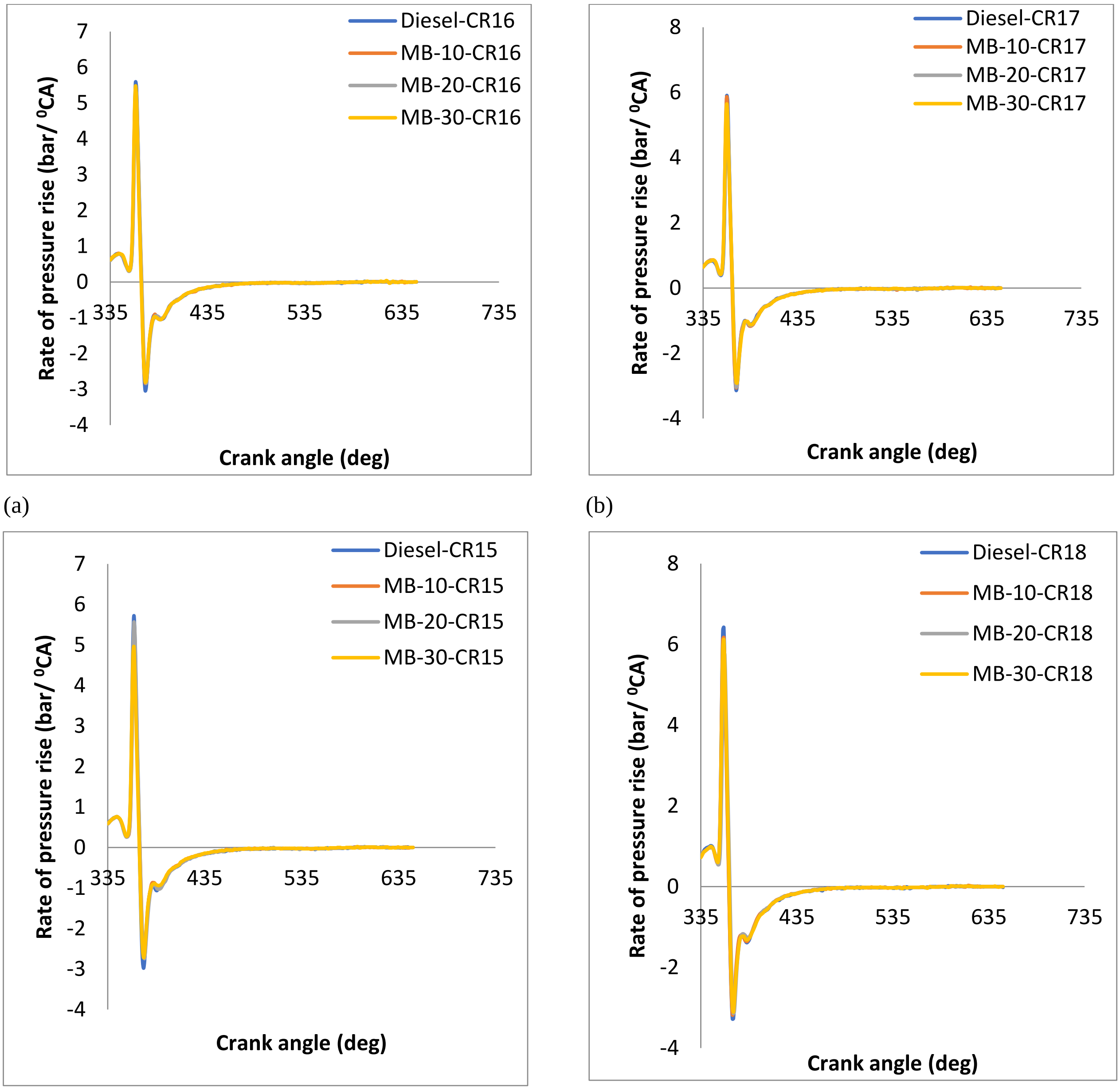
(c) (d)

Fig. 5 Variation in NHRR for different fuel bends at (a) CR-15, (b) CR-16, (c) CR-17, and (d) CR-18

for biodiesel blends MB10, MB20, and MB30, respectively, at a higher CR ratio of 18:1 and 359°CA. When comparing the higher CR of 18:1 to the lower CR of 15:1, the recorded highest ROPR increases by 12.23, 26.95, 4.68, and 23.38% respectively for the diesel and biodiesel blends MB10, MB20, and MB30 at higher CR of 18:1. The increased temperatures and pressures resulting from higher CRs can expedite the chemical reaction rates of the combustion process. This leads to accelerated combustion, as evidenced by a higher ROPR (Singh & Agarwal, 2018). Additionally, it is noticed that the maximum ROPR for diesel at each CR exceeds that of biodiesel blends due to the superior combustion properties of diesel, such as lower viscosity and higher calorific value compared to Moringa oleifera biodiesel blends.

3.5 Mean Gas Temperature

Figure 7 (a)−(d) depicts the changes in the mean temperature of the combustion products for varied CR and fuel mixtures. The results suggest that a higher CR reduces the MGT of the combustion products for all tested fuel blends. At a lower CR of 15:1, the highest MGT for diesel and biodiesel blends MB10, MB20, and MB30 are measured to be 1303.69 °C, 1226.05 °C, 1287.39 °C, and 1217.47 °C, respectively. Additionally, the highest MGT for these fuels are recorded at 370, 371, 371, and 370°CA, respectively. The highest reported MGT reduced by 6.64, 9.49 and 1.73 % for the diesel and biodiesel blends MB20 and MB30 at higher CR of 18:1. Meanwhile, for the biodiesel blend MB10 MGT is increased by 3.5% at higher CR of 18:1. This is ascribed to the higher ID at the lower CR of 15:1, which results in greater fuel accumulation before combustion begins and, subsequently, higher temperatures during the uncontrolled combustion stage (Warkhade & Babu, 2018). Moreover, Moringa biodiesel blends exhibit lower MGTs compared to diesel. This can be attributed to the higher cetane number and inherent oxygen content of biodiesel, which reduces the ID and, thus, the fuel accumulation, resulting in lower MGT during uncontrolled combustion.



(a) (b)

(c) (d)

Fig. 6 Variation in ROPR for different fuel bends at (a) CR-15, (b) CR-16, (c) CR-17, and (d) CR-18

3.6 Ignition Delay

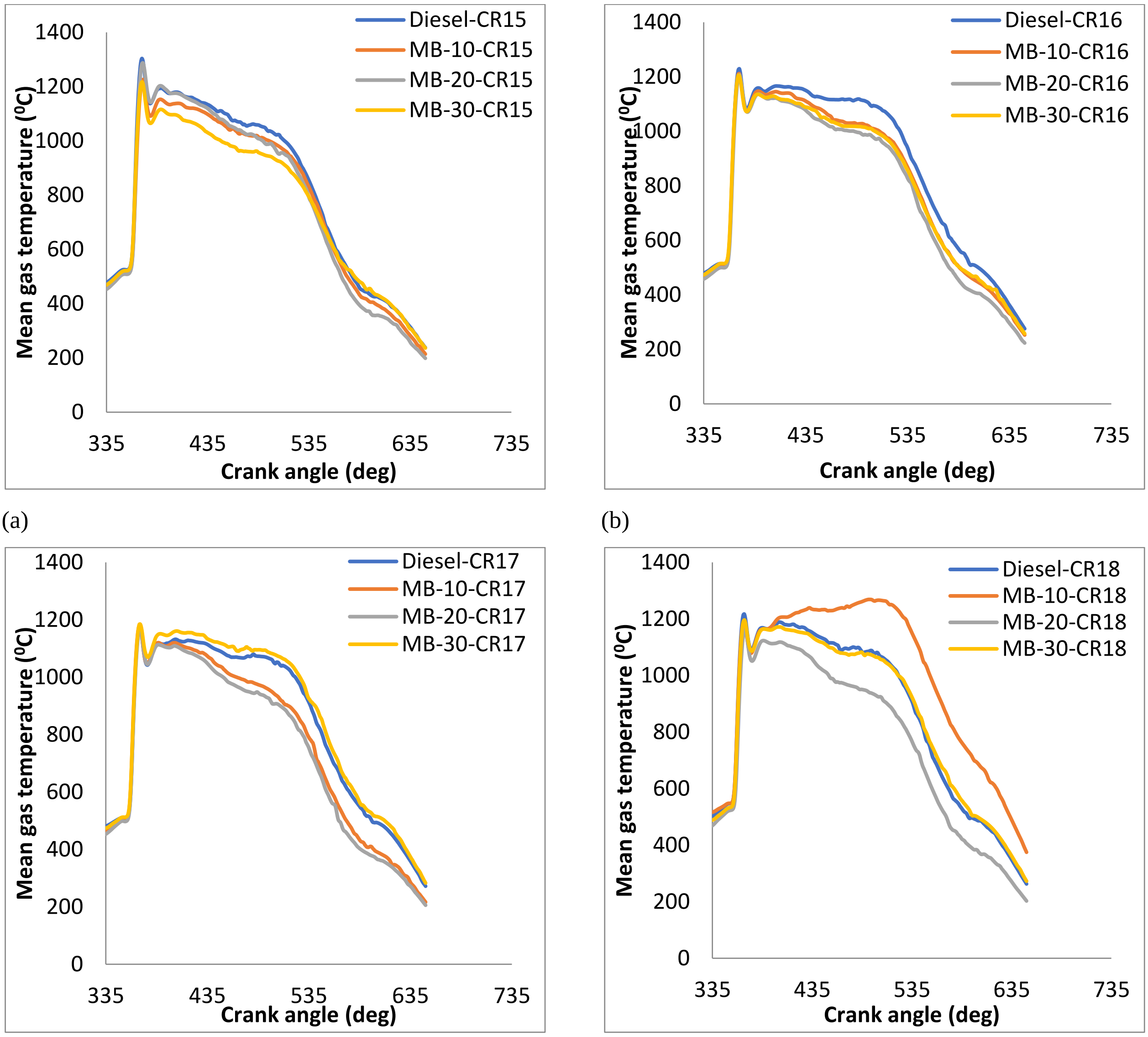
The ID, measured in °CA, represents the time interval between the start of fuel injection and the onset of combustion.

Figure 8 displays the variation in ID across different CRs for various fuel blends. The findings show that an increase in CR decreases the ID for all fuel blends. At a high CR of 18:1, the minimum IDs reported for the diesel and biodiesel blends MB10, MB20, and MB30 are 17, 16, 17, and 16°CA, respectively. This reduction in ID is ascribed to the higher temperature and pressure within the engine cylinder with increased CR, resulting in a shorter vaporization time and a rapid start of combustion. Moreover, the ID of the biodiesel blends MB10 and MB30 is noted to be shorter than that of diesel. This is likely due to the higher cetane number and inherent oxygen content of the biodiesel, which facilitate quicker ignition and combustion (Tat, 2011; Rajasekar & Selvi, 2014).

3.7 Combustion Duration

The combustion duration refers to the time span between the start and end of the combustion reaction.

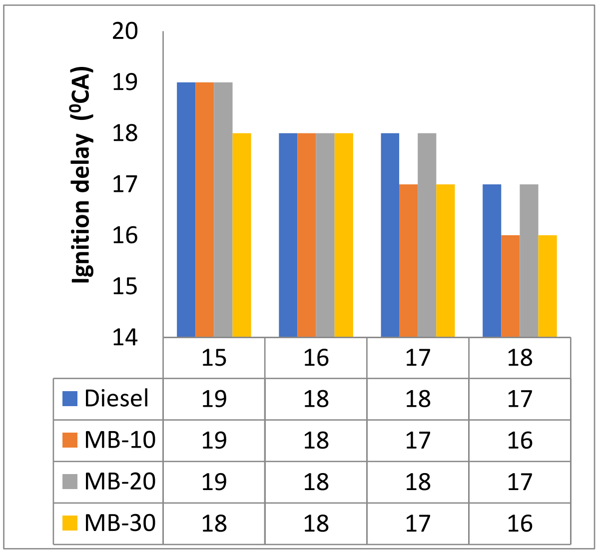
Figure 9 illustrates the variation in the combustion duration for different fuel blends at varying CRs. The results indicate that an increase in CR reduces the combustion duration for all tested fuel blends. The shortest combustion durations for diesel and biodiesel blends MB10, MB20, and MB30 are found to be 15, 15, 15, and 16°CA, respectively, at a higher CR of 18:1. This reduction is due to the higher temperature and pressure inside the engine cylinder at higher CRs, which accelerates the combustion reaction. Additionally, it is observed that at higher CRs, the combustion duration of



(a) (b)

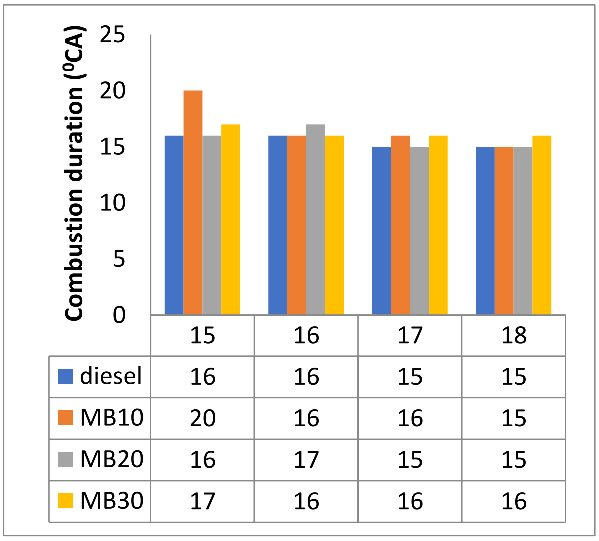
(c) (d)

Fig. 7 Variation in MGT for different fuel bends at (a) CR-15, (b) CR-16, (c) CR-17, and (d) CR-18



	15	16	17	18
■ Diesel	19	18	18	17
■ MB-10	19	18	17	16
■ MB-20	19	18	18	17
■ MB-30	18	18	17	16

Fig. 8 Variation in ID for different fuel bends at CR-15, CR-16, CR-17, and CR-18



	15	16	17	18
■ diesel	16	16	15	15
■ MB10	20	16	16	15
■ MB20	16	17	15	15
■ MB30	17	16	16	16

Fig. 9 Variation in combustion duration for different fuel bends at CR-15, CR-16, CR-17, and CR-18

biodiesel blends MB10 and MB20 matches that of diesel, owing to improved atomization and reduced vaporization time caused by increased cylinder temperature and pressure

4. CONCLUSION

The study aimed to investigate the effect of CR on the combustion characteristics of a VCR-CRDI type diesel engine using blends of diesel and Moringa oleifera biodiesel (MB10, MB20, and MB30). The experimental results led to the following conclusion:

(1) For all the tested fuel blends, CP, CHRR, and ROPR increased with the increase in CR. The highest CP was reported at a CR of 18:1; with diesel and biodiesel blends MB30 reaching 70.83 and 69.21 bar at 367and 366 °CA, respectively. The maximum CHRR was recorded at the highest CR of 18:1 for diesel and biodiesel blend MB10, measuring 1.36 and 1.5 kJ at 499 and 508°CA. Furthermore, the maximum ROPR for diesel and the biodiesel blend MB10 were found to be 6.42 and 6.17 bar/°CA, respectively, at a CR of 18:1 and 359°CA.

(2) The highest NHRR and MGT for all tested fuel blends were observed at a lower CR of 15:1. Specifically, the diesel and biodiesel blend MB20exhibited NHRR values of 69.75 and 67.53 J/°CA, respectively, with combustion occurring at362°CA.Meanwhile, the highest MGT for diesel reached 1303.69°C, while the MB20 blend achieved 1287.39 °C, both at a CR of 15:1 and 370 and 371°CA.

(3) The minimum ID observed for diesel was 17°CA, whereas biodiesel blends MB10 and MB30 showed a lower ID of 16°CA at a CR of 18:1. Besides, the minimum combustion duration for the diesel was 15°CA, which was also observed for the biodiesel blends MB10 and MB20.

(4) The utilization of Moringa oleifera biodiesel blends in diesel engines is supported by their comparable performance characteristics to diesel, including CP, CHRR, NHRR, ROPR, and MGT. Experimental findings suggested that Moringa biodiesel can be effectively employed in engines at a higher CR of 18:1 without significantly impacting engine performance.

CONFLICT OF INTEREST

The authors declare no competing financial interests or personal relationships that could influence the findings reported in this paper.

AUTHORS CONTRIBUTION

Vasant Patel: Conceptualization, Methodology, Experimentation, Data Collection, Interpretation of results, Writing-Original Draft. **Vyomesh Buch:** Supervision, Critical Feedback, Interpretation of Results, Writing – Review & Editing.

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